MULTIMODAL INTERACTION FOR ENHANCING TEAM COORDINATION ON THE BATTLEFIELD

A Dissertation

by

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Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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August 2013

Major Subject: Computer Science

ABSTRACT

Team coordination is vital to the success of team missions. On the battlefield and in other hazardous environments, mission outcomes are often very unpredictable because of unforeseen circumstances and complications encountered that adversely affect team coordination. In addition, the battlefield is constantly evolving as new technology, such as context-aware systems and unmanned drones, becomes available to assist teams in coordinating team efforts. As a result, we must re-evaluate the dynamics of teams that operate in high-stress, hazardous environments in order to learn how to use technology to enhance team coordination within this new context. In dangerous environments where multi-tasking is critical for the safety and success of the team operation, it is important to know what forms of interaction are most conducive to team tasks.

We have explored interaction methods, including various types of user input and data feedback mediums that can assist teams in performing unified tasks on the battlefield. We've conducted an ethnographic analysis of Soldiers and researched technologies such as sketch recognition, physiological data classification, augmented reality, and haptics to come up with a set of core principles to be used when designing technological tools for these teams. This dissertation provides support for these principles and addresses outstanding problems of team connectivity, mobility, cognitive load, team awareness, and hands-free interaction in mobile military applications. This research has resulted in the development of a multimodal solution that enhances team coordination by allowing users to synchronize their tasks while keeping an overall awareness of team status and their environment. The set of solutions we've developed utilizes optimal interaction techniques implemented and evaluated

in related projects; the ultimate goal of this research is to learn how to use technology to provide total situational awareness and team connectivity on the battlefield. This information can be used to aid the research and development of technological solutions for teams that operate in hazardous environments as more advanced resources become available.

DEDICATION

To Willie Joe Cummings and Hallie B. Johnson...you left too soon.

ACKNOWLEDGEMENTS

First, I would like to thank my advisor Dr. Tracy Hammond who welcomed and supported me and helped me realize my academic goals. I'd like to thank my committee members Dr. Ann McNamara, who inspired me to pursue creative solutions in my research, Dr. Dylan Shell, for providing guidance and constructive feedback when I needed it, and Dr. Nancy Amato, for helping me keep my priorities straight and supporting me during tough times. I'd also like to thank Dr. Ricardo Gutierrez for putting me through hell in CSCE 666 and for pushing me to always strive for better results. I'd like to thank Dr. Mark Billinghurst, my advisor overseas, for helping me pursue so many rewarding research opportunities. I'd like to thank Dr. Ann Morey for fueling my passion for learning through film and for devoting countless hours toward making me a better writer, without which I may have had far fewer publications, and for helping me to obtain my certificate in film studies which resulted in the work presented in Appendix B.

I'd especially like to thank Dr. Tiffani Williams and her protege Dr. Suzanne Matthews who kept me on the path to graduation when so many obstacles threatened to derail me.

Thanks to the wonderful staff in the Computer Science department including Kathy, Bruce, Jeremy, Tony, Kay, Theresa, Marilyn, Valerie, Tina and many others. Thanks to all my academic siblings in the Sketch Recognition Lab, Stephanie, Paul, Drew, Francisco, Ayden and Sashi. And I'd especially like to thank my brothers on the R.C.D.V.S., Manoj, George, Chris and Jimmy Ho, as well as LTG Frank Helmick and members of the XVIII Airborne Corps without whom this research wouldn't have been possible.

I'd like to thank my adopted Texas families, the Ukanwas, the Owens, the Beattys, the Fritzs, the Simontons and all the members of Katy Community Church, for their love and support. Most of all I'd like to thank my own family: all my uncles and aunts, especially Alice Johnson, Jackie Johnson and Dorothy (Pep) Mack, for their support, my grandma, Lois Cummings, who is my personal cheerleader and antidote for my impostor syndrome, my little sister, Dominique Cummings, the artistic genius and the only one that really gets me, my dad, Larry Cummings, who taught me the power of perseverance and a positive attitude, and my mom, Beverly Cummings, whose limitless patience and love is my model of perfection.

And most importantly, none of this would be possible without the strength and through the will of God (1 John 4:4, Philippians 4:13).

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1. INTRODUCTION

Team coordination, communication and awareness are key factors in the successful completion of a team activity [37]. A team can be defined as two or more interdependent agents that are invested in a common goal [114]. Our target team consists of humans and possibly drones that must coordinate their tasks to achieve a goal. In the context of this research, team coordination is the ability to engage in synchronized activities without the need for direct contact either by physical or visual means or through verbal communication. Team awareness is the ability to have continuous knowledge about the status of teammates and the environment without direct contact or communication. The goal of this research is to learn how to use technology to enhance team coordination on the battlefield and therefore, we focus on a very specific set of users: teams that operate in high-stress and hazardous environments.

Soldiers on the battlefield, rescue-aid workers (police, medical personnel, *etc.*) in disaster areas, and firefighters in fire-engulfed structures are all examples of teams that operate in hazardous environments. As a result, they all share common challenges to team coordination. On the battlefield, Soldiers must guard themselves from enemy assault and navigate unfamiliar terrain while avoiding disastrous elements (*i.e.* fire) and completing their missions. In these types of environments where multi-tasking is critical for the safety of the team member and the success of the team operation, it is important to know what forms of interaction are most conducive to team tasks. This dissertation explores how technology can be used to enhance team coordination in these scenarios. To answer this question we've conducted an ethnographic analysis of Soldiers and come up with a set of core principles

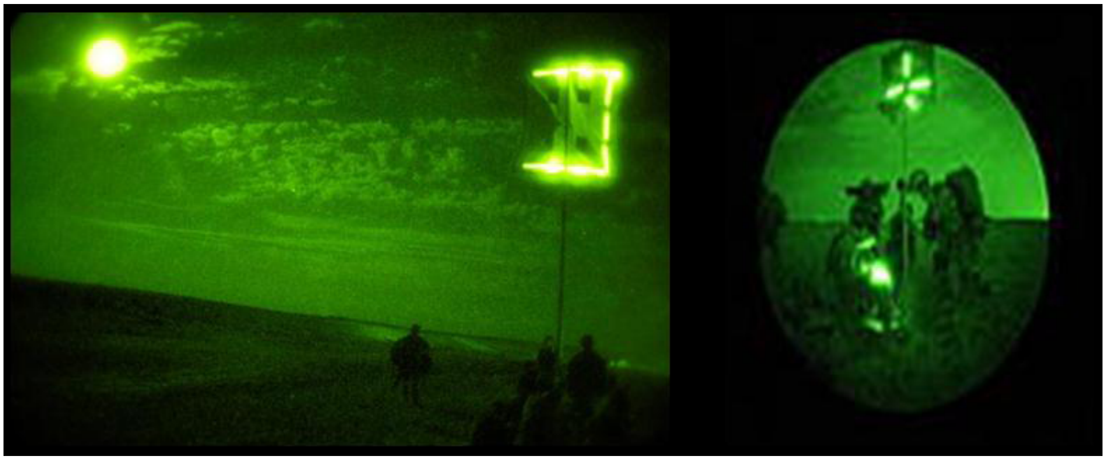


Figure 1.1: Stiner Aids as viewed through Night Vision Goggles (NVG).

to be used when designing technological tools for these teams.

1.1 Importance of Team Coordination for the Soldier

Teams that work in hazardous environments must effectively mitigate the following challenges to team coordination: disconnection from team members, navigation of unfamiliar terrain, danger from surroundings, ineffective task/resource allocation, time pressure and the additional stress and cognitive load that these factors may cause [36, 78, 90]. Team coordination is vital to U.S. Military operations. When team coordination is compromised by uncertainty, danger, and time constraints, it may lead to mistakes that can adversely affect the mission [114, 36]. In many battlefield scenarios the environment and the operating constraints of the mission do not allow for direct contact until the team‘s task is complete. Therefore the success of the mission is directly dependent on Soldiers operating autonomously but working to complete a unified task. Current research suggests that technological solutions can assist with this task and enhance team coordination on the battlefield [77, 75, 49, 87].

To give a compelling example on the importance of team coordination, we examine the current operations of paratroopers. Paratroopers are Soldiers specially trained to conduct airborne operations [18]. After being dropped into unfamiliar terrain at night, units of paratroopers must quickly assemble in locations pre-assigned during mission planning. The current assembly system is based on the use of Stiner Aids. Stiner Aids, introduced by General Carl Stiner in the 1980s, are panels of infrared (IR) chemical lights that are invisible to the naked eye and attached to the end of large (15 foot) telescopic poles (Figure 1.1). The lights are positioned to form different symbols that correspond to pre-designated assembly points. When Stiner Aids were first introduced, they provided a reasonably safe and effective system for marking assembly points. The Night Vision Goggles (NVGs) required in order to be able to see the chemical lights were only available to the U.S. Military at the time. Therefore, there was little concern about enemy forces being able to detect Stiner Aids.

Unfortunately the Stiner Aid has many flaws in today's battlefield scenario. The visibility of Stiner Aids can be limited by ambient light conditions from airfield lighting, surrounding areas, and fire. The line of sight visibility is also affected by the distance and intermittent terrain between the Soldier and the Stiner Aid. These visibility challenges can cause significant difficulties for Soldiers landing outside of the line of site of their designated assembly areas. As a result, Soldiers will often wander from one distant light to another to find their assigned Stiner Aid. This impedes team coordination by compromising the integrity and safety of the team; when team members are scattered, they are more vulnerable to enemy attacks. In addition, valuable time that could be devoted to completing the mission is wasted.

The weight and bulk of the Stiner Aid is also a significant burden on the paratrooper. The device takes up as much space as a secondary weapon. A secondary weapon could assist team coordination by providing more protection for Soldiers and their teammates if necessary. Also, since Stiner Aids are mounted on a 15 foot telescoping pole, they make an unwieldy addition to the Soldier who must drop with one (typically two Stiner Aids are used per assembly point). Once on the ground, the weight of the pole requires two paratroopers to hold it up, restricting them from other operations, such as defending themselves. This also affects team coordination because valuable human resources are allocated to menial labor rather than to critical tasks. Finally, NVGs are now widely available to non-military entities, meaning that assembly points would be extremely visible and thus exposed to any adversary. Being exposed to enemy forces makes the entire team vulnerable and compromises the success of the mission. Because of these detriments to team coordination, the U.S. Army is eagerly seeking a new solution to the navigation and assembly problem.

Today's battlefield scenario has changed drastically in the following ways: 1) legacy technology is more accessible by adversaries 2) teams now consist of more than just humans (*i.e.* drones) 3) new technological advances are available to use in the development of tools to aid team coordination. As a result, we need to reevaluate the factors that affect team coordination, as well as ways to address them, in this new context.

1.2 Research Question

This dissertation seeks to answer the question, how can one best use current technology to address challenges to team coordination such as disconnection from team members, navigation of unfamiliar terrain, danger from surroundings, ineffective task/resource allocation, time pressure and the additional stress and cognitive load that these factors may cause.

The Sketch Recognition Lab (SRL) at Texas A&M University explores the development of human-centered systems that use mediums of interaction that go beyond traditional mouse and keyboard interaction. We utilize various input/output methods (*i.e.* sketch-based input, augmented reality, haptics and physiological sensors) and technologies to create effective interaction experiences. Over the past 3 years we have explored interaction methods through the implementation of applications in multiple domains which are outlined in later chapters. Through this research, we have discovered the most optimal mediums for navigation, interaction with maps, ah-hoc networks and unmanned air vehicles in support of battlefield missions. Ultimately we have combined these technologies into a solution developed to meet the needs of users who work in high stress environments.

This dissertation contains an ethnographic assessment of the Soldier and existing supporting technologies targeted for military use and other similar domains, as well as an investigation and evaluation of interaction design principles for supporting multiple tasks on the battlefield. The resulting findings, although focused on the battlefield scenario, are theoretically applicable to other teams that operate in hazardous environments such as rescue-aid workers and firefighters for whom navigation and team member coordination are also important factors [78, 90].

This dissertation presents the following contributions:

1. A multimodal solution for the Soldier performing a variety of team coordination tasks, such as the navigation and assembly, including detailed implementation and evaluation by Soldiers of all interaction methods and data inputs applied to the problem
2. An ethnographic analysis of Soldier needs and challenges
3. A set of design principles for creating a multimodal interface for promoting situational awareness and coordination of teams that operate in hazardous environments

1.2.1 Detailed Implementation and Evaluation of the Team Coordination Solution

To address challenges to paratrooper team assembly and coordination, we have developed a multi-modal mobile navigation solution, which uses GPS-enabled computers to function as beacons to mark assembly points, and Android phones to function as receivers and aid Soldiers in navigating to these assembly points. The resulting solution addresses the immediate challenges to paratrooper navigation and assembly. The load of the paratrooper is decreased significantly and mobility is increased; the Stiner Aid is replaced by a much lighter Android device carried by the Soldier. In addition to mobility, the manpower of the team is also increased; the tablet computer is attached to equipment freeing at least 2 Soldiers in each company from the task of holding the Stiner Aid. Light and noise pollution is mitigated; the GeoTrooper application does not emit sound and, when running in night mode, cannot be seen at night outside a 3m range. We provide a secure broadcast solution with a range that covers a standard drop zone assembly area. Most importantly, the solution significantly decreases the paratrooper team assembly time.

This dissertation describes our investigation of various interaction mediums targeted toward increasing Soldier and team awareness and provides a detailed description of the solution system and research conducted to evaluate the interaction modes used. To address the challenges presented in the problem domain, we explored multiple technologies including Global Positioning System (GPS), sketch-based input, haptics, AR, and data input from physiological sensors. The data gathered from the evaluation of these technologies and the resulting solution provided valuable insight that allowed us to effectively match certain tasks and functions to an input/output mode that is most conducive to the task being performed. In addition, we were able to enhance the effectiveness of the solution to support team coordination by facilitating mixed team communication between Soldiers and drones. The use of an agile development approach to interaction design has allowed us to identify a set of interaction design principles, which are discussed in the following chapters, and resulted in a solution that successfully meets the needs of our target users: Soldiers on the battlefield.

This research has also had a broader impact in the areas of AR visualization and physiological classification research. The continual effort to improve and re-evaluate these technologies has led to collaborations with other labs including the Human Interface Technology Lab (HITLabNZ) of the University of Canterbury, New Zealand, which is one of the world's 3 leading labs in AR research and the Human Centered Multimedia (HCM) Lab at the University of Augsburg which specializes in physiological data research. This collaborative effort has lead to research on the AR visualization of user states, an area in HCI that has received very little focus, and a unique approach to the classification and application of physiological data signals [22, 143].

1.2.2 Analysis of Soldier Needs

This dissertation presents a human-centered analysis of the needs of the Soldier in an effort to improve team coordination, with a focus on the challenges of this unique user group. Our analysis was conducted over approximately seven months, with the majority of our efforts taking place at Ft. Bragg, with the XVIII Airborne Corps [23]. During this time we interviewed thirteen Subject Matter Experts (SMEs) in tactical military operations from the U.S. Army, U.S. Naval Office and from private industry defense contractors such as Boeing and Lockheed Martin [24]. We held focus group discussions with approximately twenty-three Soldiers to gain insight on challenges to the Paratrooper mission. During development, we conducted six equipment field tests and demonstrations at the practice drop zones. We also performed four military-personnel tests with a total of fifty Soldiers, and six in-house user studies at Texas A&M University with forty-one cadets from the local Reserve Officers' Training Corps (ROTC) that had field training experience.

Because this analysis was performed in full cooperation with the U.S. Army and the U.S. Navy, the findings are tailored to and can be integrated with current military operations research. The analysis provides a detailed list of independent situational conditions that correspond directly to the solution design elements. As a result, these design elements can serve as specific technological guidelines that can be applied to the same situational conditions as they appear in other military operations and/or other field scenarios.

1.2.3 Design Principles for Multimodal Interface

Through continuous development of a solution, we have explored, implemented, and tested alternative interaction methods to increase Soldier awareness and team coordination. Our research into haptic feedback, data visualization via AR, and interfaces for human-drone interaction have expanded the modality of the solution and has also allowed us to steadily increase the amount of data delivered to the Soldier without increasing the cognitive load. In addition, we've explored technologies and applied research that may be used to address the emotional and psychological side effects of exposure to high stress environments.

Continuous interaction with our solution technologies and evaluation by active Soldiers lead to the discovery and validation of the following principles:

1. Sketch serves as an easily-learned interaction method for complex mission planning. A sketch-based interface capitalizes on the affordance of annotating paper maps and offers a simple spatial reference that's very conducive for communi-

cating tactical instructions to both humans and drones thereby assisting team coordination.

2. When cognitive load is moderate, color rather than text is the best way to alert the user of an event that may require attention.
3. Haptic pulses are the best way to deliver navigation information when cognitive load is at its maximum and/or when line of sight must be unobstructed and hands must remain free.
4. Rather than forcing a predefined amount of data on team members based on roles, allowing each user to control the amount of data received through a multimodal interface can create a better user experience and increase user acceptance of the technology.
5. Significant changes in physiological data can be used effectively to assist in the automatic reallocation of tasks in the event a teammate needs assistance.

The work discussed in the following chapters provides support for these principles and addresses outstanding problems of mobility, information overload, information filtering, and hands-free interaction in mobile military applications. This information can be used to support the human-centered development of better technological solutions as more advanced resources become available.

1.3 Dissertation Organization

Chapter 2 provides details related to the interaction of teams as well as common challenges to team coordination and the motivation for a timely solution. Chapter 3 gives an overview of related work conducted in both HCI and interaction design in the research areas of military support applications, augmented reality, physiological sensors, affective haptics, and unmanned aerial systems. Chapter 4 includes information gathered about the problem domain as results from our ethnographic study of Soldiers. Chapter 5 includes a detailed description of the first implementation of a solution to improve team assembly and lessons learn through evaluation by paratroopers. Chapter 6 describes the implementation and evaluation of hands-free solutions created to increase situational awareness. Chapter 7 discusses efforts to increase team awareness by providing teammate events. Chapter 8 includes the use of subliminal haptic feedback for exchanging physiological data and providing continuous teammate status. Chapter 9 discusses our investigation into affective classification as a means of further enhancing team awareness. Chapter 10 discusses lessons learned through the development of a component that allows interaction with non-human team members (*i.e.* autonomous drones and aerial vehicles). Chapter 10 summarizes the overall contributions and lessons learned from these endeavors.

2. MOTIVATION

Teams that operate in hazardous, high-stress environments must battle common challenges to team coordination. The overall unpredictability of most scenarios that they encounter can have an adverse affect on team coordination and, by extension, the success of the team mission. The outcomes of their efforts are highly uncertain due to rapidly changing environments and situational constraints. Failures in operation that result from these challenges can possibly be prevented with the right tools. However, before we can determine what technological solutions will be advantageous, we must first take a look the way in which teams interact to complete a task as well as the common problems that affect team coordination.

2.1 Team Interaction

As stated in the Introduction, a team can be defined as two or more interdependent agents that are invested in a common goal [114]. To achieve this goal, agents must perform individual activities (or subactions) as part of a collaborative effort. What makes this collaboration more than just a coordination of separate tasks is the fact that the completion or non-completion of theses activities imposes some constraint on the team accomplishing the overall activity [52]. So how does the team accomplish its goal? The nature of joint action by a group of agents is characterized by having a shared set of beliefs or intentions constructed by collaborating agents with the goal of performing a group action [74]. Agents must form individual plans for their activities based on the mutual beliefs of the group, but they also need to know the status of the entire group effort to be successful. In addition, each agent must believe the the unified goal is attainable. Having this information allows the agent to create a mental model of the situation and commit to performing his/her individual actions. In the case of agents interacting as a team, a shared mental model is also required to effectively coordinate individual tasks so that the team can act as a single agent.

Team coordination is vital to the success of U.S. Military operations; lack of team coordination can result in failed mission objectives and errors with devastating consequences [36]. Because plans may change with time and given the nature of the situation, a technological tool must also account for incomplete plans and provide information to allow agents to change their individual plans (and set of beliefs) [51]. For example, if a team member is unable to perform his/her assigned action, then the team may need to revise its plan in order to complete the group action.

Soldiers must constantly adapt to the ever-advancing nature of warfare. Technology is more accessible to adversaries today and the military must constantly search for new technological solutions that will provide an advantage to its forces and efforts. Fortunately, recent advances in mobile computing and context aware systems, as well as the pervasiveness of drone technology have provided the resources needed to create solutions to aid the Soldier on the battlefield. As a result, we need to explore these options to find ways to alleviate the challenges to team coordination. To learn how to better use technology to assist team coordination we looked at the the difficulties encountered by teams with a particular focus on how paratrooper team coordination is affected.

2.2 Challenges to Team Coordination

A *lack of communication* is probably one of the most severe detriments to team coordination. When team mates share their understanding of the team's mission, it helps to create a common mental model of the goal and how to best execute it [119]. However, when unforeseen circumstances occur, the mental model may change and without communication, team members cannot guarantee that alternative actions will be coordinated. Therefore it is vital that team members have a access to the same information and can communicate the status of their individual tasks to their teammates. In the paratrooper scenario, Soldiers must maintain radio silence and cannot communicate face-to-face. Therefore team members are largely unaware of the status of their teammates' actions and cannot make informed decisions should the situation call for it.

Another significant challenge to team coordination is the unfamiliarity of the environments which can result in *disorientation*. In many cases, the disaster and combat environments are located in areas completely unfamiliar to the team, making it difficult to train very specific operations or predict their outcomes. For example, paratroopers are specially trained to conduct airborne operations at test drop zones. Airborne operations involve the strategic movement of ground forces to conduct forcible entry via parachute assault to capture key objectives for follow-on military operations. Careful planning maximizes the chance that paratroopers will land on the drop zone in the vicinity of their intended assembly areas. However, even under ideal conditions, paratroopers still land roughly 75 feet away from one another in unfamiliar terrain, typically at night, and intermixed with many other units with their own assembly areas. The most highly trained unit can take up to 20 minutes before the first few Soldiers begin to arrive at the assembly area. Unforeseen circumstances can degrade these conditions significantly, leaving paratroopers vulnerable for much longer periods of time; it is very likely that the entire company may not be present at an assembly point for up to two hours. These factors are anticipated and addressed to the maximum extent possible through navigation training, NVGs, and physical conditioning, but other factors that are beyond control, such as missed or changed drop zones, can threaten reassembly and reorganization.

In addition, we must also address the challenge of *time pressure* as it applies to this scenario; time constraints can induce stress and compromise team coordination. In the case of the paratrooper, time constraints are directly related to the safety of the individual Soldier; the longer the Soldier engages in the assembly task, the more susceptible he/she is to an enemy attack. However, studies have shown that an increase in time-induced stress does not necessarily affect team performance if the information readily available represents a common mental model shared among team members [43]. Without this information, or the ability to share it via direct communication, team actions can become highly unpredictable.

Many of the teams discussed must work under time constrains that can result in casualties if not met. This scenario is further complicated by the threat of danger from *situational hazards*. Rescue aid workers must work in situations where there are hazardous weather or environmental conditions; this may include operating near volatile equipment and/or in unstable structures. Combat scenarios probably represent the most hostile conditions as it can be more difficult to determine from which direction danger may emanate. Situationalhazards can make the organized completion of a team task very difficult and even impossible in some cases.

These challenges to team coordination also serve as both *physical and mental stressors* for the individual team member. Paratroopers in particular are under a huge cognitive load during missions due to dangerous combat scenarios. In addition, recalling pre-mission intelligence, processing real-time information, and trying to remain aware of danger signals within the environment can quickly lead to information overload. Extended heightened stress can have adverse affects on both physical and mental performance, the result of which may be temporary diminished cognitive capabilities or long-term conditions such as Post Traumatic Stress Disorder (PTSD) [63]. Stress can impair a person's judgment and result in rushed decisions without careful consideration of all information available, which in turn leads to erratic behavior and a total breakdown of team coordination [119].

In addition to mental stress, many of these teams must engage in strenuous physical activity for extended periods of time. A combat-loaded paratrooper weighs over 400 pounds and carries over 200 pounds of equipment when exiting the aircraft. Adrenaline will assist the paratrooper in navigating to his/her assembly point when accurate information is available, but extensive searching while carrying this unbearable load quickly leads fatigue which also impedes team coordination by slowing down the reorganization process.

In the new battlefield, the *pervasiveness of technological aids* is now becoming a common way to address these challenges to team coordination. While in many cases, the use of technology has assisted in efforts to improve team coordination, proper use and integration of new tools into existing processes can also be a challenge. Technological aids, if limited in usability and relevance to the individual team member, may result in a lack of team acceptance and hurt team coordination more than no solution at all [75]. Therefore it is very important to not only carefully consider the challenges to team coordination, but also to address them with a focus on how best to serve the needs of the individual team member.

3. RELATED WORK

There is a large body of work and research devoted to finding technological solutions for enhancing team coordination. A majority of the work is focused on assisting teams that work in office-like environments. This is not surprising given the vast market of office support products targeted at increasing work flow and productivity [46]. However, with the pervasiveness of mobile devices and technological advances in mobile computing, recent research efforts are now equally focused on providing tools to assist the mobile user and fortunately our target teams fall into this category.

The tools developed to assist in team processes can vary greatly depending on the target use, however, most team collaboration efforts center around training, scheduling, planning, tracking and sharing information in an effort to maximize situational awareness [12]. Early versions of location-aware systems used for mobile gaming showed an increased potential for team coordination and situational awareness capabilities. By using Cell phone ID, GPS, or assisted GPS technologies, applications can be used to locate members of a team and allow for direct communication. Songs of North is an example of a Cell ID location-based role playing scavenger hunt game [104]. Decay watch is also a scavenger hunt game that uses GPS and allows mobile blogging and chat [17].

In many hazardous situations, the mode of information presentation must be adapted to provide mobility and hands-free interaction for the user. In addition the format of the information presented has to take into account a reduced capacity for information processing by the user. For example, tracking tasks are fairly simple when the situation allows time for focused attention of a navigational map. However, this is a luxury our target teams do not have and therefore existing research has been focusing on ways to essentially repackage this type information. Studies conducted at the Army Research Laboratory have shown that standard methods of static map display are mentally demanding and that moving map displays reduce navigation time [26]. Rohs et al. used human studies to compare the performance of three different modes of map interaction with a handheld device: joystick navigation (scrolling and panning), the dynamic peephole method (map is fixed, device is moved; overall context is not visible), and the magic lens paradigm (map is fixed, device is moved; overall context is visible) [113]. Their results showed that the two methods of navigating maps through physical movement of the device produce the best results in terms of task performance and error minimization. Furthermore, a study conducted by Seager et al. evaluated a dynamic interface with embedded GPS technology in comparison to a static map [116]. The study noted that users found positioning systems that give directions more useful in situations where the maps are not well defined.

In the rescue aid area, technological solutions are being provided to not only assist in team coordination, but also to enhance team coordination training. Toups and Kerne developed a location-aware system with the purpose of delivering emergency response education to firefighters [124]. Their system provides a visual context of the user's location in a virtual environment for the purpose of conducting team building exercises. In terms of navigation, Thomas et al. explored the use of AR in an outdoor environment as a means of providing visual cues during orienteering and navigation tasks [123]. Applications such as these give us insight into methods for creating a multimodal display for our location-aware system that could be applicable to a wide range of teams that work in high stress environments.

3.1 Augmented Reality (AR)

Augmented Reality is another technology that has emerged as an optimal information visualization method for mobile location-aware systems. Reitmayr and Schmalstieg created a mobile navigation system that provided an AR-based interface for information browsing and navigation functions [108]. This system was used as a virtual tourist guide and contained a detailed 3D model map of Vienna. The navigation system contained data pre-loaded and specific to one location. In addition, the complete system‘s data handling model would require a server-based database and an established network [107]. Similar concepts applied in the military domain resulted in systems like the Super Cockpit which used AR to assist in piloting tasks such as low altitude navigation and targeting, and the Battlefield Augmented Reality System (BARS) which assisted the dismounted warfighter by providing information about urban environments via a Head-mounted Display (HMD) [75]. Interactive Dirt is another AR-based military system that uses a wearable projector-camera system that was designed to bring HCI to extreme teamwork situations, such as military stability and support operations [82]. The designers focused on maintaining situational awareness while providing a mobile system that is highly adaptable and brings new information (projected images of maps or orders) into new domains.

Augmented Reality has been used to enhanced environments for various outdoor location-aware games such as GunSlingers, UnderCover, and BotFighters which use the underlying cell phone network to transmit location information to different players [5, 143, 106, 100]. Similarly treasure hunt inspired games use cell phone ID (Songs of the North), GPS (Decay Watch), or Assisted GPS (SwordFish) to locate the users and direct them to treasures using clues [17]. These systems utilize information readily available from mobile devices to determine the location of the user.

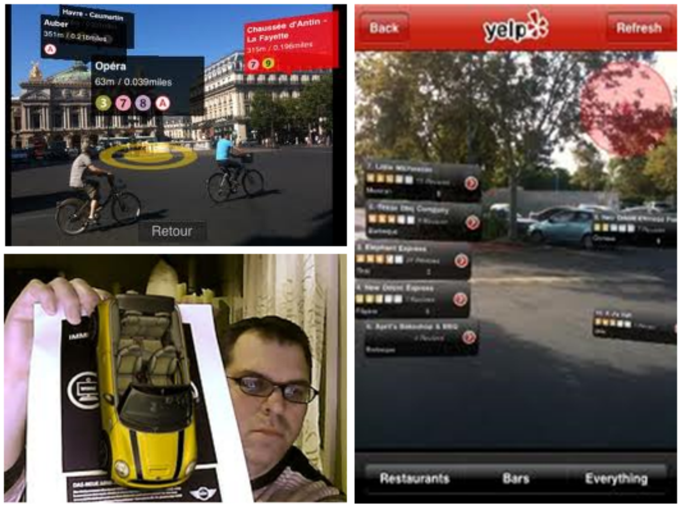


Figure 3.1: a) Top left, *Metro Paris Subway*: AR App for iPhone [102] b) Bottom left, AR advertisement for MINI Cooper [84] c)Right, *The Monocle*: AR view for Yelp's mobile application [66]

AR has also been used for countless consumer-related products such as mobile applications for locating restaurants and merchants, and even educational products for children. Mansley et al. showed how richness in feedback in a game environment, in terms of adding a more meaningful representation and different modalities of information representation, can make up for the latency in a positioning system [79]. While these systems can provide useful information that can influence how the user interacts with her surroundings, they do not provide in-depth information about other users of the system; information that can enhance how they communicate and interact with potential teammates.

In areas of education, Doswell explores the use of a mixed reality-based instructional system is to assess the level of comprehension of students studying robotics and programming concepts [31]. Virtual instructors and programmable robots were used to enhance problem-solving skills through project-based learning in science and technology. In the project, lab reports and questionnaires were used to measure the students level of comprehension.

These type of augmented reality applications have utilized various tracking techniques including sensor based, vision-based, or a hybrid of both. Sensor-based tracking methods make use of sensor inputs such as GPS, gyroscope, *etc.* to determine the proper location of a generated virtual image. Vision-based tracking methods use the size, orientation and location of fiducial markers to calculate changes to the generated image (Figure 3.1).

3.2 Physiological Signal Analysis

Much of physiological signal analysis research has been focused on identifying unconscious emotional responses such as facial expressions [34]. Some studies show a possible correlation between heart rate, body temperature and emotion [35]. However in recent years the focus has shifted to identifying overall user state and emotion recognition.

Pavlidis presents a novel approach to physiological signal analysis. Using a thermal camera directed at the user with face tracking methods, the authors were able to compute superficial blood flow, cardiac pulse, and breathing rate, and thus were able perform the physiological monitoring without the use of contact equipment and without hindering freedom of motion [99]. The physiological data was used to identify the onset of stress, irregularities in heartbeat and sleep apnea.

In a study conducted by Honig et al. physiological recordings of participants were collected in a simulated driving context using the Mind Media NeXus-10 device which included the following sensors: electrocardiogram (ECG), electromyogram at the neck (EMG), skin conductivity between index and middle finger (SC), skin temperature, pulse and respiration [58]. Honig was able to recognize relaxed and stressed user states with close to 90% accuracy.

While stress recognition is an important area of physiological signal analysis, emotion recognition has emerged as the more challenging problem. There has been extensive research on various feature extraction and classification methods for emotion recognition. Chanel conducted an evaluation of 2 linear classifiers (Nave Bayes and a classifier based on Fisher Discriminant Analysis (FDA)) on electroencephalographic (EEG) signals and other peripheral signals (ECG, SC, *etc.*) combined to assess the arousal component of emotions [15]. Their findings showed that classification methods in which there is a lesser sensitivity to correlated features (FDA) worked better on the combined signals. Although more recent research has been focused on identifying emotion with a small context of physiological data, their results may be an indicator that the addition of EEG data as a signal input may prove to be beneficial to recognition accuracy with the use of non-linear classifiers.

Kim et al. used skin temperature variation, electrodermal activity and heart rate derived from electrocardiogram (ECG) signals as input to calculate time-domain features such as heart rate variability (HRV), mean and standard deviation [65]. Their goal was to identify the best set of features for short segments of a signal. Using pattern classification, they were able to create an off-line user-independent recognizer that had an accuracy rate of 78.43% and 61.76%, for the recognition of three and four emotion categories, respectively.

A very important study conducted at the University of Augsburg focused on identifying user emotion state through music stimuli [136]. During the study 3 participants were asked to select four of their favorite songs reminiscent of specific emotional experiences and corresponding to four emotion categories: Joy/Happiness (enjoyable, harmonic, dynamic, moving), Anger (noisy, loud, irritating, discord), Sad (melancholic, reminding of sad memory), and Pleasure/Bliss (slow beat, pleasurable, slumberous). Three participants were made to listen to these songs everyday for

25 days while connected to the following sensors: Electrocardiogram (ECG) - measures activity of the heart, Electromyogram (EMG) - measures muscle activity, Skin conductivity (SC) - measures sweat levels, Respiration (Resp), Skin Temperature (Temp), and Blood Volume Pulse (BVP). Data from this study was used to create a corpus of physiological signal data that could be used for other feature extraction experiments. In a later study, Honig used these data signals and derived four additional signals: 2 to measure instantaneous heart rate, 1 for respiration rate and 1 for pulse transit time (PTT). The Augsburg Toolbox was used to calculate statistical features for each of the signals [135]. Honig added additional features, calculated using a sliding method, in order to separate the signals into classes representing the four emotional states. Given the length of the analysis window in samples (let's call it w), each feature was calculated on w previous samples and computed recursively to make it efficient and suitable for on-line classification. To counteract the affect of rounding errors, the recursive result is thrown out every w steps and the feature is computed using the original equation.

Classification of physiological signals is difficult because the duration of emotions are not predictable. Reliable classification requires a relatively large context and real-time processing of large amounts of data is problematic for commonly used feature extraction approaches. As a result, most classification is performed offline (on prerecorded data). Honig claims that his method of classifying physiological signals can be performed on live data. However, at the time this dissertation was written, this method has yet to be tested.

In addition to the study of emotions, physiological sensor data has been explored on a more basic level in an effort to identify correlations with the human state. For example, existing research efforts in the psychological fields have suggested there is a relationship between acute physiological responses and post-traumatic stress disorder

(PTSD) [53]. PTSD is an anxiety disorder that usually results from exposure to terrifying events (*i.e.* violent personal assaults, environmental disasters, accidents, military combat, *etc.*); it is characterized by difficulty sleeping, feeling emotionally numb and/or detached, and being easily startled.

A current study being conducted at the West Point Military Academy aims to find a correlation between PTSD and unconscious facial expressions. Subjects are made to watch videos that become progressively gruesome while their facial expressions are monitored; at the same time sensors are used to monitor changes in skin conductance, heart rate, and blood pressure in an effort to validate the facial expression of emotion. The authors referenced Ekmans work on clues to deceit and faking emotions in order to emphasize how hard it is to fake a physical response when the emotion or facial expression is not genuine. This study was based on a similar experiment conducted by Dr. Paul Ekman in which a group of participants were made to watch a film depicting bloody surgical scenes and asked to lie and say they were watching a movie about flowers [34]. The purpose of this experiment was to determine if people could successfully hide facial expression of their true emotion while a lie was taking place. Another study conducted at the National Center for PTSD collected heart rate and skin conductance data in an effort to predict PTSD in women who had been physically attacked. They found that a physiological reaction to monologues related to trauma, in particular a sustained increase in heart rate resulting from numbing symptoms, occurred in most cases after completing the study.

A Brain-computer interface (BCI) is a direct path of communication between an external electronic device and the brain. BCI-based communication research was first conducted in the early 1970s by Jaques Vidal at the University of California, Los Angeles [134]. In his work, Vidal focused on the observation of electroencephalographic (EEG) signals. EEG signals are fluctuations of electrical potential along the scalp created by neurons in the brain. EEG signals can thus be measured outside the brain itself in a non-invasive way via wearable headsets. Vidal proposed a set of experimental strategies for BCI-based communication that are mirrored after traditional human-computer communication. His strategies included matching objects, binary acceptance and rejections, and choosing between visual alternatives. Vidal also stressed the importance of operant conditioning, and thus encouraged game playing experiments in order to provide opportunities for rewarding and reinforcing participants [134].

Much EEG-based communication research has been focused on restoring communication and movement to paralyzed individuals via the extraction of different signals [140]. Visual evoked potentials have been used to gage a wearers focus on different presented symbols or graphics [83] [121] [134]. Sutters work resulted in participants being able to type 10-12 words per minute [121]. Birbaumer et al. used slow cortical potentials (SCPs) to allow patients with amyotrophic lateral sclerosis to spell out words by selecting letters from an electronic list [10]. This process required many training sessions and resulted in a speed of roughly 2 characters per minute, but did not require any muscle control. The P300 wave, which is elicited by infrequent auditory or visual stimuli, has also been used to make selections by BCI wearers [117, 38] . Participants focused on a desired character in a grid of options; the difference between the P300 wave for a grid containing a desired character and one without the character is used to make the selection. This method does not require any training.

While there has been extensive research on classifying the user state using EEG data, real-time user state classification has seldom been explored for EEG in conjunction with other physiological data. This is most likely due to the fact that EEG datasets can be extremely large (some BCI headsets can obtain up to 64+ channels of data). EEG data can also vary greatly depending on the user and the type of equipment used.

3.3 Affective Haptics

The use of arousal synchronization as a form of communication has been explored in systems like *imPulse*. This system focuses on the need for intimacy and the potential for heartbeat synchronization as a means of communication [76]. This system uses lap-sized stations that transmit heart rhythms from one user to another in the form of vibrations and blinking lights. Users interact with these stations by placing their hands on the device. The lack of mobility and the occupation of the users hands are limitations we sought to overcome in implementing a similar interaction method for our system.

A substantial amount of research has been conducted regarding Second Life, especially in the field of Computer-Human Interaction. Most notable in comparison to our research is *iFeel_IM* a system that recognizes 9 distinct emotions by analyzing conversation in Second Life. These emotions are used to simulate similar emotions responses in the user using a suite of haptic devices and portrays the user‘s emotions on his/her avatar using *EmoHeart*. The haptic devices each serve to simulate a specific sensation, such as tickling, warmth, and a hug [89]. One such device is HaptiHeart, which is worn on the chest and uses a speaker to simulate a heartbeat at a rhythm determined by the system. Unlike Emotivibe, which simulates the actual heart rate of another person, HaptiHeart simulates a heart rate designed to influence a specific emotional state in the wearer.

Hug Over a Distance uses an inflatable vest to simulate a hug when remotely triggered by another user via stuffed koala [85]. This system sought to recreate physical interaction however the implementation was only marginally successful (users found the simulated hug unrealistic, the vest ”weird”, and the overall system lacking in applications). Lemmens et. al. explored the use of a body-conforming vest equipped with 64 tactile stimulators as a means of enhancing the viewing and entertainment experience when watching movies [73, 126, 127]. This immersive experience also had limited success; it failed to engage the user‘s sense of enjoyment or emotional attachment. *PillowTalk* explores the notion of social intimacy with a system of networked pillows outfitted with sensors and designed for public spaces [115]. *PillowTalk* is most notable for its mapping of a wide variety of bio-inputs to actions carried out by the system. Pillows uses bluetooth and wifi to aggregate inputs collected by the system and direct output to the optimal location. We developed our interface with successes and failures of these projects in mind: the use of a haptic vest as a means of output is very feasible as long as it isn't cumbersome, and utilizing emotionally-relevant output such as a heartbeat should resonate with the user.

3.4 Unmanned Aerial Systems

In the areas of UAS interface design, various UAS control and communication methods have been explored. Some of these methods include voice recognition, joystick control and even screen icon interaction to name a few [103]. A sketch-based UAS interface is a logical extension in this realm. The use of quick sketches to show or clarify concepts is a natural and effective form of communication. Sketch recognition is the interpretation of hand-drawn sketches by a computer. It presents a unique problem because no two free-hand drawn sketches are alike. As a result, identifying important shapes and/or text and determining their meaning can be quite a difficult AI problem.

In applications involving geographic information systems (GIS), even minute changes and inputs are often complex and tedious as a result of the non-spatial input methods used by most programs [11]. Geospatial analysis involves the evaluation and processing of geographic datasets from many applicable areas including flight planning, military mission planning, land development, *etc.* Many of the editing tools in popular GIS applications are based on mouse and keyboard input, which is not similar to the common practice of marking up hardcopies of maps. For this reason, many applications have been created to try and capture sketches and translate them into meaningful data for programs.

For example sketch-based programs such as nuSketch Battlespace and COASketch have been developed to simplify the creation of military course of action diagrams [41, 54]. NuSketch Battlespace uses glyphs and spacial reasoning while COASketch uses a free-hand sketch recognition approach. GeoSketch is a geospatial application that uses free-hand sketches to alter or augment geographic datasets in various map formats [21]. The user's freehand sketches can be understood by trained gesture recognition algorithms and translated into basic editing functions. In areas of defense, GeoSketch can interpret shapes on a map similar to those used in course of action diagrams. The location data and meanings of these shapes can then be used to deliver important mission planning information to location-aware systems. GeoSketch provides sketch-based interaction as a visual bridge between the graphical representation of geospatial maps and the user and therefore has been used as a basis for interactions methods to navigate or control unmanned aerial vehicles.

These works provide justification for continued research into technological solutions to aid team coordination. Some of the solutions are outdated, but they show how technology can be used to assist with the performance of certain team-coordinated tasks. As of yet, none of these applications provide an overall model to mitigate the challenges to team coordination encountered in hazardous environments. This thesis presents a solution to these problems through a set of design principles for technological tools within this domain.

4. ETHNOGRAPHIC ANALYSIS OF SOLDIERS

A team of 5 research members from the Sketch Recognition Lab (Danielle Cummings, George Lucchese, Chris Aikens, Manoj Prasad, and Jimmy Ho lead by Dr. Tracy Hammond) conducted an ethnographic study at Ft. Bragg, North Carolina. During a series of monthly visits we shadowed Soldiers of the XVIII Airborne Corps as they conducted their training to gain detailed information about their job and the challenges they face and to experience first hand the paratroopers' daily performance. We held discussions with focus groups and whenever possible, we participated in the paratrooper training exercises and documented our reactions.

4.1 Paratrooper Drop Practices

As stated in the previous chapter, the paratrooper's job is to strategically conduct forcible entry via parachute assault to capture key objectives for military operations. The airborne assaults usually consist of 2 types of drops: an equipment drop also known as a heavy drop (HD) and a personnel drop. The HDs can include approximately 33 platforms containing vehicles, supplies and artillery packaged in containerized delivery system (CDS) bundles (Figure 4.1). The personnel drops can include placement of approximately 2,000 soldiers or more.

Prior to the jump, soldiers study a map of the landing zone and are briefed on where they are expected to land within the drop zone (DZ) and where they are to navigate in relation to the drop location. They then can compute the direction and approximate number of paces to the assembly location relative to the determined flight path so that they know what to do when they land. The equipment and personnel are loaded onto Alpha Echelon 68 C-17 aircrafts (Figure 4.2). Soldiers are organized on the plane near their designated assembly teams and/or near their

Figure 4.1: Heavy Drop (HD)

equipment. The units are seated in an order that corresponds to the relative location of their target areas on the ground. For example, if team A needs to assemble near the "top" of the DZ, then their members will be seated closest to the door on each aircraft and they will be the first ones to jump. This is to increase the likelihood that soldiers from the same units will land near the same location in the drop zone. Significant leaders and equipment that is of great importance to the mission are distributed among the aircrafts in order to minimize the affect of a single aircraft failure on the success of an entire mission. There are usually two Stiner Aids assigned to each unit, and 2 Soldiers are tasked with erecting one Stiner Aid. These pair of Soldiers are intentionally placed on different aircrafts to maximize the chance that one of the two Stiner Aids will make it to the ground. If for any reason, the drop zone is compromised, the aircrafts must continue on and either make a second pass of the area at a later time or switch the location of the DZ. Delaying the drop and/or relocating the DZ will affect the placement of forces on the ground. Even a slight change in drop timing can significantly alter the drop location (Figure 4.3). A one second delay can displace a Soldier hundreds of feet from his/her intended target on the ground; if a Soldier hesitates when jumping out of a plane, he/she will often be

Figure 4.2: Alpha Echelon 68 C-17 aircraft [55]

forced out to minimize the impact of further delay, which only serves to disorient the Soldier even further. A single pass and drop in a DZ is considered a success, but it is common for planes to have to do a double pass or drop because of incidents such has Soldier hesitation, equipment failure, enemy fire, *etc.*

The main strategy of a paratrooper airborne operation is surprise. The drop process occurs very rapidly with the aircrafts flying over the DZ in a very tight formation and dropping cargo and personnel in as short an interval as is possible without risking collision (Figure 4.4a). The HDs are dropped from the plane first to avoid crushing Soldiers on the ground. When the paratroopers have jumped out of the plane, they are trained to look toward the location of the planes as they fall to help orient themselves. They descend to the ground and, depending on environmental conditions, have a moderate to severely turbulent landing (Figure 4.4b). This landing often causes immediate disorientation, so the paratroopers must look up at the sky again to determine the last known flight direction of the aircrafts. This practice of

Figure 4.3: Paratroopers cannot delay jumps over the Drop Zone (DZ) [109].

(a)

(b)

Figure 4.4: (a) Large groups of paratroopers jump from the planes in a small time interval [47]. (b) Rough landings can disorient paratroopers [48].

watching the aircraft provides some indication as to the possible location of their assigned HD (which should be behind them in the flight path trajectory) or their assembly location. However, one significant problem mentioned by paratroopers is that if the landing recovery takes too long, the planes may already be out of visible range by the time the Soldier is able to look up. This is especially true if the Soldier is jumping from the last plane in the line of aircrafts. After being dropped into unfamiliar terrain at night, units of paratroopers must quickly assemble in their assigned units with their equipment; to do this they head in the supposed direction of their assembly location and then scan the horizon for the Stiner Aid with the chemical light code for their unit.

Soldiers stated that assembly can be a very confusing and chaotic task. Unfortunately since the Stiner Aid is so heavy, the team members that are tasked with erecting it are not always the first ones to arrive at the assembly point which only adds to the confusion as Soldiers are sometimes searching for a Stiner Aid that may not even be there. Ambient light from the moon or other sources makes the Stiner Aid difficult to locate. In addition, noise discipline is required, meaning that they are not allowed to openly communicate with their teammates to assist with this process. Once the entire unit has assembled into a coordinated fighting force, they may proceed with the mission.

Trainers and team leaders informed us that the entire process may take 20 minutes for a highly experienced and efficient team of paratroopers. However, if the team is inexperienced and/or if there are complications, the assembly task may take up to two hours or more. In some instances; members of the unit never find their assigned assembly location and unit resulting in casualties (this has happened in training exercises where, even without the threat of an enemy encounter, lost Soldiers died of hypothermia).

4.1.1 Containerized Delivery System Specifications

MAJ Thomas and LTC Mertsock arranged an meeting with airbase operational test bed team. The operational test bed team is a team of experts who configure the HDs with drop analysis tools which include a data collection tool, accelerometer and GPS to analyze the rate of decent, time of parachute release, time of impact and various other data collected to analyze the drop. The team noted that if a dropping package experiences more than 28.5G for extended period of time, the package is sure to be damaged after landing. The force experienced by the package at the time of impact is about 70 - 90G for span of few milliseconds. When securing additional equipment to the HD, the team stated that finding a secure place on the HD and packaging the equipment to dampen the forces during impact are the two main factors for successful equipment operation upon landing. As with any drop, there is always a chance of the parachute release mechanism falling causing damage to the HD or any other external equipment; to mitigate this, extremities are secured within the package as much as possible. They showed us different types of packing material used to secure dropped loads. The team stated that there is no standard process to package all the heavy drops; the packaging structure differs with each heavy drop and so does finding a secure spot in the heavy drop to place sensitive material.

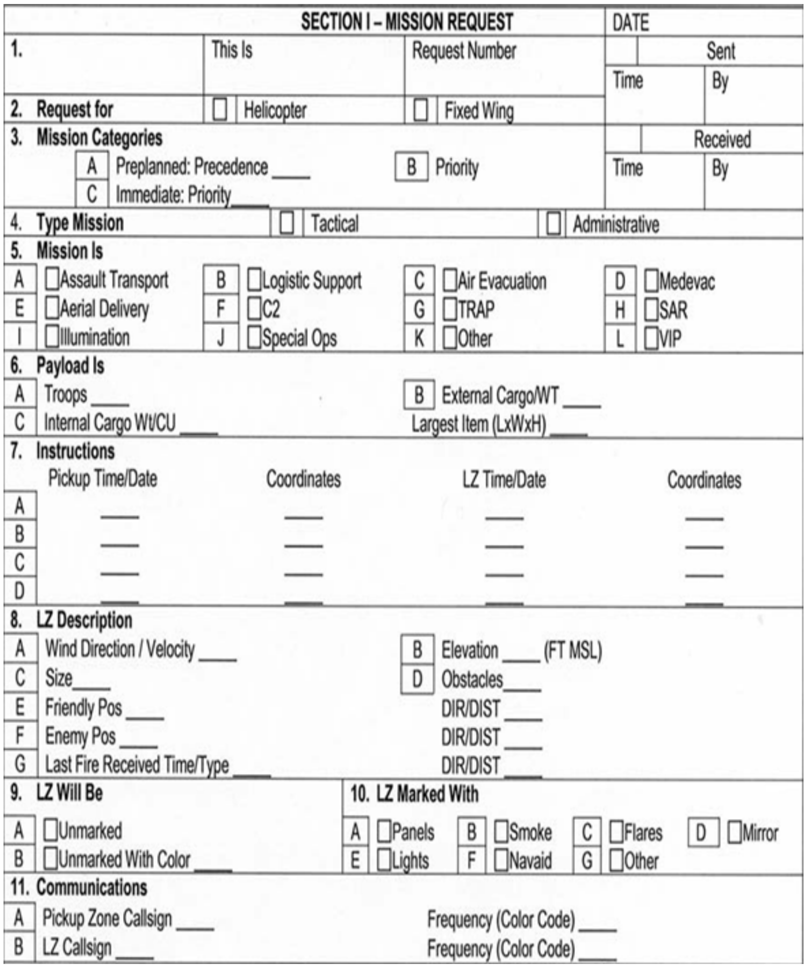
4.1.2 Soldier Habits

During our study we interviewed paratroopers with varying levels of experience. We found that younger Soldiers tended to rely more heavily on technological devices than older, more experienced Soldiers. However, many of the more experienced Soldiers were both familiar and comfortable with using mobile computing devices and owned smartphones. They stated that years of training had given them the confidence to rely on what they know and what they were trained to do in situations where their devices would prove useless.

On the contrary, more inexperienced Soldiers secretly admitted to frequently using location-aware applications such as Google maps on smartphones or a Garmin GPS device to assist them in their navigation tasks during training exercises. This practice is technically not allowed and highly discouraged as it allows Soldier to rely on technology that will be either unavailable or useless in the field. In addition through further discussion with the Soldiers, we discovered that many of them routinely jumped with their smartphones unprotected and stored in one of the outside cargo pockets of their uniforms. They also revealed that their phones, although unprotected with special ruggedized cases, did not break upon landing.

During focus group discussions the Soldiers talked about how disorienting the entire drop experience is. Soldiers commented that the Stiner Aids were often very difficult to identify unless you were in a fairly close proximity (ambient light from the moon or other sources interferes), meaning that it was hard to identify the unit designations until they had traveled a majority of the distance toward possibly the wrong Stiner Aid. And because there are so many Stiner Aids, a Soldier can easily get fatigued running from one glowing light to another. They stated that a navigation aid (possibly in the form of a wristwatch or some other device that could be secured to their person) would greatly benefit the assembly process. As expected, the group members were somewhat divided on how much navigation information should be delivered by the device. Some Soldiers only wanted a directional indicator, similar to a compass, that they could reference while performing their normal trained navigation exercises, while some Soldiers wanted to be able to see an entire map that showed the location of not only the assembly points, but the location of their teammates as well. However, after some debate amongst themselves, they determined that the later level of awareness may be justified for team leaders only.

Soldiers also stated that if they encounter adversaries during the mission, they are required to destroy any and all materials that can provide intelligence to the enemy. In a specific case, they stated that if the sensitive information was located on some handheld device, protocol dictates that they were to destroy the device completely (usually by shooting it) to prevent the enemy from acquiring it.



SECTION I – MISSION REQUEST

DATE

Sent
Time By

Received
Time By

1. This Is Request Number

2. **Request for** ☐ Helicopter ☐ Fixed Wing

3. **Mission Categories**
A Preplanned: Precedence ____ B Priority
C Immediate: Priority ____

4. **Type Mission** ☐ Tactical ☐ Administrative

5. **Mission Is**

A	☐Assault Transport	B	☐Logistic Support	C	☐Air Evacuation	D	☐Medevac
E	☐Aerial Delivery	F	☐C2	G	☐TRAP	H	☐SAR
I	☐Illumination	J	☐Special Ops	K	☐Other	L	☐VIP

6. **Payload Is**
A Troops ____
B External Cargo/WT ____
C Internal Cargo Wt/CU ____
Largest Item (LxWxH) ____

7. **Instructions**

	Pickup Time/Date	Coordinates	LZ Time/Date	Coordinates
A	____	____	____	____
B	____	____	____	____
C	____	____	____	____
D	____	____	____	____

8. **LZ Description**
A Wind Direction / Velocity ____
B Elevation ____ (FT MSL)
C Size____
D Obstacles____
E Friendly Pos ____ DIR/DIST ____
F Enemy Pos ____ DIR/DIST ____
G Last Fire Received Time/Type ____ DIR/DIST ____

9. **LZ Will Be**
A ☐Unmarked
B ☐Unmarked With Color ____

10. **LZ Marked With**

A	☐Panels	B	☐Smoke	C	☐Flares	D	☐Mirror
E	☐Lights	F	☐Navaid	G	☐Other		

11. **Communications**
A Pickup Zone Callsign ____ Frequency (Color Code) ____
B LZ Callsign ____ Frequency (Color Code) ____

Figure 4.5: Example Air Support Request (ASR) form

4.2 Field Request Processes

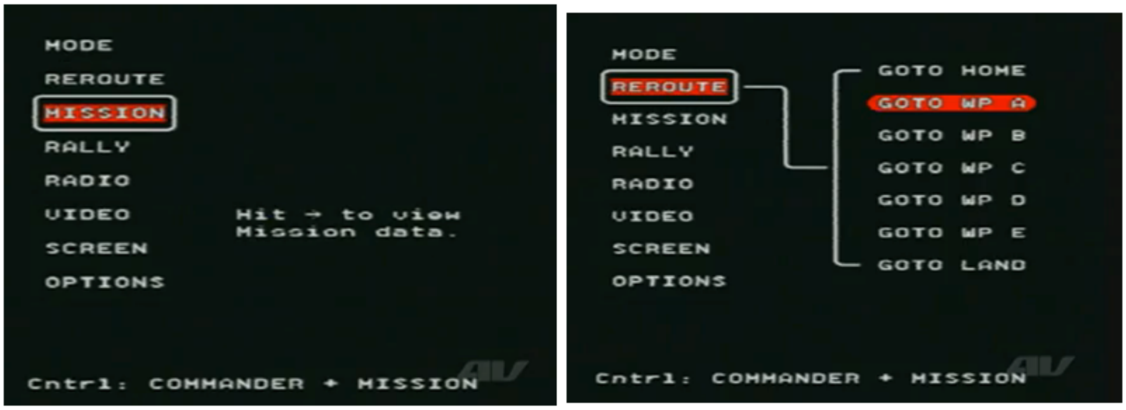
During the process of completing their mission, Soldiers may encounter circumstances in which additional supplies or even a medevac is required. When this occurs, Soldiers in the U.S. Army and the U.S. Navy will initiate an Air Support Request (ASR) (Figure 4.5). We interviewed four Navy personnel (pilots and Marines) and two Army officers from ground based units, who all had involvement in cargo supply and/or medical evacuation procedures through field operations, to determine how an ASR is conducted. We sought to understand current practices for ground-based Soldiers interacting with manned helicopters when requesting cargo re-supply.

We asked the interviewees to assist us in creating an extensive list of Soldier support scenarios which we consolidated into 13 examples, two of which are listed below:

1. *A Soldier needs a resupply of bullets and food. His team is in hiding, waiting for an assault planned for a day from now. The team is located outside, in the mountains, and are without tents. He makes the request at night, so as not to give away his position with bright lights or loud noises. He's probably wearing gloves that are big and clumsy. He's tired and may not be thinking as clearly as normal.*

2. *A vehicle convoy is traveling on a humanitarian mission to a city. At some point the vehicle can no longer progress through city streets. The Soldiers park the vehicle, leave a small security detail to guard the caravan and proceed on foot. Upon arrival at their destination, a Soldier requests Humanitarian assistance packages (10 bags wheat, 10 bags of rice, 10 bags of oil,* etc.*).*

In scenarios like these, Soldiers on the ground would use a ruggedized Combat Net



Hit → to view Mission data.

Figure 4.6: Menu-based Unmanned Air System (UAS) interface

Radio (CNR or equivalent) to communicate using the Single Channel Ground and Airborne Radio System (SINCGARS). These communications have a limited range and therefore, the Soldiers don't always know who they're contacting; if they reach a nearby unit, then the message is passed on until it reaches its recipient. All radio communications are kept as short as possible. There is a standard 9-line message that ensures that the minimum amount of information needed to complete an ASR is received. The information in the 9-line varies slightly depending on the military affiliation but they all include the type or request and location of the requester, as well as the call frequency. The 9-line is meant to guide communication, however, in tense or critical situations, communication standards may fail and the receiver and/or pilot must find a way to get the information he/she needs to complete the requests efficiently. For example, a few of the pilots we interviewed stated that when multiple requests need to be filled it was often challenging (and difficult emotionally) to determine which requests required priority. Soldiers on the ground may offer exaggerated information (*i.e.* "Get my buddy out now, he's dying") with the noblest intentions of convincing a pilot to respond to them first.

If the pilot that responds to the ASR has to go into hostile area, he/she will proceed with an armed escort for protection.When the pilot is within range of the specified cargo drop location, he/she will contact the requester on their frequency and notify them of the estimated time of arrival (ETA) so the Soldier can mark the landing zone (LZ). LZ markers can range from mirrors to flares to VS-17 marker panels that contain bright colors and fold out to draw attention to the LZ. In addition, every squad or team leader carries an IR strobe light that can be attached to a Soldier's helmet or other article of clothing or equipment to reveal the Soldier's position to friendly aircrafts at night. When the cargo drop is complete, Soldiers load the supplies onto convoy trucks or helicopters, and then navigate to their destination while avoiding threats and obstacles along the way. Traditionally these requests are completed by human pilots, but in order to minimize the number of casualties, these requests are starting to be performed by unmanned aerial vehicles (UAVs) controlled by human pilots from a safe location. However, the technology used to interact with UAVs relies on dedicated hardware, counter-intuitive user interfaces, and user proficiency (Figure 4.6). As such, there is a need for improved interaction methods that will allow Soldiers to easily communicate with and/or control unmanned air vehicles.

5. IMPROVING TEAM ASSEMBLY

Previously we described the Stiner Aid system currently used to assist with the assembly task of paratroopers conducting night missions in the field. Unfortunately this process uses an antiquated system and does not address the needs of today's battlefield scenarios. In addition, the Stiner Aid system does not effectively assist with challenges to team coordination, but rather, as our study revealed, adds to them by causing confusion and uncertainty during assembly. Therefore a solution is needed that uses the information obtained during the ethnographic analysis to better understand and establish principles regarding how technology can best be used to contribute to team coordination on the battlefield. In this chapter we describe the system design that resulted in a technological solution to replace the Stiner Aid. We also discuss how the iterative development and evaluation of this solution lead to the formulation and validation of the following design principle mentioned on page 8: *Allowing each user to control the amount of data received through a multimodal interface can create a better user experience and increase user acceptance of the technology.*

5.1 Design Considerations

Prior to developing a solution, there are various environmental and operational factors that must be considered. For example, cellular services will not be available in the battlefield, however GPS is a receive-only broadcast, available worldwide; it is an especially good solution for drop zones since selected areas, in order to be suitable for a drop, must be free of trees and other obstructions which normally may interfere with GPS signals.

Each assembly point has a Stiner Aid with a unique visual marker. Paratroopers use night vision to locate the chemlight or IR marker. When the Stiner Aid was invented in the 1980s, the US Army was the only institution in the world with night vision capabilities. However, night vision equipment is now ubiquitous and the US military no longer commands a strategic advantage. As LTG Helmick, Commanding Officer of the XVIII Airborne Corps, often states, "We don't own the night, we share it". For this reason, it is vital that any solution developed minimizes light pollution, even in the IR spectrum; this prevents the Soldiers from becoming a target to enemy forces during night missions. Also, because of the covert nature of most operations, it is critical that Soldiers maintain radio silence and minimize noise. Therefore the solution system must not require audible input or emit noises that would draw unwanted attention to Soldiers.

Military and airborne training exposes paratroopers to standardized equipment and methods of navigation. For example, paratroopers are trained to use a compass and map to quickly identify cardinal directions and bearings in order to track the potential location of assembly points. The military uses the Military Grid Reference System (MGRS) for locating points of interest in drop zones. Stiner Aids also afford certain forms of interaction; Soldiers are trained to visually identify assembly points. Stiner Aids keep a Soldier's eyes up and scanning the horizon, and as a result, they maintain a higher level of situational awareness. Mobile solutions to their coordination tasks must be based on these established precedents so that the technology can be more easily integrated into field operations. Specifically, any solution must support current training methods, enabling Soldiers to complete their mission even when technology fails. Additionally, mobile solutions should capitalize on the existing knowledge domain to increase ease of use and understanding. For example, many of the Soldiers we interviewed either owned or had experience using smartphones, and therefore were very comfortable using them.

However, we knew that requiring paratroopers to look down at a small display on a phone draws their attention away from their surroundings. Any proposed solution must provide the Soldier with near constant situational awareness at a low cognitive cost. Simplified interfaces that mimic tools currently in use within the commercial sector can greatly decrease Soldiers' cognitive overhead and allow them to dedicate their attention to their current tasks.

As mentioned in the previous chapter, the combat-loaded paratrooper weighs over 400 pounds. Any added weight increases the burden of an already unbearable load. The Soldier is already carrying a large amount of materials in terms of size and unwieldiness. Therefore minimizing the size and weight of the equipment a paratrooper must carry is critical for maintaining their safety and increasing their mobility.

5.2 Solution Design

To address the navigation problem, we have developed a multi-modal mobile navigation system, called GeoTrooper, which uses Global Positioning System (GPS) enabled ruggedized computers to mark assembly points, and Android handsets to aid Soldiers in navigating to these assembly points. The GeoTrooper system was implemented using light-weight commercial off-the-shelf devices, some of which are already included in the equipment carried by paratroopers. With the previously mentioned considerations in mind, we developed a two-part mobile navigation system using SIM-card–free Android-based smartphones and GPS and Wi-Fi equipped Panasonic ToughBooks (ruggedized tablet computers) (Figure 5.1). The physical locations of the ToughBooks are used by unit commanders to mark the position of individual assembly points; the ToughBooks broadcast their GPS coordinates to the Android devices using an ad-hoc Wi-Fi network. The Android smartphones, run-

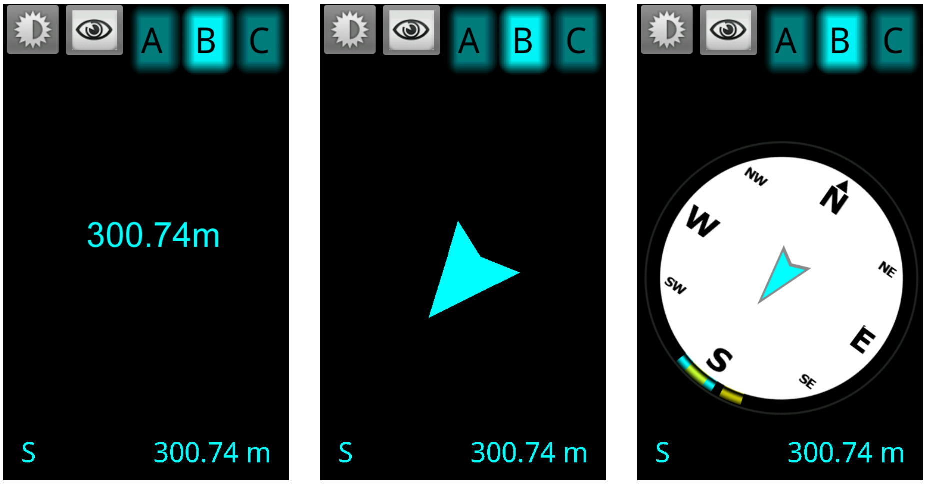
Figure 5.1: Assembly point broadcast hardware with external Wi-Fi antenna and GPS receiver.

ning our GeoTrooper application, act as personal navigation devices for individual Soldiers, and constantly search for assembly points' broadcast signals to help the Soldiers navigate to the assembly points.

We chose to use Android smartphones without SIM cards for our system prototype due to the fact that phone service may not be available in combat environments, and because they're relatively lightweight, low cost, have GPS capabilities and include a fairly easy development platform. For testing and evaluation, we used Motorola Milestone smartphones running Android 2.2. For the assembly points, we chose to use ToughBooks because they are ruggedized, fairly inexpensive and can be fitted with external antennas to achieve maximum wireless range. While ToughBooks are not as portable as smartphones, they are lighter and less bulky than the Stiner Aid they would be replacing.

5.2.1 User Interface

The GeoTrooper navigation application has two main functions: locating and identifying assembly point broadcasts with a backend process, and helping Soldiers to navigate to the assembly points with the main interface. The interface is split into two parts. The top bar displays which assembly points have been located by

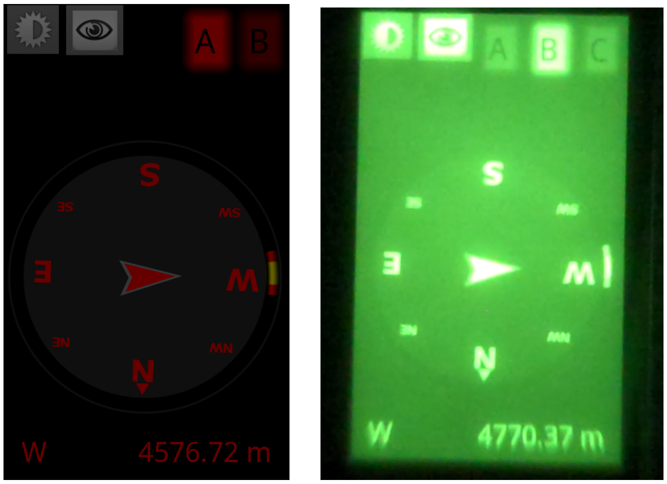


(a) (b) (c)

Figure 5.2: (a) Distance view, (b) Arrow view, and (c) Compass view on the mobile navigation interface.

Wi-Fi, allowing the Soldier to choose which one of these he needs to navigate to. As new assembly points are discovered, the menu grows horizontally; the Soldier is able to scroll through this list by swiping the screen, and selecting an assigned assembly point by clicking the button. Once the assembly point has been selected, the rest of the interface is used to present one of several navigation interfaces tailored after commonly used military navigation tools (Figure 5.2). The Soldier can switch between these views using a horizontal swipe. All of these interfaces provide a user-toggled Night Mode. Night Mode cuts down on light emission by dimming the screen's backlight and changing the interface's color scheme (Figure 5.3). This configuration renders the UIs virtually invisible outside of a 3m range in nighttime conditions.

The simplest navigation view is the Distance View which shows the distance in meters to the selected beacon (Figure 5.2a). This view was developed for the experienced paratrooper who prefers to rely on his/her own skill and navigate with minimal

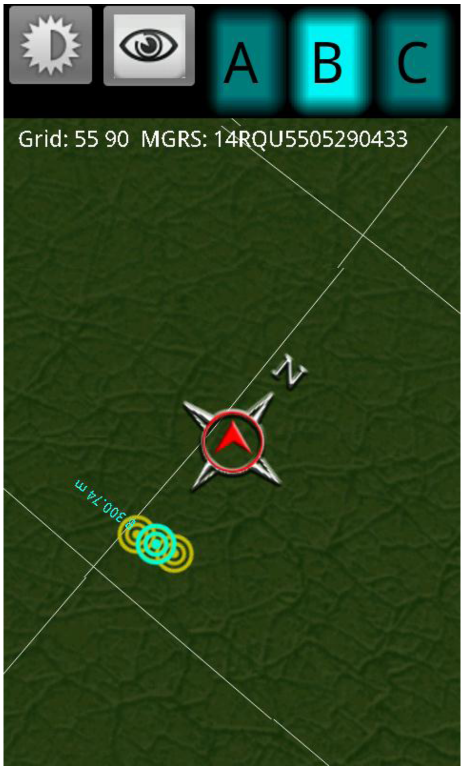


(a) (b)

Figure 5.3: (a) GeoTrooper running in Night Mode (NM). (b) GeoTrooper interface through NVG.

technological assistance. The Arrow View provides slightly more information; it consists of an arrow pointing towards the currently selected assembly point as well as the distance and azimuth to that assembly point (Figure 5.2b). The purpose of this view is to give the Soldier basic navigation directions without requiring significant cognitive processing. This view was specifically requested by multiple Soldiers during initial evaluations.

An alternative to the basic Arrow View is the Compass View (Figure 5.2c). This view is intended to present the relative location of all nearby assembly points, in an interface that is conceptually familiar to Soldiers. The Compass View consists of the same elements as the Arrow View, but overlaid on a compass face. A ring around the outside of the compass contains arc-indicators that point in the general direction of all located assembly points. A single blue indicator points toward the currently selected assembly point, and smaller, yellow indicators point toward other, unselected assembly points. The Compass View reinforces traditional navigation



Grid: 55 90 MGRS: 14RQU5505290433

Figure 5.4: Military Grid Reference System (MGRS) View

techniques.

5.2.1.1 MGRS display

Another navigation tool that Soldiers are familiar with is a map with an MGRS grid overlay. Prior to any mission each Soldier must become familiar with a map of the battlefield and memorize the MGRS coordinates of backup assembly points. We leverage this visual memory and pre-mission training in the Map View, a view that displays icons representing the position of the phone in relation to the position of detected beacons in the surrounding area on an MGRS map. In this view we display each assembly point and the Soldier's position as markers on a top-down map with MGRS coordinates overlaid on top (Figure 5.4). This interface provides navigation information in the context of coordinates that the Soldier must already be familiar with, as well as providing positions of other important locations over the entire battlefield. Similar to the Compass View, a blue marker is used to designate the currently selected assembly point and yellow markers are placed over all other assembly points. The map is always centered on the Soldier's position, which is marked with a special icon denoting the Soldier's heading relative to north.

At the time, this technology was not available for Android in the military sector, or in the commercial domain. Because the GeoTrooper system utilizes GPS components, we then had to find a method of converting GPS coordinates to MGRS coordinates. We accomplished this by adopting the Open System's Mapping Technology (OpenMap) open source programmer's toolkit provided by BBN Technologies [7]. By using this toolkit, we were able to take advantage of the embedded coordinate conversion algorithms without having to create an entirely separate application for processing.

We created the map to change the view and direction based on the position of the phone. This allows the user to see the direction and location of the beacons around him/her in relation to the current direction that the phone is pointed at all times. This makes the data much easier to view in comparison to most interactive maps where the map is static and the small user icon indicates direction, or, in worse cases, direction can only be determined when the icon/device is in motion. The grid is rendered to scale based on the distance to the furthest beacon in the beacon array. For example if the furthest beacon is 700m away, then the map is created showing beacons within a radius of slightly more than 700 meters. The threshold distance (and zoomed view) is set to about 1.5 km since this distance is more than .5km outside the recommended distance that should exist between a paratrooper and his/her assembly point. Any assembly point outside of this radius would not represent a feasible target during a mission. This view requires no interaction from the user, but instead responds to the direction that the phone faces and updates the data accordingly. Because this system is meant to impose a minimum cognitive load on the user, pinch and zoom interaction was not implemented; these features would require that the user interrupt his/her task to interact with the map, and therefore was not a useful feature in a field scenario.

5.2.2 Communication & Security

The paratrooper missions are frequently carried out by a large number of units (hundreds to thousands of Soldiers). Therefore the most critical factor to the success of airborne operations is not the covertness of the drop, but rather the rapid assembly of paratroopers on the ground. Assembly must be performed without engaging enemy troops, as the airborne force is most vulnerable during this assembly time. As a result, our system communicates the location of assembly points, but also utilizes encryption to prevent immediate danger even if detected. The main goal is to ensure that the paratroopers have landed, assembled and that the mission is underway long before there is any significant threat to the assembly points. Because an established communication network is usually absent in the DZ, we needed to create an adaptable system for information dissemination that can be used in the absence of large scale communication infrastructures.

Although this solution is rooted in the military domain, our system can be adapted for other scenarios where information needs to be propagated to a large, disconnected group of people (*i.e.* crowds at public gatherings or events). While a persistent wireless data connection may be an ideal way to handle communication, any wireless connection that relies on a large scale infrastructure is unfeasible when large numbers of users attempt to connect all at once. This may be the case in public gatherings in which crowds of thousands may assemble. Persistent wireless data connection is also not feasible when such infrastructures cannot be consistently maintained. In many instances, users are attempting to access the same information (*i.e.* during emergency broadcasts). Alternatively the desired data can be effectively encoded into small enough segments so that a persistent connection is not required. In general, ad hoc networks with established protocols allow for communication between devices in a variety of situations and domains without relying on infrastructure. The flexibility of such networks has been thoroughly explored, along with the different technologies used to create them [16]. Wi-Fi is the most ubiquitous of these technologies and provides a large broadcasting range. Wi-Fi enabled phones and laptops are now more commonplace than standard radios or walkie-talkies. As a result, Wi-Fi is beginning to emerge as a necessary transmission method for large broadcasts. While theoretically some Wi-Fi access points can support over 100 connected devices, large networks may become unusable due to dropped connections and performance will suffer as many users attempt to connect simultaneously to access points and access large sets of data [133, 72, 19]. Not requiring a connection in order to send and receive information circumvents this problem.

Key elements in the implementation of our system are independence from an existing communication infrastructure and the communication protocol that we use to pass information between assembly points and from assembly points to the smartphones. We create an ad-hoc network as a medium of communication and opted to use a novel, simple, yet robust method that uses Wi-Fi service set identifier (SSID) strings to pass information.

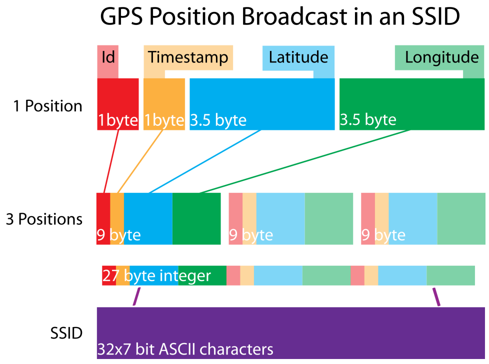


Figure 5.5: SSID as used by Geotrooper.

5.2.2.1 *Novel Broadcasting Algorithm*

Each assembly point creates its own Wi-Fi access point with relevant information encoded in the 32 ASCII characters that make up its SSID. Any beacon or receiver within range is then able to receive the broadcast information by simply performing a scan and decoding the SSIDs that are found. This allows information to move between devices (nodes) without having to establish a connection, thereby allowing nodes to communicate even if they are near the practical limit of their transmission range. Thus, messages can be broadcast over a distance farther than the maximum distance allowable to establish a Wi-Fi connection.

In order to allow an unlimited number of receivers and minimal broadcast noise, the Wi-Fi access points are broadcast only and no actual connection occurs. As such, the Wi-Fi access points can be set up for a brief interval, further minimizing broadcast noise, and allowing multiple messages to be broadcast in a series, all the while providing little interruption to other existing Wi-Fi transmissions. A broadcast interval as short as 10 seconds has been successfully tested. We discovered that broadcast intervals occurring for less than 5 seconds may not provide enough time for the Wi-Fi access point to establish itself. Receiving an established broadcast takes a fraction of a second, and there is no limit to the number of simultaneous systems that can receive an established broadcast.

We encrypt the encoded message before broadcasting it via the SSID using the RSA algorithm [111]. Each SSID is composed of up to three beacon messages (Figure 5.5). Each beacon message is 9 bytes long, and consists of a beacon ID, a timestamp for the last minute of a GPS update, the latitude, and the longitude. We encode the concatenated message due to practical requirements of SSIDs. In theory, 32 7-bit ASCII characters provide up to 224 bits of space to place data. In practice this is lessened due to inconsistencies in the way devices read SSID strings. Three characters in particular, NUL (0x000), TAB (0x011) and LF (0x012), have to be avoided when using Android devices due to weaknesses in the SSID parsing code. This means that any data fit into a 7-bit character must be base 125 instead of base 128. In total this leaves 27 bytes of space for information to be stored. Because standard PGP/RSA encryption can allow for any characters, the encoding step involves converting from base 128 to base 125, and then back again on the receiver end.

5.2.2.2 Receiving

Both the smartphones and the assembly points receive data broadcasts using the same scanning and decoding process. The first step of this process is performing a scan for Wi-Fi access points. This returns a list of SSIDs corresponding to access points within range. Each SSID string is decoded and the relevant data is extracted. If the decoded SSID does not comply with our format then the application determines that the SSID was not generated by a node in the system and it is thrown out as not being a viable broadcast.

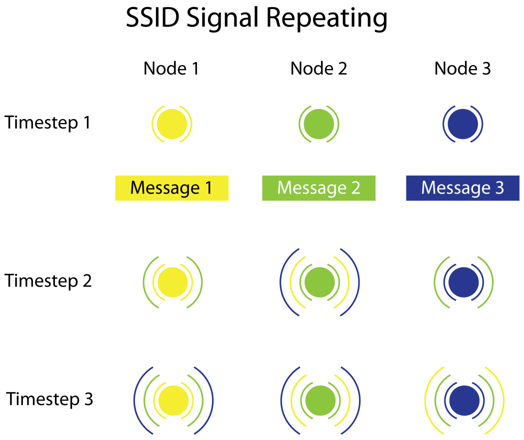


Figure 5.6: An illustration to show how the signal repeating works. The assembly point location gets propagated through out the network.

5.2.2.3 Repeating

In order to maximize the broadcast range of an individual node's message, messages are repeated by other nearby nodes. Assembly points, upon receiving location information about other nodes, take the most recent location information based on its timestamp. Assembly points then choose two nodes in a round robin fashion and encode the data into their own SSID. In practice this repeating behavior allows a receiver to find an assembly point even if the receiver is not within range of that assembly point's Wi-Fi signal, so long as there is a path of intermediary points which connect them. This provides a clear advantage over the line of sight requirements placed on Soldiers through the use of Stiner Aids, and effectively allows for chains of assembly points to cover entire drop zones as needed.

Repeating broadcasts increases transmission delay. However, because our messages are short, multiple messages can be broadcast simultaneously. If a network of three assembly points is placed in a line of maximum broadcast range, where each node needs 9 bytes for its information, then full propagation is achieved after

3 broadcast cycles. This process is outlined in Figure 5.6. In general, the speed of propagation is dependent on the number of bytes that each node uses and how often a new network is created. If the length of information to be transmitted is less than 13 bytes (27/2), nodes can append discovered messages to their own for compound repeating. If only a single node's information can be stored within an SSID at once, then each discovered node's message is repeated in a newly created network SSID.

5.3 Evaluation

The majority of our development and evaluation activities were performed in the 4 months leading up to the final proof of concept demonstration in December of 2010. During this time, we utilized an iterative design method that consisted of frequent system modifications (agile development cycles) based on stakeholder feedback; this gave stakeholders (*i.e.* target users, project managers, subject-matter experts, *etc.*) a sense of ownership over the system. The evaluation conducted over these months allowed us to create effective interfaces that align to the established conceptual models of paratroopers and Soldiers in general. During this time, we performed a series of seven iterative testing scenarios with active military personnel; these tests lead to the discovery of a design principle regarding the multimodal interface that was later evaluated. The details of this and other evaluations are described in the following sections.

5.3.1 Overview

Four military-personnel tests were conducted with 50 Soldiers of the U.S. Army XVIII Airborne Corps in Fort Bragg, North Carolina. The remaining three user studies were conducted with 23 local cadets of the ROTC, who receive similar military training and can provide a basic model for how Soldiers operate. There were two main objectives for each user study: to test the overall functionality and design of the GeoTrooper system (*i.e.* how well did the Soldiers perform assembly tasks while using the system?), and to evaluate the usability of the system (*i.e.* was any feature on the system difficult to use, lacking or superfluous?). We also used this time to immerse ourselves in the field training environment and converse with the Soldiers in order to gain a better understanding of the experiences of our target user base.

The ROTC tests were performed at a local park on open terrain that is similar to training drop zones at Ft. Bragg. The first two tests took place during the day and contained three assembly points, while the final test took place at night and used four assembly points. We conducted this night test in order to evaluate the night modes of the receiver interfaces.

The Fort Bragg tests were performed on practice drop zones with 10 to 15 male Soldiers from a variety of Airborne units. All Soldiers who participated were actively serving paratroopers, and thus possessed background knowledge of the required tasks and the purpose of our solution system. Prior to each test, we conducted group interviews with the Soldiers to discuss the current training methods, and to get feedback on their effectiveness; these interviews also gave Soldiers the opportunity to share some of the outstanding needs and challenges of paratroopers.

5.3.2 Evaluation #1 (August 2010)

The XVIII Airborne Corps trains on a various open field drop zones at Ft. Bragg, one of these being the Siciliy drop zone (DZ). During the August visit, the Sicily drop zone was tested for the presence of any Wi-Fi or radio signals that might interfere with the ad-hoc network created by the GeoTrooper system. This was accomplished by testing for signal interference every 15 seconds while navigating through the center line of the DZ during the Joint Forcible Entry Exercise (JEFX), as well as additional testing along the outskirts of the DZ. No conflicting frequencies were found anywhere on the DZ. We also conducted a preliminary test to verify the beacon signal distance at four different locations on base. At each location the beacon signal maximum distance was approximately 600m. The range of the Wi-Fi signal was less than preferred; this is partly due to the reduced signal strength of the transmitter equipment, which is far less than the advertised power. We believe this is partly due to the FCC regulations on signal transmission strength.

5.3.3 Evaluation #2 (September 2010)

In September, we performed demos of the system with three different groups of Soldiers. The first of these was a demo to 5 soldiers from the Airborne Buddys group at the JFEX on September 13th, 2010. The demo consisted of turning the system on and showing the group the various optional user interfaces available with the beacon and receiver.

A second demonstration of the system was performed with members of the personnel security detachment for XVIII Airborne Corps; these soldiers had varying levels of experience. The Soldiers were allowed to handle and test the receiver and beacon devices and voice their concerns. This informal evaluation provided vital information on the user interfaces for both the beacon and receiver that allowed us to begin making significant improvements to the system. The original prototype contained one view: an Arrow View with additional bearing and distance information similar to the compass. Soldiers from this group stated that they liked the arrow and compass information, but that they preferred that the compass be modified to resemble a military compass that they currently used. Some Soldiers also stated that having a Military Grid Reference System (MGRS) that identified their location and the relative location of the beacons would increase the usability of the system.

We had learned during our ethnographic study that Soldiers were pre-assigned to a specific assembly point prior to the mission. For this reason, we designed the original prototype to display information for one beacon only, the beacon representing the assembly point to which the Soldier was assigned. However during this evaluation Soldiers stated that it is important for them to be able to switch between beacon locations in the event that their assembly point was compromised. This feedback provided the first justification for a design principle: we discovered that the (1) Soldiers felt that access to all situational data available was critical. We made the suggested modifications to the system before returning for a third demonstration.

5.3.4 Evaluation #3 (September 2010)

The third demonstration involved twelve total Soldiers of the XVIII Airborne Corps and was followed by the first hands-on field test of the GeoTrooper system. The field test allowed us to identify functional bugs inherent in the system. Following the test, we conducted group discussions and distributed user questionnaires to gain feedback on the user interfaces and the system's functionality.

This test revealed a few minor bugs in the system. We discovered that because we had not implemented a method to store beacon signal timestamp information, the beacon repeating function occasionally incorrectly repeated old beacon locations, requiring the devices to be restarted once or twice to repeat the correct updated information once out of range. We also discovered that when two beacons were accidentally started with the same beacon name (due to user error), the system would alternate back and forth between them due to conflicting data. In spite of these glitches, all participating Soldiers were able to navigate to each of the beacons which were completely hidden within the tree-line (light canopy).

During the group discussions we received many suggestions on how to improve the receiver UI, which at this time contained only the Compass view, the MGRS view, and a drop-down list of active beacons. Some Soldiers, primarily those who had less experience with smart phones, had difficulty using and locating the drop-down beacon list and suggested an alternate interaction technique: being able to directly tap on the yellow icon of the neighboring beacon. It was also noted that the compass view emitted the most light pollution and that a low light version would need to be implemented. Soldiers did not automatically know that blue indicators signified the direction of their beacon and that yellow indicators signified the location of the neighboring beacons. To address this issue, we later opted for placing the name of the beacon next to the beacon icon on the map and at the top of the interface screen to make that more obvious.

The participating Soldiers liked both the MGRS view and the Compass view and were able to effectively navigate using either interface. Some Soldiers requested a third receiver view without the compass, but simply an arrow pointing to the beacon. Although this was provided in the original interface and modified on request, the Soldiers saw value in the simplicity of the arrow view during the field studies, and therefore the view was re-added. They also requested a fourth view that contained only the grid textual coordinate location and distance.

During our ethnographic study and through meetings with stakeholders, we had determined that the Soldier's role determined the level of detailed information that should be available to him/her. However, at this point we began to observe a progression in the amount of information requested by the Soldiers (from least to most rich: Distance, Arrow, Compass, Map). These observations, in conjunction with the feedback we received, lead us to the second justification of our design principle: we discovered that (2) Soldiers wanted to control the amount of data received in order to accommodate their level of experience rather than their role. With stakeholder approval, we again made the suggested modifications and later sought to validate whether this design would create a better user experience and increase user acceptance of the solution.

5.3.5 Evaluation #4 (October 2010)

During our October visit, we conducted a focus group discussion at the Advanced Airborne School to gain additional feedback on the overall modifications to the system. Leaders, Major Thomas, Major Farmer, First Sergeant Buffaloe, and two other Non-Commissioned Officers (NCOs) were given hands-on time with both the receivers and beacons. Four receivers were provided, and we gave a brief lesson regarding their use and functionality. Two beacons were moved to various locations to demonstrate their location updating functionality of the system. The Soldiers asked our team members various questions and provided excellent feedback relating to the viability and usability of the system. Questionnaires were handed out to the Soldiers to allow for additional comments and suggestions.

Our second iteration of field tests took place at Pike Field. Three beacons were placed at various locations on the field and in the tree-line surrounding it. Four receivers were set up for the test. Seven Soldiers arrived at the testing site after the beacons had already been hidden beyond direct line-of-sight. After being briefed on the system's functionality and the goal of the test, the Soldiers began navigating to the beacons. Each of the three beacons successfully broadcast its location and relayed the location of the other beacons within range. The Soldiers were able to find each of the hidden beacons. The Soldiers provided feedback throughout the field test on both the current interfaces and the needs of a robust system to be used in the field. The Soldiers also filled out questionnaires to provide additional comments and feedback.

Following the user study we returned to the test field to perform a more focused test on the system's broadcasting range. Two beacons and one receiver were used for this test. A maximum range of 565 meters was found between the receiver and the farthest beacon being relayed. Each beacon was run for approximately 40 minutes without system or power failure or loss of GPS signal. A second test was then performed with all three beacons to test the repeater functionality. Each beacon was placed at a relay distance between 250 - 300 meters; this test yielded a maximum connection range of 899 meters.

5.3.6 Evaluation #5 (November 2010)

Based on feedback from the previous month's evaluations, we determined that the UI had reached a stable state in development. Therefore, the developments leading up to the November evaluations were mostly internal to the system and not focused as much on the UI as previous iterations. During the November visit, we tested the range and repeater capabilities of the system again, this time with 5 beacons at the Solerno DZ. This was a significant developmental accomplishment to allow for daisy chaining and repeater capabilities of five beacons, as each additional beacon that functions as a repeater increases the overall range of the system. We noted that when the beacons were laid flat on the ground in the rolling hills (versus at waist level), the range was significantly reduced from up to 600 meters to approximately 300 meters. Thus, beacons were placed approximately 250 meters from each other to allow for effective daisy chain repeating.

We conducted another field study with Soldiers from the A319 unit; our goal for this study was to test the near-complete prototype design before the final demonstration in December and to begin initial training for stakeholders to be able to conduct their own field exercises using the system. When the participants arrived to the testing location we left three of the beacons in place, and removed two beacons. At this time, SFC Burke gave the Soldiers a 20 minute hands-on instructional lesson to describe how the to use and set up the beacons and receivers. Soldier instruction, system set up, and use occurred completely without our assistance. This was an extremely significant milestone as it was evidence that the GeoTrooper system had reached a deployable status.

SFC Burke instructed the A319 Soldiers on how to setup the beacons and operate the receivers effectively. We were encouraged by the fact that all of the A319 Soldiers wanted to volunteer to set up a beacon, implying that the beacon set up was sufficiently simplified to allow for easy operation. Two beacons were set up by the Soldiers themselves at different locations near the front of the DZ. The beacons were set up successfully with the exception of one issue that became noticeable halfway through the testing event. The issue was that one team accidentally started up two instances of the beacon program. One was set to start immediately, and the other was set to start after a twenty minute delay. As such, after twenty minutes, the second broadcast started and, as the second instance could not access the GPS because it was used by the first instance, the second instance reported default GPS coordinates instead. These false values started to propogate throughout the system, and the second instance caused other false values to start relaying themselves as well. This field test provided valuable information from this system-preventable user error.

Pairs of paratroopers were then given receivers and instructed to navigate to the beacons that their fellow Soldiers and our own team had set up. The A319 Soldiers were each given unique ordering of beacons to visit using their receivers (such as A,E,B). The Soldiers were able to navigate successfully to at least 3 separate beacons before the bug was discovered. Some Soldiers searching for other beacons did not notice the bug and reported that everything worked well for them. After discovering the bug (described above) in the beacons, we reset the test and again had Soldiers navigate to beacons placed at different locations. The paratroopers were able to navigate to all beacons successfully in this second trial.

5.3.7 Evaluation #6 (December 2010)

The final demonstration was a repeat of the same user study conducted at the Solerno DZ. This time thirteen Soldiers were scheduled to participate in the user testing. We conducted a briefing session prior to the study and each Soldier was given a consent form, a testing task list and a feedback questionnaire. We provided the Soldiers with an overview of the system and lead a group discussion on some of the possible applications and outstanding needs and challenges of paratroopers.

We then instructed the Soldiers on how to operate the beacon and the Android receiver phones. We distributed the phones to the Soldiers and gave a brief demonstration in order to familiarize the Soldiers with the functions of both the receivers and the beacons. During the first iteration of the field test, we set up 2 beacons in the field without Wi-Fi amplifiers. The Wi-Fi antennas were mounted on easel stands in order to simulate their position on a heavy drop configuration; this positioning also provided increased wireless broadcasting range and strength. One beacon was assigned to be set up by two Soldiers from the testing group. The eleven remaining Soldiers were split into five teams of two and one single and given receivers. Once the two beacons we set up began broadcasting, we instructed the Soldiers to turn on their phones and start the receiver application. The teams were instructed to navigate to the first beacon shown on the receiver and then proceed to all three beacons; they were then to regroup at the starting point once all three beacons had been located. Once the eleven Soldiers with the receivers had regrouped, all the equipment was returned to the starting location.

In the second iteration of the field test, we had three groups of two Soldiers set up each of the three beacons. During this test, two of the beacons were taken out to a range of over 600 meters and set up with amplifiers. The remaining seven Soldiers were split into three teams of two and one single and given receivers. Once all three beacons were broadcasting, the Soldiers were instructed to turn on their phones, locate all three beacons and then regroup at the starting point when finished. Upon completing the second test, the Soldiers were asked to fill out a feedback form and the demonstration was concluded. The system functioned successfully and produced no errors in both trials.

During the briefing and testing events, some of the Soldiers offered the following comments:

1. The receiver should function as a beacon and allow messages to be sent to other beacons. The Soldiers would like to be able to send messages at the push of a button alerting their teammates if they're hurt and need help, if they're engaging an enemy, if the receiver has been compromised, *etc.*

2. Coordinates from the Military Grid Reference System are far more useful than latitude/longitude coordinates. Each of the views in the receiver application should show the Soldier's current grid location as well as the grid location of the beacon in focus.

3. The receivers should allow the Soldier to enter in a set of coordinates and show him/her how to navigate to that location.

4. A satellite map view should be provided in order to reveal if there are any obstacles within the target beacon's direct path.

5.4 Results

Overall, we conducted group interviews with a total of 73 Soldiers and ROTC cadets during both development and testing phases in order to gather background information on the problem domain in addition to obtaining feedback about the system. We also compiled evaluation data from 29 participant questionnaires collected during formal user studies of the final prototype. During this effort we discovered that (1) Soldiers felt that access to all situational data available was critical and (2) Soldiers wanted to control the amount of data received in order to accommodate their level of experience rather than their role. These findings lead to the formulation of the following design principle: *Rather than forcing a predefined amount of data on team members based on roles, allowing each user to control the amount of data received through a multimodal interface can create a better user experience and increase user acceptance of the technology.* In this section we provide data to support this principle.

5.4.1 System Usability & Effectiveness

We asked the Soldiers to rate their level of experience with the technology present in the GeoTrooper system (Figure 5.7). A majority of the participants reported a fair amount of experience with computers which produced an average 4 out of 5 rating ('very experienced'). However, there was a wide variation in terms of their exposure to smartphones and mobile applications with ratings ranging from 'no experience' to 'expert'; the average rating put the groups in a 'some experience' range.

More experienced Soldiers (in terms of paratrooper duty and training) appreciated the Distance and Arrow views, however, the majority of the Soldiers we tested, who were still in training, found both the Map view and Compass view visualizations to be equally useful, with a preference for the Compass view. In addition, allowing

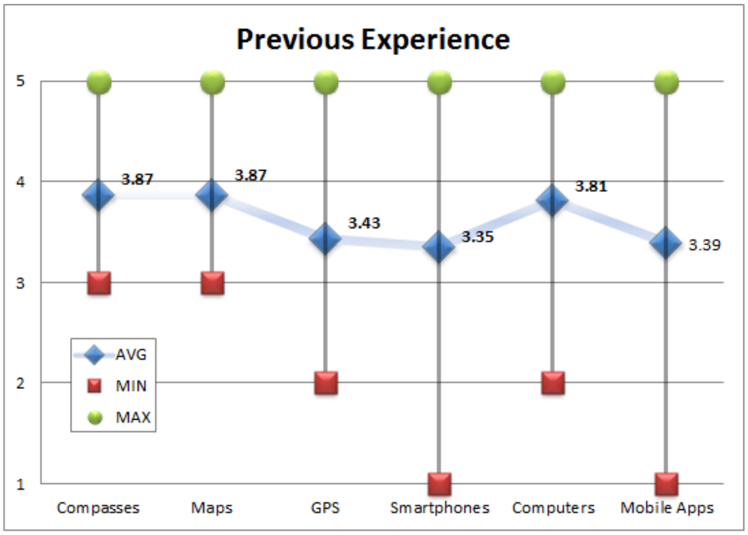


Figure 5.7: Previous experience with the technology used in GeoTrooper.

them to select their target beacon gave the Solders control over the information obtained which received a more favorable response than in previous evaluations where the information displayed was fixed.

Participants evaluated the system's usability and provided feedback on how easy it was to access specific information with the system with a rating of 5 corresponding to a 'very easy' interaction. Participant responses are shown in Figure 5.8. The average rating on usability of the system was 4.5, indicating that participants ranked the UI views provided between 'easy' and 'very easy' to use by all Soldiers regardless of rank, role or experience. During group interviews, both Soldiers and ROTC members reiterated this by reporting that they found the GeoTrooper system very user friendly and easy to learn. One Soldier stated that GeoTrooper was "very easy to use for me at the Joe level" ('Joe level' is a term used to denote a new paratrooper with limited experience). Another participant said that GeoTrooper "...was easy and reliable to use. This is exactly what Airborne Soldiers need." Unlike previous

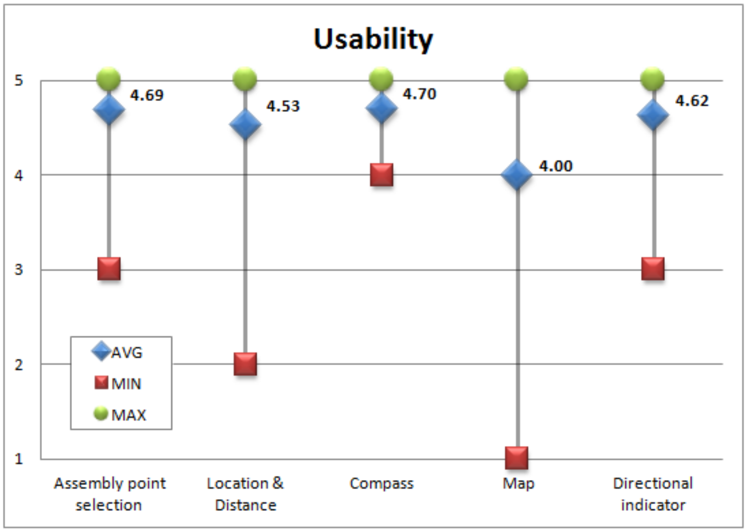


Figure 5.8: Rated usability of GeoTrooper's various interface components.

evaluations, the December demonstration produced no negative comments regarding the UI. This fact, as well as the data presented, provides support our design principle for the multimodal interface.

The effectiveness of the system was most apparent during field tests in the 1 km wide simulated drop zone. Every participant was able to navigate to all assembly points in the area within 25 minutes or less (an average of about 8 minutes per assembly point). This shows a significant improvement over training assembly times (without GeoTrooper) which could take an hour or more for locating only one assembly point. Participants further evaluated GeoTrooper's effectiveness in regards to how well it assisted them in completing their assembly task; they were asked to rate the system's responsiveness, accuracy, *etc.* and determine how much they felt the system contributed to their success in locating assembly points. The results in Figure 5.9 show an average rating of over 4 out of 5 in every category.

Four participants rated the system poorly for location accuracy; these participants stated that their devices showed the location of the assembly point with un-

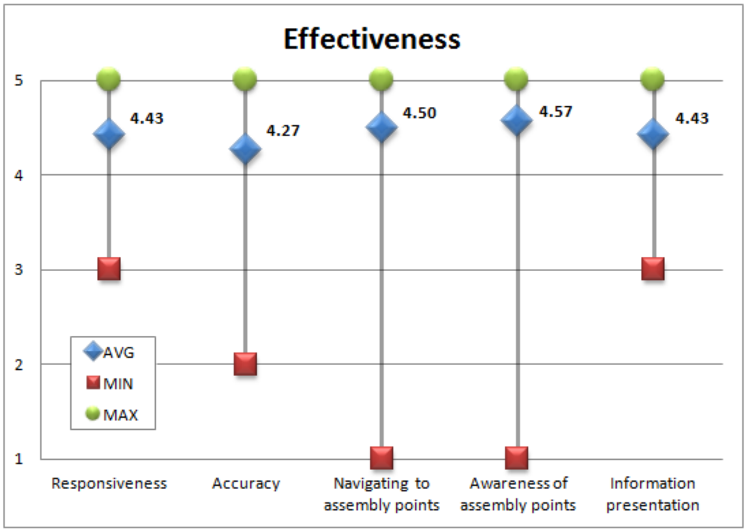


Figure 5.9: GeoTrooper's rated effectiveness in relevant categories.

certainty of 10-20m off the actual position. This is a constraint posed on the system by the GPS components and the GPS capability of the phones. The positioning accuracy depends on the GPS hardware used; normally a good device will be accurate to within 3m. We did take this into account for future tests, however, Soldiers also remarked that the system need only lead them to a region within line-of-sight of a target assembly point, as they would then be able to generally see where their unit has assembled. Furthermore, ROTC members commented on the Night Modes, saying that light pollution was very minimal on the receivers and was not visible beyond approximately 3 meters.

One major benefit of our solution is that it can be integrated into the training process in a way that allows the commanding general to turn the technology on and off in order to test the soldiers ability to assemble using traditional methods when the need arises. However, the greatest limitation faced by the GeoTrooper system was that it required Soldiers to hold the device while navigating. Soldiers did not want to have to lower their weapon to reference a mobile device. Even though a quick glance at the interface provided the needed information, the process of obtaining this information would not be adequate in combat scenarios. Soldiers suggested providing an arm strap to hold the device in place or moving to a more "watch-like device" (*i.e.* WiMM One) in future designs. To address this problem, we later added an eyes-free haptic feature to the system which is discussed in more detail in chapter 7.

5.4.2 Broadcasting Capabilities

We found that a single node's broadcast could be picked up at a maximum range of 565 meters using an external omni-directional antenna alone, and at over 1000 meters with the addition of an 1 Watt amplifier. It should be noted that such amplification of Wi-Fi signals goes against Federal Communications Commission (FCC) restrictions and that we did so during tests under the supervision of military personnel on base. We successfully tested a maximum of six beacons in a single network, although most tests on base featured a four-beacon network spread throughout a 1000 meter radius. Broadcast signals were found and displayed by the smartphones and other beacons that were within range.

5.5 Other Application Domains

Although our application was developed to help paratroopers locate equipment and teammates after a nighttime airdrop, the solution could also be useful in non-combat scenarios. For example, U.S. Paratroopers were instrumental in the United States' response to the earthquake crisis in Haiti in 2010. In crisis response situations like this one, a location-aware beacon system would allow support forces to locate airdropped food and medical supplies, and generally provide relief quickly after dropping into a disaster area. In this scenario GeoTrooper assembly point ToughBooks could be affixed to aid packages before they are dropped out of planes, and could then be effectively located by ground teams using the smartphones.

The advantages of our system lie in its ability to establish an ad-hoc communication infrastructure wherever it is needed. Our system can easily be adapted to other domains which require an established dynamic, ubiquitous and effective communication medium for large-scale coordination efforts. This is especially true in situations where there is a high demand for information contained within small amounts of data by a large amount of people in a contained space, and where audio communication is not a viable option.

One domain of interest is that of emergency coordination; in essence focusing on an ad hoc alternative to the emergency broadcast system. When a disaster occurs, evacuation points in urban areas can be broadcast to citizens via an ad hoc network using a standardized initial acronym for global emergency broadcasts that specifies the relevant distance and hops necessary. Any computer could be set up to project an emergency broadcast, and any computer within distance could either listen to or repeat the broadcast as appropriate, which could be done with or without security or encryption. Given the power of social networking, allowing users to decide if they want to repeat the broadcast could be an effective means of echoing emergency broadcasts. Areas could have their own broadcast node that would send its location and ID to emergency applications running on mobile devices and public displays augmented with backup power supplies and Wi-Fi scanning capabilities. This information would point citizens to the closest evacuation point or safe area as the situation warrants. Emergency personnel could send additional codes to citizens and other team members identifying hazards in different areas. This would require a database of short (a few bytes each) codes that can be encoded into an SSID. Once a network is found containing the proper ID, the emergency codes would be decoded and the subsequent information would be shown in a user-friendly way. GPS-enabled nodes would allow points to be moved as needed and this new information to still reach citizens and emergency personnel.

Another application for GeoTrooper is large-scale coordination and broadcast communication for public events such as the Austin City Limits (ACL) music festival that attracts 70,000 fans each year. During the festival, event-related news and updates are posted on the Internet, however it is difficult for fans to connect with their smartphones because of the extremely high demands placed on mobile broadband providers. A modified GeoTrooper system would provide an alternative form of communication between ACL staff and attendees. Location-based or general nodes could broadcast event news throughout the park with the relevant codes and official identifiers encrypted to prevent falsification. Any smartphone running the mobile application could then scan for networks, decrypt the information, and choose whether or not re-broadcast the information. In this fashion, the desired information is available to attendees without the need for an Internet connection or multiple SSID reads.

5.6 Contributions of this Phase

In this phase of the research project we provided justification for designing a UI that allows Soldiers to control the amount and format of navigational data received regardless of role. We also conducted evaluations which showed that this design approach created a better user experience and increased user acceptance of the technology.

In addition to validating this design principle, we provided the following contributions:

1. Developed a light-weight replacement solution for the Stiner Aid that meets all military requirements

2. Created an embedded map that presents data in an MGRS standard format

Figure 5.10: ModLive monocular HUD [105].

used by the military

3. Created a novel ad-hoc notification system that can be used in other domains

5.6.1 Broader Impacts

The work presented in this phase has influenced other location-aware systems developed for mobile navigation and communication purposes. One of these was developed for the MOD Live monocular head mounted display unit which was designed to allow skiers and snowboarders control their mobile devices and take calls on the slopes (Figure 5.10).

The MODLive is one of few displays that functions as a self-contained android device. For this reason, the device was used to create a hands-free navigation interface for a geographical surveying application (Figure 5.11). Using technology from the solution system, we created a new system that consisted of two independent applications: a client application that receives location information and points the user to the point of interest, and a server application that sends the location.

This system differs from the original solution in that it uses Bluetooth to communicate location information between devices instead of Wi-Fi SSIDs; the location information is also not encrypted. The system can be used by two people: one to send the locations and another to receive them and navigate (this design was requested

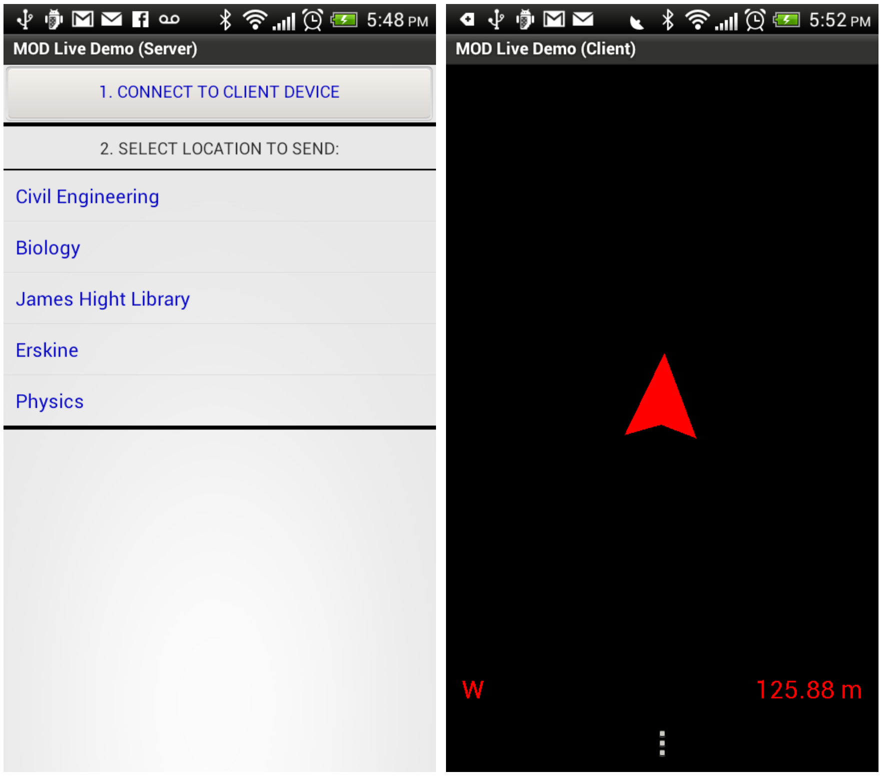


Figure 5.11: Delivery navigation tool on the MOD Live device.

by the client since the surveyors operate in teams). This system was demoed for Trimble, a local company in New Zealand that researches cutting-edge positioning technologies. This application provided a hands-free solution for directing their surveyors, however it can be used in just about any scenario where navigation via an HMD might be useful (*i.e.* hiking and other outdoor sports, rescue operations, *etc.*).

Once we had a solution for the navigation and assebly problem, we knew we needed to provide a means of addressing the concerns presented by the Soldiers during testing as well as a solution for addressing the challenge to team awareness. We decided to research augmented reality (AR), haptic technology and physiological data input in the next phases of development. Ideally, a haptic vest can be used to extend situational awareness by connecting (via Bluetooth) to the wearer's mobile device and providing directional indicators through the use of vibro-tactile actuators. We also believe that the use of physiological data can serve as valuable data input for allowing paratroopers to engage in silent communication and overall team awareness. Early prototypes as well as preliminary testing revealed promising early feedback on the usability of UIs containing these elements. This work is discussed in chapter 8, but an in-depth exploration of haptic feedback can be found in the thesis of SRL research member, Manoj Prasad [101]. The research into AR enhancements and physiological data inputs are described in more detail in the next chapters.

6. INCREASING SITUATIONAL AWARENESS

In the previous chapter we have provided a technological solution to replace the Stiner Aid system. Moving forward, we wanted to increase the usability of the system by enhancing the data visualization method to make this system more efficient in limiting the cognitive load on the Soldier. We believe that augmented reality (AR) serves as the best data visualization and feedback medium for this purpose. In addition to AR, we include a haptic feedback feature that can be felt through the device. An AR view fed through a head-mounted display (HMD) and haptic feedback provides a solution to multiple challenges voiced by Soldiers in the previous chapter: 1) it allows the Soldiers to keep their hands free to perform other mission-critical tasks, 2) information presented via AR can contribute to an increased awareness on the battlefield without compromising the Soldier's attention on their current task and 3) the use of an HMD or haptics would not produce any external light emissions.

The use of haptic feedback as a means of aiding in orientation has been explored in haptics research [130, 131]. This research has shown that navigation information can be effectively delivered using vibrating tactors, although the tactile display presented in these works has yet to be compared to other forms of navigation (*i.e.* map, compass, *etc.*) or evaluated in scenarios with high cognitive load. However, this previous research allowed us to formulate the following principle: *Haptic pulses are the best way to deliver navigation information when cognitive load is at its maximum and/or when line of sight must be unobstructed and hands must remain free.* Owing to the nature of our paratrooper scenario, our solution provides the means to evaluate this principle as well as the use of AR as a data visualization medium.

Figure 6.1: Halo Heads Up Display (HUD): 1. weapon information 2. shield bar 3. grenades 4. motion tracker 5. scoreboard and voice chat mode 6. aiming reticule 7. ally location indicators 8. objective indicators 9. other, minor indicators [1]

6.1 Design Inspiration

The concept an AR-based UI design is influenced by various interface elements found in popular First-Person-Shooter (FPS) games (*i.e.* Marine Doom (military influenced version of original Doom game, early fps), Ghost Recon: Future Soldier, Halo, Call of Duty, Medal of Honor, SOCOM, *etc.*). These type of military-based FPS games often depict near-future battlefield technology. For example, Ghost Recon: Future Soldier, the latest addition in a popular line of military FPS games, features technologies such as optical camouflage, personal UAV drones, and real-time battlefield intelligence delivered via AR through a Heads Up Display (HUD) (Figure 6.1). The HUD is a UI element shared by many if not all of the FPS games listed above. As a result, this type of interface is very familiar to gamers. Not surprisingly, many of the military's new recruits fall into this gamer category, and as a result, the U.S. Army has begun to capitalize on this fact. U.S. Army is using video games to recruit from the Digital Generation, a generation born into a digital world, networked and full of multimedia [125]. Military FPS games such as Full Spectrum Warrior serve as simulation training for military warfare, teaches players how to work as a team and coordinate their activities to achieve complicated missions; making battlefield practices seem almost natural [132]. Full Spectrum Warrior and America's Army were developed in cooperation with the U.S. Army and presents an accurate portrayal of real-life missions and scenarios encountered by Soldiers [29]. The America's Army game franchise was created for the purpose of obtaining new recruits by showing players what it's like to be a Soldier; the game not only simulates missions, but also shows the different Army schools and entry-level Soldier training tactics. The DoD has also taken advantage of this trend; the DoD Modeling & Simulation Coordination Office provides simulations for the purposes of training the warfighter.

Video games are one of the more recent sources of obtaining valuable data for the purpose of improving HCI design methods. Analysis of HCI in PC games have shown that games that make it easy for users to form, join and perform tasks as a community and games that present information to users in a manner that does not interrupt the flow of work contribute to usability [32]. These contributions can be applied to various domains that adopt a similar type of gaming interface. Research has also shown that games contain a value system that shapes the nature of gameplay [6, 62]. Our goal is to incorporate this method of creating a network of values that will give users an incentive to perform targeted tasks in an efficient manner.

6.2 GeoTrooper 2.0

We have utilized specific elements from a few of the more popular military-based FPS games (listed above) in order to offer affordances to our target user group:

Soldiers. We believe that this approach not only puts our solution system on the cutting edge of new battlefield technologies, but it makes the system easier for new Soldiers pick up and use since they are already familiar with the features of the UI. We will describe the details of these UI elements in the following sections.

6.2.1 Prototype

During early development stages, we implemented a prototype AR View to verify that the beacon information could accurately be portrayed using AR. AR provides continued situational awareness since the Soldiers are able to view the location of the beacons in the context of their own world. AR also allows Soldiers to search for assembly areas as they do currently (by searching for beacons of light in the distance), the only difference is that now they're using their phone as a viewfinder. Using this method, light pollution is not a problem since the phone's camera screen will display a beacon icon with low contrast colors and reflect the lighting conditions of the surrounding area (nighttime). In effect this provides the Soldier with a virtual equivalent to the Stiner Aid, but without the associated visibility issues and excessive infrared emission.

We implemented a prototype using the Wikitude API [137]. We created a separate activity to launch the Android phone's camera feature and passed the locations of each of the beacons saved in the beacon array. Wikitude allows the developer to create locations of interest in this way. For each location object created, Wikitude attaches a virtual text box icon to the relative GPS position and overlays the icons onto the video feed from the Android's camera (Figure 6.2). This implementation gave us a basic example of how information could be delivered in an AR format, and the Wikitude API provided an on touch feature for its icons that could easily be used to display additional information related to the phone when the icon is touched. The

Figure 6.2: Beacon shown through Wikitude AR.

drawback with using Wikitude is that is is not freely customizable for our needs; we could control how the data is shown.

In addition to the AR view, we implemented a haptic feedback feature using the Android device's vibration motor; when the device is pointed in the direction of the selected assembly point, it vibrates with a specific pattern. The haptic interface can be used with the device's screen turned off, allowing the user to navigate without needing to look down, and thus allowing them to maintain situational awareness.

We evaluated both the haptic updates and the AR View prototype by conducting preliminary user studies in Veterans Park (College Station,TX), an area that contains terrain similar to the training drop zones at Ft. Bragg. We set up 3 beacons within a 1km radius and performed 2 test iterations with a group of 10 cadets. We divided the participants into 2 groups of 5 and asked them to navigate to each beacon in the network. One group used the haptic feedback as a guide during the first iteration, and the other group used the augmented reality view to perform the same tasks. In the second iteration, the groups switched their mode of interaction. The user study concluded with a questionnaire to gain additional feedback from the participants.

Participants using the haptic feedback to guide them were able to navigate to all beacons in the network in less than 15 minutes (or approximately 5 minutes per beacon), which showed us that the effectiveness of this data presentation method could potentially be comparable to the other views and warranted further development and evaluation. They reported that the changes in the vibration patterns were easy to understand and they were able to use the feedback to help them navigate to their target points. When using the augmented reality view, participants reported that in some cases the icon would sometimes drift away from the beacon and or its elevation in relation to the beacon was skewed in closer distances. However, most of the participants were able to navigate to the beacon's general vicinity and then locate the beacon on sight.

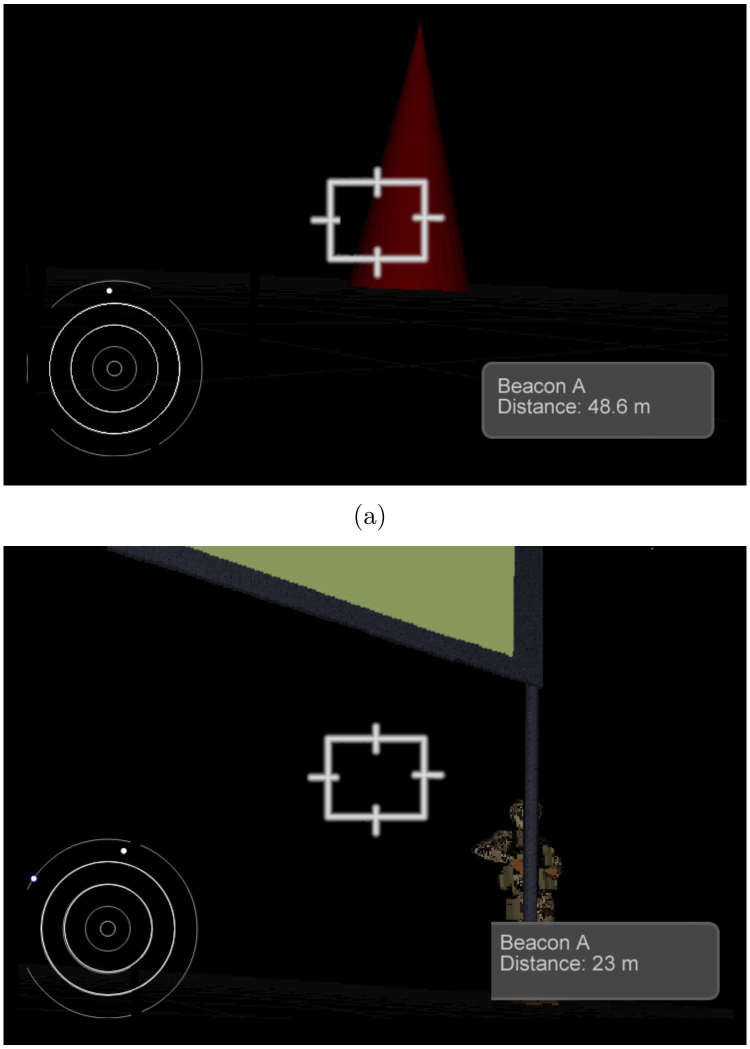
6.2.2 Visualization

As mentioned before, the AR view mimics the current process of using Stiner Aids for navigation by providing an overall view of the beacon network with unique graphic representations. This new feature is made possible through the use of the OutdoorAR library, which is a software development framework for easily building outdoor AR applications on mobile platforms [57]. A developer can mix and match ready-to-use framework components and design the domain application logic and user interface while spending less time implementing basic functions required in AR visualization, such as tracking an rendering. The library provides location and orientation tracking of the mobile device using various sensors, including GPS, accelerometer, gyroscope, and magnetometer. Once beacons are discovered, the visualization created shows 3D models representing each beacon superimposed into the camera view and the models are registered to the assembly points in the real world (Figure 6.3a).

In addition to the 3D models registered on the real world, the AR visualization also shows the location of all beacons on a small radial map, similar to the compass view, in the bottom left corner, which makes easier to spot assembly points that are outside of the camera view. This radial map provides a view of the network that's very similar to the motion tracker and map display available in the HUD of popular FPS games. Using the phone as a viewfinder clipped to their weaponry, the Soldier simply has to point the device toward the direction he/she is interested in. An on-screen target is shown in the AR view which, when centered on a beacon indicator, provides detailed information about the beacon within the bottom right corner of the screen. The information provided does not impair the Soldier's line of site, nor does it require direct interaction to operate. If using an HMD, obtaining information about each beacon is even more convenient. In addition, the light pollution problem is eliminated completely through the use of an HMD which also allows a more realistic representation (Figure 6.3b).

6.3 Evaluation

We conducted a user study with 9 cadets of the local ROTC, who had field training experience. The purpose of this study was to evaluate the effectiveness of the AR visualization and obtain data to validate the previously mentioned principle regarding haptic feedback for navigation. We hid 2 beacons in an open terrain with an area of approximately $6000m^2$. Each cadet was given an Android smartphone with the GeoTrooper system installed. Participants were given a brief overview of the system and asked to simulate an assembly task by navigating to each beacon hidden in the field primarily using the information presented in the AR view. The participants were allowed to reference the other views during this task for later comparison. We timed each participant and recorded the total time it took them



(a)

(b)

Figure 6.3: (a) Simple beacon representation in AR View for Android phone. (b) AR Virtualization of Stiner Aid for HMD.

to navigate to each beacon and back to a designated finish location as a team. We repeated the study with the same participants and asked them to use primarily the haptic feedback for navigation (again, other views were referenced for comparison).

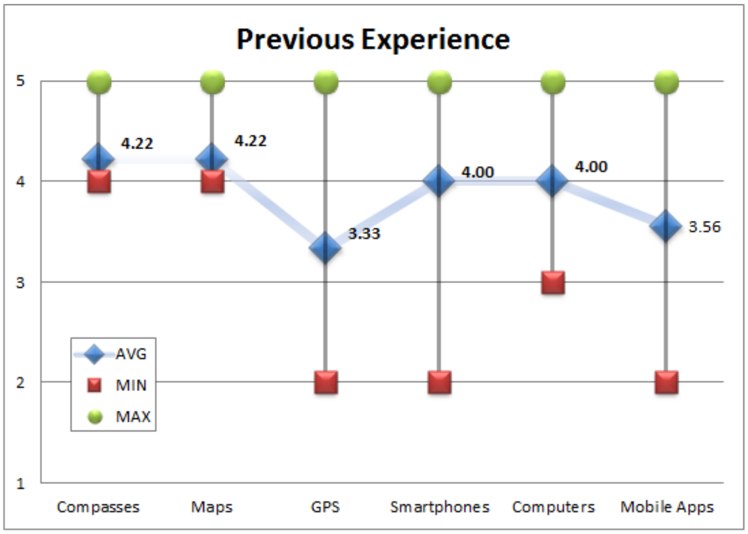


Figure 6.4: Previous experience with the technology used in GeoTrooper.

6.4 Results

Upon completion of the exercise, we gave each participant a questionnaire and asked them to give their feedback on the system. Once again, we asked the Soldiers to rate their level of experience with the technology present in the solution system (Figure 6.4). These participants reported a higher amount of experience in each technology category than the participants from the first wave of user studies (this is not surprising considering we were working with an overall younger group). However, like the first group, there was a wide variation in the level of expertise reported concerning smartphones and mobile applications with ratings ranging from 'little experience' to 'expert'.

Participants then commented on the usability of each component. Figure 6.5 displays participant responses with a rating of five corresponding to 'very easy' interaction. The AR view received an average rating between three and four signifying a rating between 'neutral' and 'somewhat easy'. Based on participant feedback, we

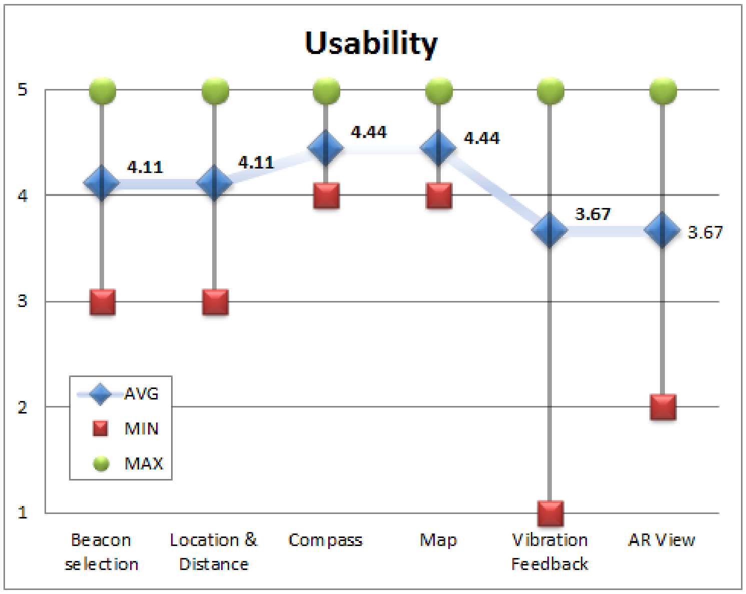


Figure 6.5: Rated usability of GeoTrooper's various interface components.

discovered that the data visualization appealed to the cadets, but, as expected, they preferred to use this view with an HMD. They also commented that when looking through the camera view in the daytime, glare was an issue. The haptic feedback also received an average rating between three and four signifying a rating between 'neutral' and 'somewhat easy'. The haptic ratings were below the ratings for the Compass and the Map by 0.77 in terms of ease of use. We believe this is due to the fact that the compass and map are frequently used in navigation training, whereas haptic feedback is not.

And finally, participants were asked to rate the system's responsiveness, accuracy, *etc.* and determine how much they felt the system contributed to their success in locating assembly points. The results in Figure 6.6 show an average rating of well over four out of five in most categories. The accuracy got a rating below four due to the system's response when in close range of the beacon (the indicators begin to switch erratically when less than 3 meters from the beacon due to GPS margin of error).

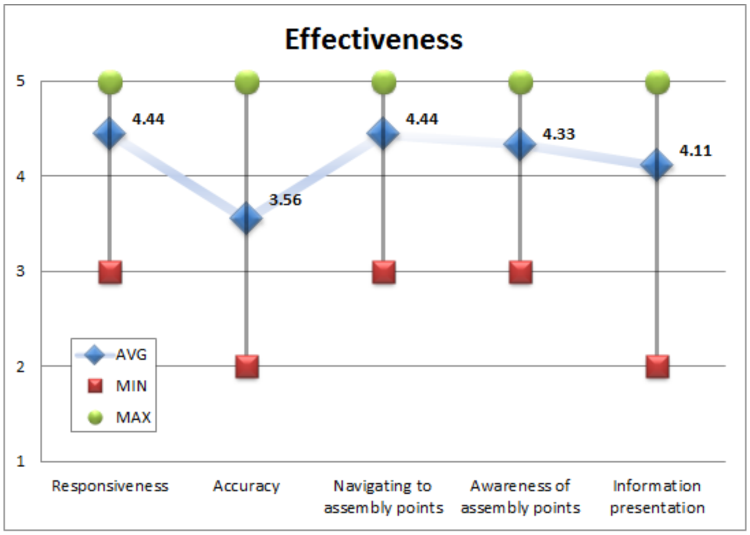


Figure 6.6: GeoTrooper's rated effectiveness in relevant categories.

On average, it took participants 4.9 minutes to navigate to each beacon within the field and rendezvous at the finish point. We should mention that although many of the participants completed the task using a brisk walk (in an actual mission scenario Soldiers would navigate at a much quicker pace) they still completed the assembly task almost fifteen minutes faster than the reported time for a highly trained unit using Stiner Aids.

All participants stated that the system was easy to use and that they had no problems locating the beacons. We were surprised to find that many of the participants preferred that the beacon icons get smaller instead of larger in the AR view as they closed in on the beacon location. We discovered that this is to prevent occlusion of the actual device once the participants have located it. We agree that this transition from the virtual to the real object will help to reinforce the effectiveness of the system. Many of the participants seemed very pleased with the AR view stating that "it was fun to use" and that it would be their view of choice "when the beacon is very far away."

While the haptic feedback ranked lower in ease of use when compared to the Map and Compass views, the navigation times and the usability ratings still shows that haptic feedback has the potential to be easily learned and effective in providing navigation information. However, further investigation was needed to determine if haptic feedback is the best way to deliver navigation information to the Soldier when cognitive load is high; this effort is discussed in the following chapter.

In this phase we justified the design principle regarding the use of haptic feedback for navigation and created a hands-free AR-based visualization for our solution system. By providing these alternative views of the of the beacon network we:

1. Developed a real-time visualization of beacons within the battlefield.
2. Utilized a visualization medium that allows for greater situational awareness.
3. Allowed hands-free interaction with the receiver phone clipped to weaponry, clipped on a Soldier's body, and/or through the use of HMDs.

7. IDENTIFYING TEAMMATE EVENTS

As mentioned in the previous chapter, we created hands-free solutions that will assist team coordination by providing greater situational awareness to individual team members. We now focus on providing awareness to the team as a whole and creating an evaluation scenario appropriate to test our previously formulated design principle which states that *Haptic pulses are the best way to deliver navigation information when cognitive load is at its maximum and/or when line of sight must be unobstructed and hands must remain free.* For this to be possible, we had to modify our user study by introducing factors (*i.e.* competition, goals, rewards, time-limits, *etc.*) that would increase cognitive load and emulate a high-stress mission scenario.

During initial evaluations of the solution system, Soldiers stated that being able to press a button and send messages to their teammates when they required assistance would allow them to better coordinate their efforts when unforeseen circumstances occurred. However, in order to avoid potential shortcomings in the solution, we steer away from sacrificing hands-free interaction. Previous research in EEG-based communication has shown that it is possible to trigger events without direct manual interaction [10, 140, 134]. Based on the success of this research, we formulated the following principle mentioned on page 8: *Significant changes in physiological data can be used effectively to assist in the automatic reallocation of tasks in the event a teammate needs assistance.* To evaluate this principle, we build upon our solution and provide team awareness by using physiological inputs instead of direct interaction to send messages to alert team members of their teammates' status.

7.1 Implementing Android Beacons

The first part of this effort involved converting the Android phones used in the GeoTrooper system into beacons. We decided to tie the phones into the ad-hoc Wi-Fi network and make them function in the same manner as the ruggedized computers. In order to accomplish this, we had to control the Wi-Fi tethering feature of the phones, which was not available in the Android API at the time and therefore had to be done using reflection (or modifying the behavior of the phone's Wi-Fi tethering functions) at runtime.

Since the paratroopers essentially operate as one-man armies until they can assemble, the initial purpose of the phone beacon was to alert other paratroopers if a teammate needed assistance. If this was not the case, then the paratroopers should continue on route to their assembly points without interruption. However, when a particular event occurs, the phone turns into a beacon and sends out its encrypted location through the network, alerting all other receivers (Figure 7.1). The events that cause these alerts are explained in detail in the following section.

The Android beacons are distinguished from the mini-computer beacons by the IDs; the computer beacons are identified by a single capital letter whereas the Android beacons are identified by a single lowercase letter. The system displays the unique IDs through the picker menu and also through the icons used. In the map view, circular signal icons represent the computer beacons and single person icons shown in red signify a teammate in danger. These icons appear on the map when an alert is received. In the AR view the beacons are identified by red cones and persons are identified by accurate soldier models.

When a team member generates a user event, the device broadcasts an alert containing a color-coded identifier for the severity of the alert. Color plays a huge

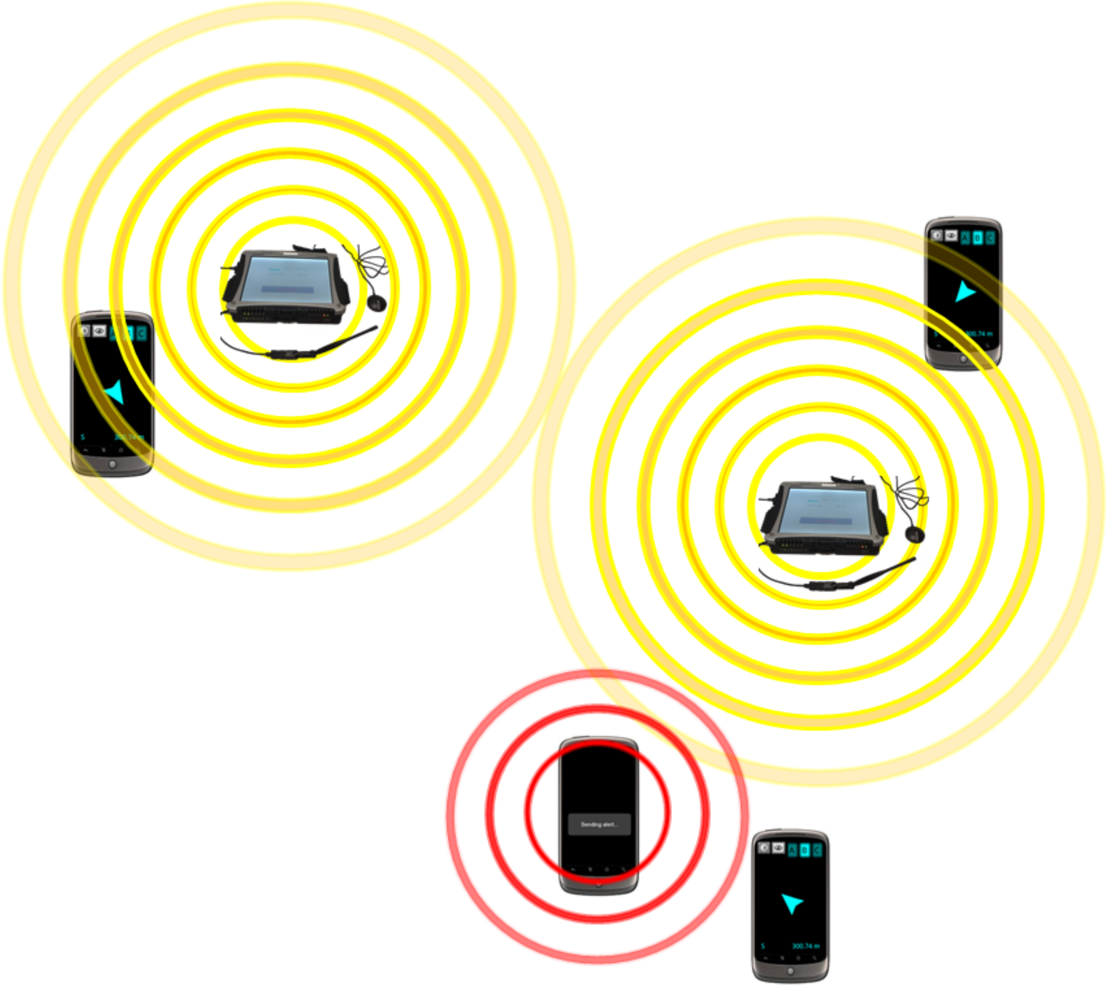
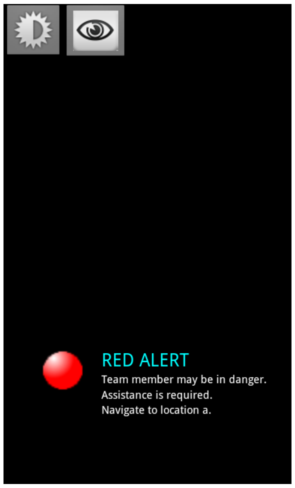


Figure 7.1: Android phones function as beacon in an alert event.

role in the effectiveness of data presentation and can have a subconscious affect on the viewer. Research has shown that the primary colors (red, yellow, blue) can produce both physical and emotional responses from the viewer [129]. By using these primary colors, we hope to be able to invoke a subconscious response from the person viewing the alert.

When the other phones in the network receive the alert, the application first displays a message with a color-coded icon (a simple color icon is more easily and



RED ALERT

Team member may be in danger.
Assistance is required.
Navigate to location a.

Figure 7.2: Red alert signifying teammate in danger.

quickly recognized than reading text [59]). Using a concept made famous by *Star Trek*, we created a hierarchical system with red, yellow, and blue alerts [112]. The significance of the colors are represented by the following:

1. Blue Alert: team member is possibly engaged. Attention level is high.
2. Yellow Alert: team member is fatigued and may require assistance to complete task.
3. Red Alert: team member's health is compromised and team member may be in danger. Assistance is required.

The alert messages containing the icon appear temporarily at the bottom of the screen; since the alerts only appear when a user event is generated, the user will always know that the alert pertains to a team mate (Figure 7.2).

In addition to this scenario, we wanted to provide a broader level of situational awareness in cases where interaction between teams is more critical. We attain this by allowing the Android receivers to broadcast a signal at all times. This presents a significant challenge because the phone's broadcasting and receiving events must be activated at different times, and the accuracy of these functions vary. On some Android phones, establishing a Wi-Fi hotspot may interfere with the phone's ability to scan for Wi-Fi connections. We did not experience these issues with the Nexus One phones that we used for testing, but we discovered that this may be an issue on some HTC models. The affect of this conflict can be lessened with manual scheduling of the broadcasting and receiving events. The receiving event occurs whenever an available network is in range, however the broadcasting event can be made to function at regular intervals similar to the computer beacons. Ten seconds is enough time for the Wi-Fi signal to reach a computer beacon or another Android phone within about twenty meters. When the signal reaches a computer beacon, the alert is propagated through the rest of the syste; therefore the locations of each phone within the system is updated and new location information is displayed every ten seconds. There is roughly a five second delay for each computer beacon that must relay the phone's location information. Therefore, phones that are farther apart will take longer to receive accurate information if there are significant changes in the device's GPS location. However, phones that are relatively close will be able to display accurate information much faster.

7.2 User Status

To monitor user status, we have incorporated the use of mobile physiological sensors. The purpose of this enhancement is to provide a solution to alert teammates when a team member is in danger without direct interaction from that team member. This can be very useful in the assembly scenario because paratroopers are unable to communicate verbally or use gestures due to low light and limited visibility. We chose to use the Zephyr Bioharness to collect physiological data from users (Figure 7.3).

The bioharness transmits data via Bluetooth to Android phones and therefore is an optimal option for collecting this data. The harness contains sensors that collect heart rate, breathing rate, device temperature, posture of the wearer, acceleration, and ECG.

(a) (b)

Figure 7.3: (a) Zephyr BT Bioharness (b) Harness can be worn comfortably across the chest and underneath clothing

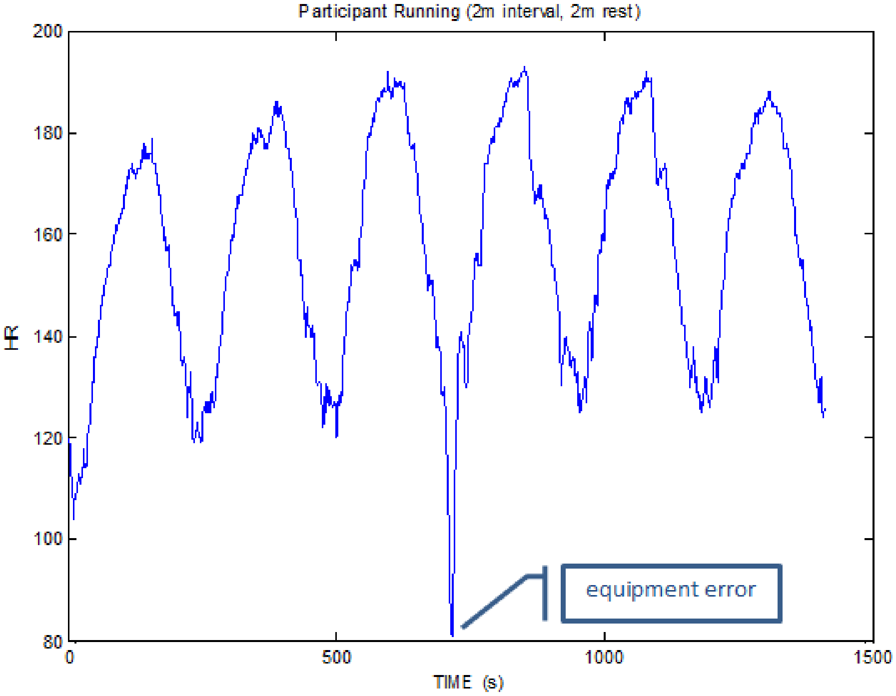
7.2.1 Events

The goal of this phase was to identify at least four distinct events that could be used to determine if a team member was in danger or possibly in need of assistance. We decided to conduct a pre-analysis and focus on physiological data that may be characteristic of states of fatigue, physical harm or danger, focused attention, and surprise (or being startled). Since these states may or may not require attention and/or action from a team member, we have categorized the alerts by level of importance.

Prior to defining our set of user-based alerts, we analyzed the physiological data obtained by the harness in an active scenario. By active, we mean that we needed to collect data from participants that were being exerted in a similar fashion to paratroopers engaged in a mission. The purpose of these tests was to determine the normal ranges for the physiological readings obtained by the sensors. To do this we conducted tests in which participants were asked to perform a series of tasks (*i.e.* running, climbing, *etc.*), sometimes to exhaustion. Using the information retrieved, we were able to define user events based on trends in the data. The first test consisted of trying to provide ground truth for using heart rate recovery (HRR) as a measure of exhaustion. Various studies have been conducted into conditions associated with HRR, and many support a relationship between HRR and exhaustion [141]. A study conducted by Lamberts et al. showed that a decrease in recovery, as measured by the difference between initial HR after recovery starts and the end HR after a set time, can signal the onset of fatigue [70]. The study suggests a diminished endurance capacity even though performance may not be compromised at this point.

During our study we asked participants to wear the bioharness while they performed stair climbing and running exercises. Participants were asked to perform the exercise at a machine-controlled pace for two minutes, then they were given one minute to rest. The pace was set by each participant; we asked them to set pace that was not overly strenuous, but would tax their ability to perform the activity while talking. The goal was to perform the activity to exhaustion and therefore the pace had to be slightly out of their comfort range in order to evaluate recovery. Our hypothesis was that the level of recovery after each interval would decrease as the participant reached an exhaustion level. We hoped to use this information to possibly identify a measure of energy and/or exhaustion in a team member.

We conducted a few initial tests to determine an optimal rest and action interval for retrieving data. Many HRR studies use a two minute rest period to allow the heart rate to return to normal after each interval. We conducted a practice study using a two minute resting period, but found that the subject did not reach exhaustion and the affect on the HRR was not as significant (Figure 7.4). We also determined the best way to secure the bioharness with the supplemental harness strap in order to



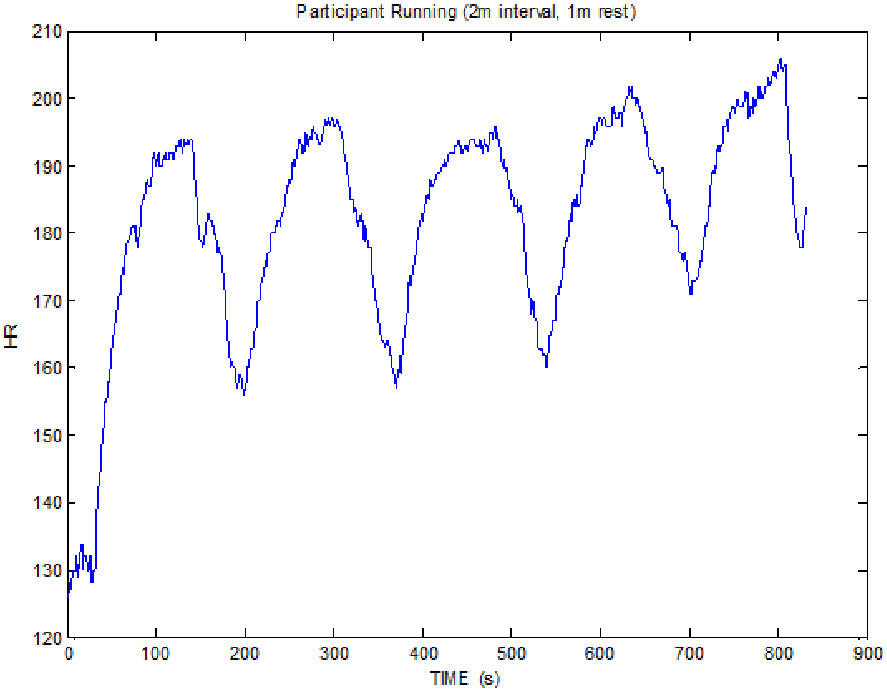


Figure 7.4: Rest interval comparison for fatigue study: HRR is signified by the ability of the HR to return to near its original value during rest periods (shown as valleys on the graph). The top graph shows consistent HRR when the participant is allowed two minutes of recovery time. The bottom graph shows a decline in HR recovery when the participant is allowed only one minute of recovery time.

maintain contact with the skin and avoid loss of data errors like the one shown in figure 7.4. Moving forward we decided to use a one minute rest interval and measure the difference between the HR at the start and end of the rest period similar to the study conducted by Lamberts et al [70].

The first graph in figure 7.5 shows the changes in HR during each interval and rest period. The peaks represent the maximum HRs during activity and the valleys represent the lowest HR achieved by the participant after one minute of recovery time. We used the following equation from Lamberts' study to calculate the percent recovery: $HHRperc = \frac{(HR_{start} - HR_{end})}{HR_{end}}$, where HR_{start} represents the HR at the start of the sixty-second rest period and HR_{end} represent the HR after sixty seconds has elapsed.

The second graph in figure 7.6 shows the decline in the amount of decrease in HR after each interval and over the course of the entire session. The overall results showed that although there were some moments of increased recovery compared to the immediately preceding interval, the amount of recovery declines about 10 - 15% by the end of the session. For each participant, the treadmill exercise showed the most consistent decline when compared to the stair climber exercise. Because the participants were asked to continue a strenuous exercise until exhaustion, we allowed them to take additional time to recovery if necessary to continue (Figure 7.5). Another trend we noticed is that the max heart rate during each interval also increased, signifying an overall increase in exertion as the activity continued.

Using this information we identified criteria to check for and handle a fatigue event:

1. when a deceleration in HR and a decrease in accelerometer activity occurs, the system starts a timer

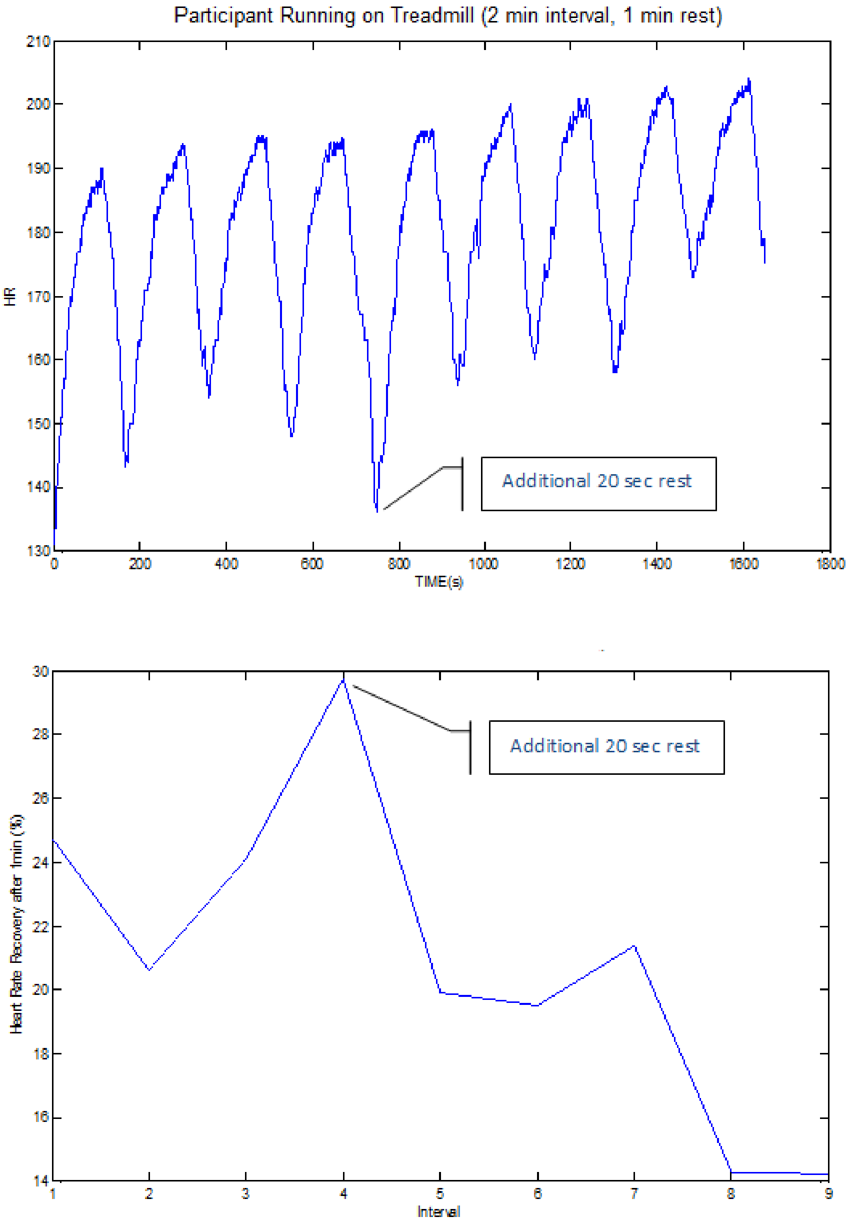


Figure 7.5: HHR from extended intense running activity to fatigue. The first graph in shows the changes in HR during each interval and rest period. The peaks represent the maximum HRs during activity and the valleys represent the lowest HR achieved by the participant after one minute of recovery time. The high peak in recovery in the second graph indicates an additional 20 seconds of rest needed by the participant after an interval.

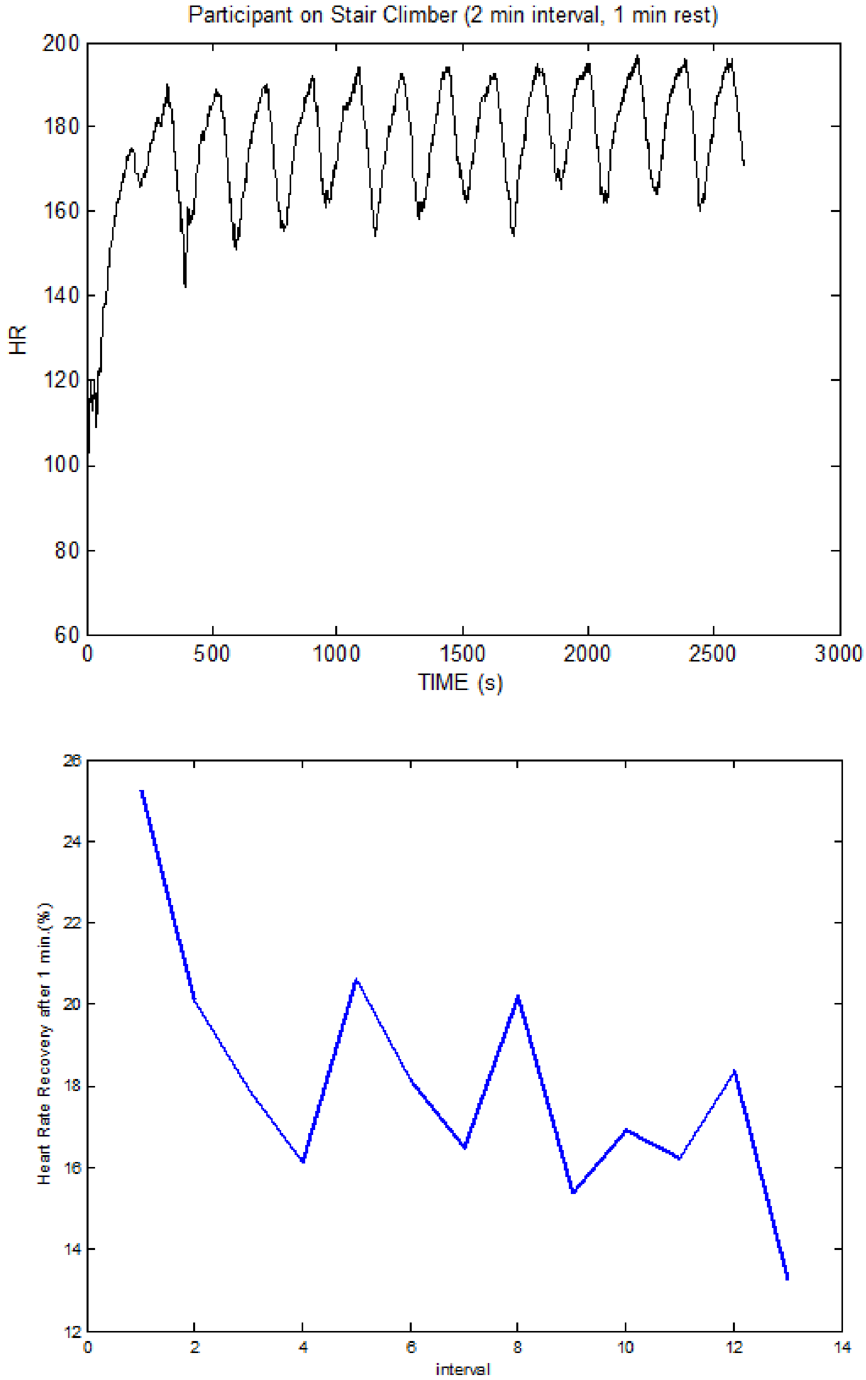


Figure 7.6: HHR from extended intense climbing activity to fatigue. The top graph shows changes in HR during each activity interval (peaks) and rest period (valleys). The bottom graph shows the overall decline in HRR over the course of the entire exercise.

2. when the timer reaches a minimum of 60 seconds the percent of recovery is measured
3. If the value meets our measure of exhaustion (less than 15% recovery), then the system will generate a yellow alert

To identify a state of physical danger or harm, we had to create our own criteria based on hypothetical scenarios. The first trigger created is based on the sensor that delivers posture data from the bioharness. The harness can determine if the wearer's torso is upright, parallel to the ground or some angle in between. In addition to posture, we monitor the GPS position of the Android device. If the GPS position does not make a significant change (defined by a change of 0.00008 degrees or about 8 meters) in more than 60 seconds and the posture measure indicates that the user is parallel to the ground (either lying down or bent over), then the system generates a red alert. We believe that these two events combined may signify that a man is down and either hurt or unconscious. This scenario is easy to simulate but for ethical reasons, it is not feasible to verify if these events are accurate in a real battlefield scenario.

Along the same lines, we identified a complementary event: if the HR falls below 55 bpm then the system generates a red alert. Since a normal HR range is 60 to 100 bpm at rest, and considering the target user group is expected to be engaged in physical activity and/or will be experiencing a certain amount of physical and mental stress, we believe that it is reasonable to expect an HR reflecting moderate or high activity. Estimated heart rate for low, moderate, and high activity are based on guidelines established by the United States Army Research Institute of Environmental Medicine [42]. Again, for ethical reasons, we were unable test this event using a real person (testing had to be simulated).

Figure 7.7: Mindwave mobile EEG sensor [88].

The next state we wanted to identify was a state of focused attention. We believe that this state is important because it may signify when a Soldier is engaged; this may mean that he/she has begun surveillance, or some other task that has caused the Soldier to deviated from his original mission and focus on something else. To do this we used an additional sensor, the Mindwave Mobile, to measure EEG activity (Figure 7.7). This headset measures attention and eye blink events and, like the bioharness, is able to transmit the data directly to an Android device via Bluetooth. Ideally the attention measure increases when the mind is engaged in focused activity, for example when completing some mental task. The Mindwave was used as a prototype to determine if it's possible to utilize EEG in a meaningful measure. Unfortunately, we did not find discernible patterns in the data that would signify a change in attention or focus during preliminary tests. However, this does not mean that this data may not one day be attainable with more sensitive equipment. Since it is not feasible to wear the Mindwave headset and an HMD, a final product would need to be an HMD that contains an embedded EEG sensor.

The last event that we tried to capture was a state of surprise (or being startled). A state of surprise can be identified by frequent responses in skin conductivity or the amount of sweat production measured by a sensor [91]. Unfortunately, given the nature of our scenario, we found that the excessive activity caused a level of skin conductance that was too great to determine a state of surprise.

7.3 Evaluation

Prior to our next large user study, we conducted preliminary tests to evaluate the effectiveness of the user alerts both in how well they were transmitted and how well they directed teammates to action. We conducted these tests at Cain Park on the Texas A&M University campus. We chose this location because it had a slightly more uneven terrain compared to Veteran's Park (the location of the previous study) and would accurately test the ability of the phones to transmit alerts in uneven terrain. We asked one participant (the "Runner") to wear the bioharness and performed certain physical activities, such as lying prostrate on the ground, and calisthenic exercises (consists of movements using one's own bodyweight) to exhaustion, as instructed in order to generate an alert for their teammates. We tasked two other participants (the "Seekers") with locating beacons until they received an alert on their phone. When an alert was received, they were instructed to navigate to their teammate's location as quickly as possible. We conducted 4 iterations of the same exercise; each time the Seekers received an alert within 40 seconds of the alert being generated by the Runner's phone, and immediately changed their task to locating the Runner. There was no direct interaction from the Runner with the receiver.

The maximum distance tested during this exercise was about 53m without the assistance of a computer beacon with a Wi-Fi range extender, however further tests have shown that the Android phones can transmit a signal of over 100m.

Using data from this study, we were able to design a user study as an interactive game. As mentioned in the Chapter 6, we believe that presenting the activities as a game and establishing a time limit will introduce an incentive to the participants and create a stressed scenario that's more realistic of the battlefield (albeit not as intense). We conducted a follow up study with nine ROTC cadets at an area that measured approximately $11011m^2$. This study was also conducted at night to simulate a night drop mission. There were 6 investigators present to help facilitate the study, observe participant behavior and to ensure that each team followed the rules of the exercise. We divided the participants into two groups of four with one participant serving as the Runner. The Runner was asked to wear two wristbands to assist with the search and rescue simulation part of the study. The rest of the participants were split up and taken to remote locations within the testing area (out of site and speaking range of their teammates). Once in position, the participants were given their team letter, either A or D; they did not know who their teammates were until the assembly task was complete.

The goal of the exercise was to simulate the confusion present in the paratrooper scenario; both teams had to assemble and navigate to all beacons, as quickly as possible. The teams could not proceed to the next beacon unless all team members had assembled at the first. The team names identified the order for which each team navigated to the beacons; team A proceeded $A \rightarrow B \rightarrow C \rightarrow D$, team D proceeded to $D \rightarrow C \rightarrow B \rightarrow A$.

During the exercise, the Runner was tasked with simulating an event to send an alert to the other participants. When one of the teams received an alert that a teammate needed assistance, they were required to navigate to Runner's location, as a group or individually, and retrieve one of the bands from the Runner's wrist. In order to simulate the paratrooper experience, we asked the teams to follow 3 rules to simulate paratrooper operation in the field:

1. They were required to navigate to all beacons and rescue their teammate as quickly, and quietly as possible. If any of the investigators caught the teams talking and/or emitting light pollution, they were directed to send the team back to their starting beacon. If an individual was caught doing the same prior to assembly, that participant would be taken back to his starting location and his team would have to wait for him to rendez-vous with the group before proceeding.

2. If an individual team member goes to assist a teammate, the group must remain at their location for their team member to return before proceeding. If the group goes, they can continue to move to the next beacon after assisting the teammate.

3. The teams were allowed to communicate using hand gestures, but they were not allowed to speak or use illumination of any kind.

The participants were free to use any of the interfaces, so all participants chose the view with which they were most comfortable.

7.4 Results

We conducted four iterations of the preliminary exercise at Cain Park. Each time the Seekers received an alert within 40 seconds of the alert being generated by the Runner's phone, and immediately changed their task to locating the Runner. Location of the runner (at a moderate walking pace) took less than two minutes for each Seeker in every trial. As previously mentioned, there was no direct interaction from the Runner with the receiver and therefore we were able to effectively demonstrate that (1) changes in physiological data could be used as a trigger to reallocate team members from a navigation to a search and rescue task. However, additional investigation was required to validate this principle, which is why we conducted the latter study structured as an interactive game.

In the interactive game exercise, the navigation times for both teams were slightly higher than the first study because of the greater distance between the beacons, however both teams were able to locate all of the beacons and complete the exercise. When the Runner generated an alert, it took less than one minute for at least one team member on each team to receive the alert. The teams' response time was slightly delayed, but this was expected due to the fact that teams had to decide their rescue strategy (either to send one person or to go as a team). Both teams completed all tasks required of them and returned to home base as a group.

During the exercise, we observed many participants initially using one of the four views on the Android device (Distance, Arrow, Compass, or Map). However, once they had a general understanding of the direction of the beacons, most rarely looked down at the device and appeared to rely on the haptic feedback from the phones to navigate. Since this exercise was conducted at night in an unlit area, participants had to devote more of their attention to their surroundings than in previous studies for safety. They also had to be able to observe the actions of their teammates and therefore could not continuously look at the receiver interface.

Owing to the lighting conditions, we conducted a recorded oral interview to obtain feedback specifically on the alert system. Again, participants were very pleased with how easy it was to navigate to each beacon and stated that the data presented was accurate. Many of the participants stated that once they had initially obtained the location of the first beacon, the vibration feedback helped them remain on track as they advanced across the area. They also stated that having this feature was helpful when they needed to keep an eye out for both their teammates and the investigators, which in the context of this exercise served to simulate the presence of an enemy threat to participants. This feedback and our observations, combined with the data obtained from the user studies conducted in the previous chapter, provide evidence that supports the principle that haptic pulses are the best way to deliver navigation information when the Soldier's attention was divided and/or focused on other critical tasks.

When discussing the alert functionality of the system, participants stated that they were able to navigate to and locate their fallen teammate with great ease. Because of their proximity, the Android phones did not all receive the alert at the same time. As a result, one of the teams had to follow one person to the Runner's location until others received the alert as well (they chose to navigate in a group). Because of the larger test area, the teams took approximately four and five minutes respectively to navigate to their fallen team mate (less time was taken when only one team mate was sent). The effectiveness of the task change, and the findings that resulted from the preliminary studies (1), supports the principle that the physiological alerts are effective triggers for task reallocation. However, one of the participants was of the opinion that this decision should always go to the team lead. So we further clarify this principle by stating that *physiological alerts can serve as an effective trigger for task reallocation as long as that task is within the bounds of the current directive (if the Soldier is alone) or aligns with the commands of the unit leader.*

Those participants that received the alert first said that they liked the color code but wanted to be able to access the alert again after it appeared to obtain more information if they're at liberty to do so. In addition, many of the participants stated that the color drew there attention to the severity of the alert more than the text presented. An alert was generated midway during the exercise when the majority of teams had already assembled. At this point, the participants stated that their senses were not as alert as when they were navigating alone (due to the perceived safety of the group), however, they were still moderately engaged in their task and therefore were unable to read and process the information on the screen in a reasonable amount of time, which is why they wanted the option to access the data later. Because of this feedback, we formulated an additional design principle mentioned on page 8: *When cognitive load is moderate, color, rather than text, is the best way to alert the user of an event that may require attention.* We took this into consideration during subsequent development phases and further explored the use of color for relaying more complex information.

Overall, participants appeared to enjoy the game interaction scenario, and we were very pleased with the responsiveness of the system in this larger test area. By restructuring the user study as a game with risks and team goals, we were able to increase the cognitive load of our participants and evaluate our design principles regarding to haptic navigation and physiological triggers. In addition, data obtained from this exercise lead to the formulation of the design principle regarding the use of color for visualizing these triggered events.

In addition to these contributions, we have expanded our solution and increased team awareness by providing an alert system that:

1. Turns each receiver into a beacon to allow tracking and monitoring of the teammate's physiological data.
2. Delivers status information through the ad-hoc network without direct interaction from the team member.
3. Increases team coordination by alerting team when a member is in danger.

8. CONTINUOUS TEAMMATE AWARENESS

In the previous chapter, we developed a solution that assisted team coordination by allowing team members to exchange status information. We also maintained the hands-free interaction methods needed to increase situational awareness by using changes in physiological data to initiate the exchange of data. However, cadets that evaluated the solution system with user events stated that the textual information presented was not as useful as the color coding. Because one of the challenges to team coordination is mental stress resulting from information overload, we had to re-evaluate the data delivery medium to minimize the cognitive load. In afddition, we wanted to possibly provide a method of preventing long-term effects of stress (such as PTSD) by providing a constant awareness of teammate status that would allow team members to know when danger was imminent prior to an alert event occurring, and/or to allow them to process varying levels of danger that correspond to reactions to stressors that a teammate may be experiencing.

On mobile devices, Haptic feedback is a common method for delivering alerts and augmenting touch interaction. By exploring these features, we can create more complicated messages and exchange more meaningful information between teammates in a way that does not require visual input. We have explored using haptic feedback as a method of connecting people by allowing them to feel each other's heartbeats. The prototype solution monitors a user's heart rate using physiological sensors and relays that information to a target device, a mobile phone or a haptic vest, that corresponds to the pulse. We believe that this interface will allow two team members to remain physically connected without physical contact.

There has been extensive research in the areas of haptic interaction as a means of coping with physical separation. Being able to talk to, see, and now to physically connect with someone over a great distance comes close to representing a complete interaction experience. Therefore, we are currently exploring how haptic feedback can be used to create that physical connection and the affect it has on biological processes. Our first approach to this effort is a solution that allows two people to share and feel each other's heartbeat through the Android phones or through a vest fitted with vibration actuators. Through our evaluation studies, we sought to determine if the use of a haptic vest can allow two people's arousal levels to become synced, a natural response of two non-strangers interacting.

Providing subliminal information about a loved one or other invested individual can affect a person's physiological responses. This response helps to facilitate an emotional connectedness with another person of interest [68]. This technology can be applicable to both social interaction and team awareness. For example, a haptic vest can be worn during Skype conversations to produce a more realistic interaction experience, or two people in a crowded room can feel emotionally connected even when they're not interacting at all. The main benefit is being able to maintain a connection over large distances. As a result, haptic feedback is an optimal interaction method for maintaining team awareness in battlefield situations. Using a buddy system, Soldiers that are unable to communicate or see each other can remain constantly aware of each other's status in a manner that's unobtrusive to their current task. The same could be true in rescue situations; teammates in hazardous environments can respond quickly if there's any significant changes in their partner's heart rate.

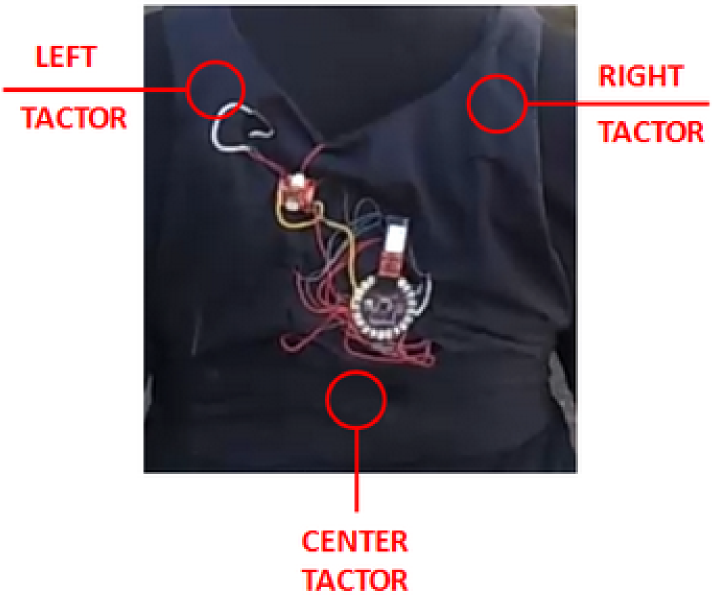


Figure 8.1: Haptic vest

8.1 Implementation

As in the previous chapter, we used the Android receovers to communicate HR information using Bluetooth and Wi-Fi technologies. The Zephyr BT Bioharness is used to retrieve heart rate data from one user and transmit the data through the network from one phone to another. However, one change we made during this phase was to incorporate and evaluate the use of a custom-made haptic vest. The haptic vest consists of a LilyPad Arduino along with LilyPad Vibe Boards placed in a Y pattern on the left shoulder, right shoulder and center of the back of the wearer (Figure 8.1).

The Android device works by taking the heart rate supplied by the bioharness and translating it into milliseconds per beat. Then the time between each beat is calculated using a standard 50ms vibration for each beat. This is obtained by subtracting the length of the vibration (50ms) from the value received from the bioharness. This pattern of vibration is updated as the harness outputs new heart rate data and the pattern is sent to the target device's (either the phone or the vest) vibration service to simulate a beating heart.

8.2 Evaluation

We designed a user study to investigate the degree and the conditions to which the arousal levels of two individuals can synchronize and how well the vibration functions on the phone and the haptic vest responded to user events. A quick response time from the vibration feature and a perceived feeling of connectedness from users would indicate that this feedback method is optimal for constant teammate awareness. The setup of the study was meant to simulate the disconnect of a great distance where two people are close enough to possibly see each other, but too far away to read facial expressions; this characterizes an ideal scenario for this solution (two Soldiers, whose view of each other is obscured by a great distance, limited lighting and/or other conditions).

We recruited 6 participants for this study: college students ages 18 - 30. We chose pairs of participants that had relationships (*i.e.* co-workers, friends or romantic partners). Participants were given two separate roles with one participant assuming the role of the Sender and the other, the role of the Receiver. Each pair was assigned a primary investigator whose role in the study along with those of the Sender and the Receiver is explained in the subsequent paragraphs.

The role of the primary investigator was to induce increased heart-rates in Participant A (who was assigned the role of Sender). The primary investigator's task was to instigate a stressed or elevated physical response in Participant A by presenting controversial and/or sensitive topics for short discussions. These topics included ille-

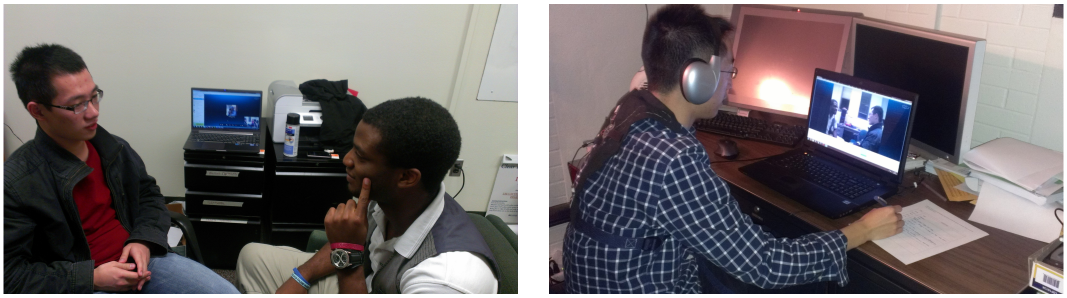

(a) (b)

Figure 8.2: (a) Interview to invoke response in participant A wearing BioHarness (Sender). (b) Observation by participant B wearing haptic vest and HR monitor (Receiver).

galization of birth control, separation of church and state, cosmetic surgery, abortion, concealed weapon laws on campus, obesity, *etc.* (Figure 8.2(a)).

The investigator engaged participant A in discussions in order to elicit changes in participant A's heart rate for Participant B (who was assigned the role of Receiver). In addition, the conversations between the Sender and the investigator were streamed via Skype to the Participant B with the audio removed (Figure 8.2(b)). The camera recording the conversations was positioned beside Participant A and the primary investigator so that Participant B could view a profile shot of both persons. The purpose of this placement was to slightly obscure the view of participant B so that he/she would not be able to infer too much information about Participant A's emotional state from their facial expressions. However, participant B could obtain some context of the heart rate response from body language. Using the video feed also provided the benefit of an approximate one second delay which allowed enough time for the heart rate information to be relayed from participant A's sensor to the haptic vest worn by participant B; this created a smooth syncing effect.

The role of the participant B, the Receiver, was to receive and analyze the heart rate of Participant A through the vibration feedback received from the haptic vest. The receiver analyzed both the video stream and the heart-rate data received and recorded written observations concerning how participant A was feeling throughout the conversation. Participant B was also outfitted with a heart rate monitor to record his/her heart rate changes in response to those of Participant A.

8.3 Results

After the study, the heart rates of both participants were compared to determine if any arousal syncing occurred. While the entire data collected does not show a particular trend, there are some areas that appeared to show syncing in arousal between participant A and B on certain questions that significantly affected participant A (Figure 8.3). This syncing seems to support the studies conducted by Konvalinkaa et al. which state that syncing occurs to allow emotional connectedness with another person in a stressed state. However, given that our participants aren't being subjected to extremely strenuous activities such as firewalking, we have to consider other factors to explain this occurrence [68]. What's more interesting is that arousal syncing occurred on a greater level in cases where participant A's heart rate dipped lower than participant B. We hypothesize that the decrease in vibration pulses relaxed participant B and faster pulses excited or even irritated participant B which in turn affected the heart rates (Table 8.1). In Trial 1 participant B's average heart rate rose about 6%. In Trial 2, participant B's average heart rate lowered about 10% and in Trial 3, participant B's heart rate lowered about 4%.

During the study, we asked participants that served as receivers to fill out a log describing what they thought participant A was feeling based on their observations and haptic feedback from the vest. We also asked them to note how the vest was responding based on the events going on in the video feed. Following the study,

Participant	Before	After
Trial 1		
A	88.8	85.2
B	63.8	67.4
Trial 2		
A	88.6	82.2
B	94.0	84.9
Trial 3		
A	94.5	88.6
B	86.3	85.4

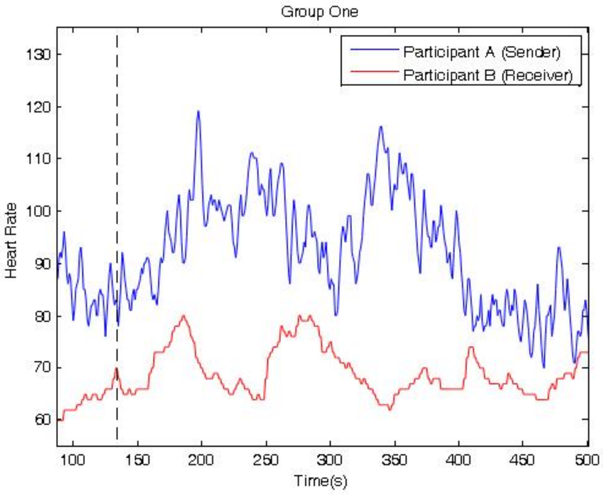
Table 8.1: Changes in average HR before and after conversation exercise

we had the participants fill out a questionnaire to evaluate both the system, the interaction method and the user study. Using their log as a reference, participants that served as receivers stated that the haptic feedback from the vest was clear in that it corresponded well to the reactions of participant A. One participant commented that the vibrations were very informative in cases where the other participant seemed to be trying to mask his emotions. In terms of interaction experience, the participants stated that they were very comfortable with the vest itself saying that the equipment was not constricting or obtrusive. They also stated that the vibrations synced nicely with the video feed and created an immersive experience.

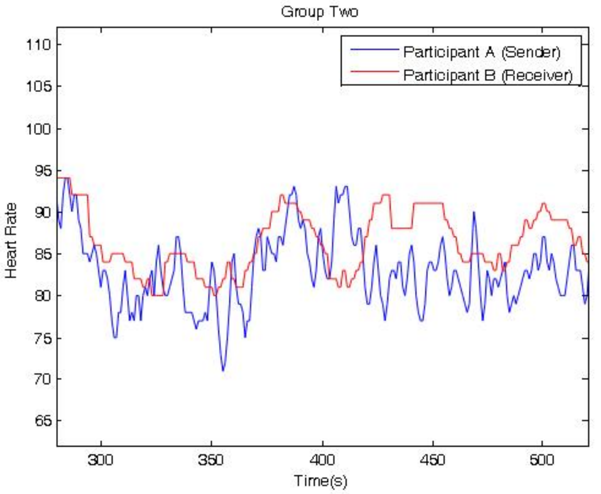
8.4 Discussion

While we acknowledge that arousal syncing may be occurring in this scenario, we're more concerned with the degree to which the haptic feedback delivered through the phones and vest helped participant B feel connected to participant A. Based on the participant feedback we believe that this interaction method will be optimal in a scenario in which paratroopers are using a buddy system to ensure team mates are constantly aware of each other. This research is still ongoing, however through this new development we have:

1. Incorporated haptic feedback as a means of increasing teammate connectedness and awareness of teammate status.
2. Created a simple method for exchanging status information between teammates with minimal cognitive load.
3. Incorporated an additional interaction medium that provides additional information to Soldiers, but keeps their hands free and their view unobstructed.



(a)



(b)

Figure 8.3: Possible arousal syncing occurrences in participants just after start of conversation. (a) This graph shows an increase in heart rates of participants A and B from group one just after the 150s mark (b) This graph shows a decrease and then a subsequent increase in participants A and B from group two just before the 300s mark

9. INVESTIGATING AFFECTIVE AWARENESS

At this point, we had two effective solutions for enhancing team awareness by allowing the exchange of team status information and presenting the information in a medium that did not cause information overload. Although we found that user alerts and the exchange of physiological information are beneficial for connecting pairs of user, we decided to increase the level of detail by identifying six additional user states in an effort to provide a greater form of team awareness. There has been very little exploration into the ubiquitous visualization of the user physiological state in real-time. In this phase we planned to implement a method of classifying physiological signals in real-time to create a visualization of the user's physiological state. We again used data from physiological sensors such as skin conductivity, EKG, EEG, temperature, *etc.* and attempted to perform affective (or emotion) classification. This level of detail may be useful for team coordination as it can be used as a means of both individual and team performance evaluation in high-stress scenarios.

In the context of this investigation, we focus on the physiological state of a user that experiences an emotional response (*i.e.* anger, sadness, fear, *etc.*) to outside stimuli. We adhere to the theory that affect (or emotion) requires some thought, but the physical response or state resulting from that emotion is somewhat uncontrollable [142]. With that said, the goal of the experiments discussed in later sections is to use outside stimuli to induce a specific emotional response and determine if there is an identifiable corresponding physical response.

In battlefield and disastrous environments, where a direct line of sight of team members is often compromised, real-time physiological state monitoring may further assist in detection and early intervention of traumatic events that could potentially lead to acute stress disorder (ASD) or PTSD. By classifying the physiological data and pairing it with corresponding visual signals, one could potentially identify characteristics of a trauma-induced panic state. This level of non-direct communication would be beneficial for a team of soldiers who need to stay informed about each others stress and panic levels.

Visual cues of the physiological state may also be beneficial in improving basic social skills. Some disorders, such as Asperger syndrome, are characterized by difficulties with social interaction; a person with Asperger's may find it challenging to recognize facial expressions and/or body language. A visualization of their counterpart's physical state can be used as a social training tool for practicing effective interpersonal interactions. This technology could also be useful in conflict resolution; by providing the participants visual representations of the opposing side's user state, participants can chose to divert a discussion or take a break if emotions get too intense. The ability to recognize and, to some extent, share the feelings and attitudes of another has been associated with altruistic reaction to the object of empathy [27].

Color will play a huge role in the effectiveness of this data visualization. In nature color serves many purposes; communication, protection, warning, attraction, *etc.* These different signals assure survival in a hostile world. Even today, the effects of certain colors register on a subconscious level in the human brain [33]. Bright colors draw response from the limbic system, the parts of the brain believed to control emotion, behavior, and other various functions [33]. Studies have shown that color alone can induce specific feelings and can be very affective in drawing attention and conveying a specific message when paired with complementing factors such as text, size and shape [8]. By using the same primary colors used for the alert system in the previous chapter, we hope to create a representation of the user state that will produce a similar response in participants who are viewing the visualization only and not the original stimulus.

While it is evident that affective information would be beneficial for team connectivity, the classification of physiological signals in real-time is difficult because the duration of an emotional state is not predictable. Reliable classification requires a relatively large context and real-time processing of large amounts of data is problematic for commonly used feature extraction approaches. As a result, most classification is performed offline (on prerecorded data). In this phase we explored methods to classify sets of biosignal data in small intervals so as to obtain real-time recognition. By performing multiple test runs using the physiological sensors, we were able to determine the best practices for collecting, recording and cataloging large amounts of physiological data which are discussed more in the following sections.

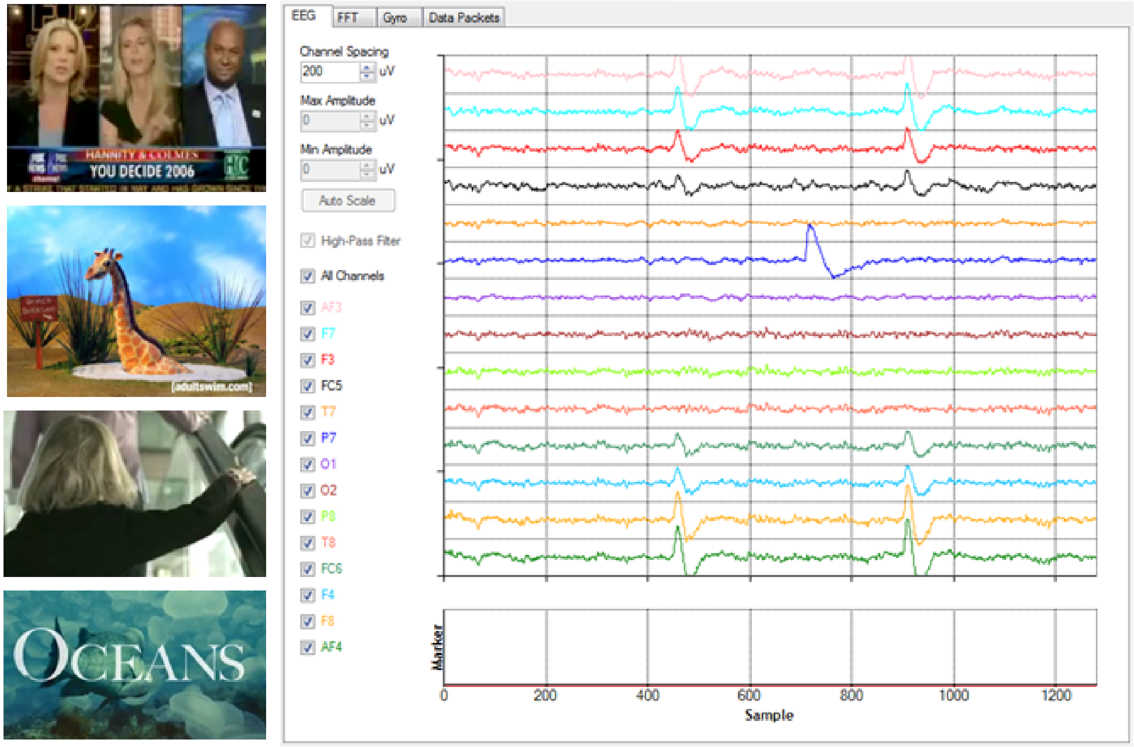
We began this effort by conducting studies to determine if it is possible to accurately classify small chunks of live data obtained from physiological sensors and still keep the latency small enough to create an effective visualization of a user's response to stimuli as it occurs. We surveyed existing research related to biosignal classification to get an understanding of data collection and analysis methods as well as general accuracy rates. We found that most existing research conducted recognition for four emotions or less (in some cases, only a stressed/not stressed state was classified) and used either data from biosensors or EEG sensors alone.

9.1 User State Classification

We attempted to classify a subset of the seven basic emotions identified by Dr. Paul Ekman: happiness, surprise, fear, sadness, anger, and disgust combined with contempt. During the initial data collection with an EEG headset, we selected 4 short video clips: a Fox news debate, a public service announcement with anti-littering, anti-road rage, *etc.* content, a clip from a comedic cartoon, and a clip from a documentary about the ocean (Figure 9.1). We used these video clips as stimuli to try and illicit an emotional response of anger, sadness, happiness, and pleasure respectively. Using the data obtained from the EEG headset during repeated viewings of the content, we performed preliminary feature extraction on the data set to determine how well basic features such as min, max, standard deviation, median, mean, range, and maximum ratio can serve to separate the state classes. This exercise helped us determine which which of the 14 signals obtained from the EEG are the most useful for identifying the user state. We created custom data signal files and analyzed them using the Augsburg Biosignal Toolbox (AuBT) [135]. This made it easy to later combine features for signals taken from other physiological sensors (SC, EMG, ECG, RESP, TEMP) and analyze them with the AuBT as well. Based on preliminary results, the calculated features listed above generated some separation of user state classes from the EEG data alone. We hoped that the inclusion of additional physiological data would help to separate the data further.

Utilizing Thought Technology's BioPac2 biometric sensors and the EPOC brain-computer interface (BCI) headset, we combined EEG data and ECG, EMG, respiration, skin conductivity, and heart rate data to find the best classification methods to determine if this combined solution is an improvement when compared to recognition methods that classify the latter signals without EEG. We used feature subset selection to determine which of the 20 available signals (14 for EEG, 6 for other physiological sensors) were significant and followed Chanel's approach regarding the use of a quadratic classifier for physiological signals.

We developed a system that would record data from physiological sensors (made by different manufacturers) connected to one person. We used images obtained from the Affective International Picture System as emotional stimuli. The system displayed an image for five seconds and recorded the data obtained from the sensors

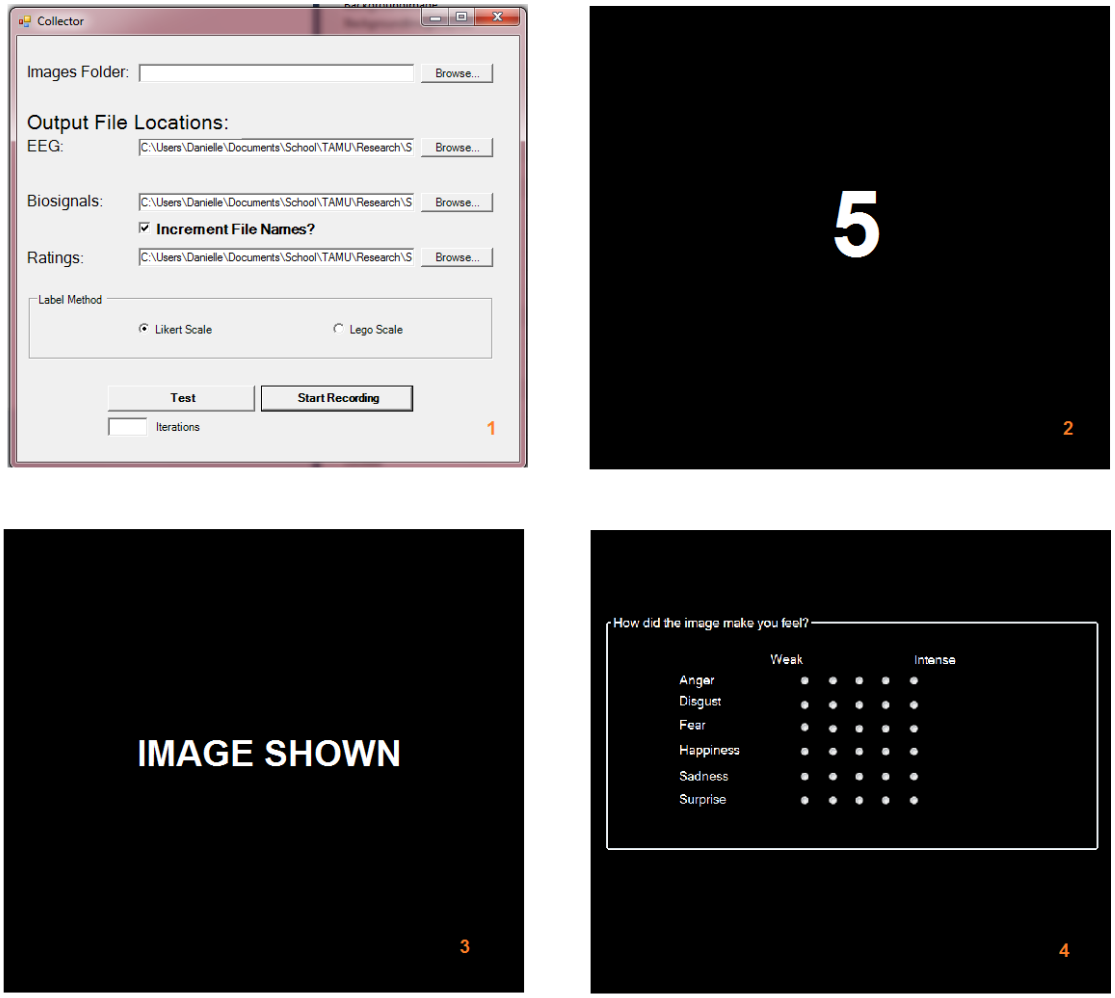


Channel Spacing 200 uV
Max Amplitude 0 uV
Min Amplitude 0 uV
☑ High-Pass Filter
☑ All Channels
☑ AF3
☑ F7
☑ F3
☑ FC5
☑ T7
☑ P7
☑ O1
☑ O2
☑ P8
☑ T8
☑ FC6
☑ F4
☑ F8
☑ AF4

Figure 9.1: Media stimuli for EEG classification

and headset. At the end of the five seconds, the participant was shown a screen where he/she could either identify one of the six emotions that we were trying to target or input their own description. They were also provided a Likert scale ranging from 1 to 10 with which they could specify the intensity of the emotion (Figure 9.2). A five second reset period was used after each rating screen in order to prepare participants for the next stimulus. We recorded data from six participants who were each shown 50 images.

The BCI headset recorded at a rate of 128 samples per second while the rest of the sensors recorded between 32 and 128 samples per second. For each five second recording, there were about 680 samples from 20 sensors. We started by doing a basic cleanup of the data; we removed any samples that were faulty due to equipment or


Collector

Images Folder:

Output File Locations:

EEG: C:\Users\Danielle\Documents\School\TAMU\Research\S

Biosignals: C:\Users\Danielle\Documents\School\TAMU\Research\S

☑ Increment File Names?

Ratings: C:\Users\Danielle\Documents\School\TAMU\Research\S

Label Method: ● Likert Scale ○ Lego Scale

Iterations:

How did the image make you feel?

	Weak				Intense
Anger	●	●	●	●	●
Disgust	●	●	●	●	●
Fear	●	●	●	●	●
Happiness	●	●	●	●	●
Sadness	●	●	●	●	●
Surprise	●	●	●	●	●

Figure 9.2: Physioligcal data collection system with Likert scale ratings

user error.

We came up with a set of 14 features; some were taken from previous works that had promising classification rates of physiological data and others were taken from research in sketch recognition. The features included:

1. Max - the maximum value in the sample
2. Min - the minimum value in the sample
3. Difference between max and min
4. Mean
5. Mean of middle values - mean of 1/3 of the values taken from the middle of the sample
6. Mean of end values - mean of 1/3 of the values taken from the end of the sample
7. Standard deviation
8. Standard deviation of mid values
9. Standard deviation of end values
10. Difference between mean of middle values and end values
11. Difference between the standard deviation of middle values and end values
12. Median
13. Normalized distance between direction extremes (NDDE) difference between the index position of the max and min values divided by the overall number of values in the sample
14. Direction change ratio (DCR) the maximum derivative divided by the overall mean of the derivatives

We calculated these fourteen features for each of the signals obtained for a total of 280 features. We then performed sequential forward selection using our quadratic classifier as a wrapper to determine which features contributed to the highest recognition rates. We conducted the first trial with the assumption that the data was strongly user-dependent. Therefore the classification was performed on each set of user data separately without any preprocessing other than some initial data cleanup. We used random sub-sampling at k=5, 10 and 12 samples as training data out of the 50 samples for each user.

In the second trial we profiled the data from each user by subtracting the user-specific means from each sample in the datasets. We hoped that this approach would show the overall variations in the users' data and that these variations would be consistent across all participants and thus create a user-independent dataset. After profiling, we combined the samples into one large dataset and calculated the same fourteen features from the previous trial. We then performed classification again with random sub-sampling at k=5, 10 and, this time, 20 samples.

9.1.1 Results

During the first trial of testing, which was user-dependent, we were able to obtain recognition accuracy rates of about 44% using 3 features on participant 1. We obtained accuracy rates of 43% for participant 2. Our accuracy rates were slightly higher than previous work that performed a study similar to ours. In addition, both rates were significantly higher than an accuracy rate resulting from chance and our test set included six classes of emotions instead of four. Specifically, our accuracy rates were slightly better than those in the study conducted by Kim et al. which also utilized a 5-6 second window of physiological sensor data but only used four classes of emotions instead of six [64]. In our case we did better than chance by a factor of 2.58 (0.43 * 6) whereas the previously mentioned study only achieved 2.48 (0.61 * 4).

Features calculated against data obtained from the occipital and parietal electrodes on the BCI headset proved to be the most significant. We found that the direction change ratio of the P7 sensor obtained the most valuable data in regards to its contribution to the recognition accuracy. The mean respiration was also a significant feature. This was not surprising given that during testing, some users tended to breath more deeply (*i.e.* the variation in chest expansion rates were higher) when the images evoked calm or joyous feelings.

During the second trials we collected data from 8 more participants. In order to perform user-independent classification, we first preprocessed the data by subtracting the user-specific means and then combined all the samples into one large corpus. Using random sub-sampling with 5 random test samples over 50 iterations, we obtained an accuracy rate of 48% (a factor of 2.88 better than chance) using the following features: the standard deviation of middle temperature values, the NDDE of T7 electrode, the difference between standard deviation of middle and end values of AF3 electrode, and the difference between max and min of AF3 electrode (all sensors are from the BCI headset).

As mentioned before, the overall goal of this work is to eventually be able to perform this type of data classification in real-time. This is why we attempted to classify the data in such small increments (5 seconds or less). In addition, we attempted to increase our accuracy rates through data smoothing methods by first eliminating EEG readings that are out of an acceptable range using Fast Fourier Transform (FFT). This also allowed us to include features based on frequency bands closely related to emotional responses [86]. We utilized a user-independent method to process the data obtained from the BCI headset and biosensors. We combined the data from all of our participants and achieved a recognition rate of 48% on 6 emotions. This accuracy rating matches that of Chanel's study which used user-dependent data recorded in large time intervals and only classified 3 user states.

9.2 Contributions of this Phase

The accuracy rates presented in this phase were not sufficient for implementation in the existing solution at the time, however we still believe that this real-time classification of the physiological state can contribute to future developments in team awareness and non-direct communication on the battlefield. As a result, the work in affective classification is still ongoing.

Through this research we have:

1. Obtained an accuracy rate of 48% on 6 emotions using only 5 seconds of data in an effort to produce a real-time response.
2. Discovered significance in sketch-based features, DCR and NDDE, indicating that there may be value in the application of these features to biosignal data classification.
3. Assigned an affective response label to our IAPS image set for use in future studies.

9.2.1 Additional Contributions

As a continuation to the affective classification work discussed in this phase, we have begun collaborative research with the Human Interface Technology Lab at the University of Canterbury and the Human Centered Multimedia lab at the University of Augsburg. We modified our biosignal data collection system to include two different types of evaluation screens: a traditional Likert scale and an image-based scale (Figure 9.3). This second scale provided a graphic representation of the likert scale values and emotion labels. The original image labeling study was conducted again at the HCM lab, this time using the image-based scale as an evaluation tool. The

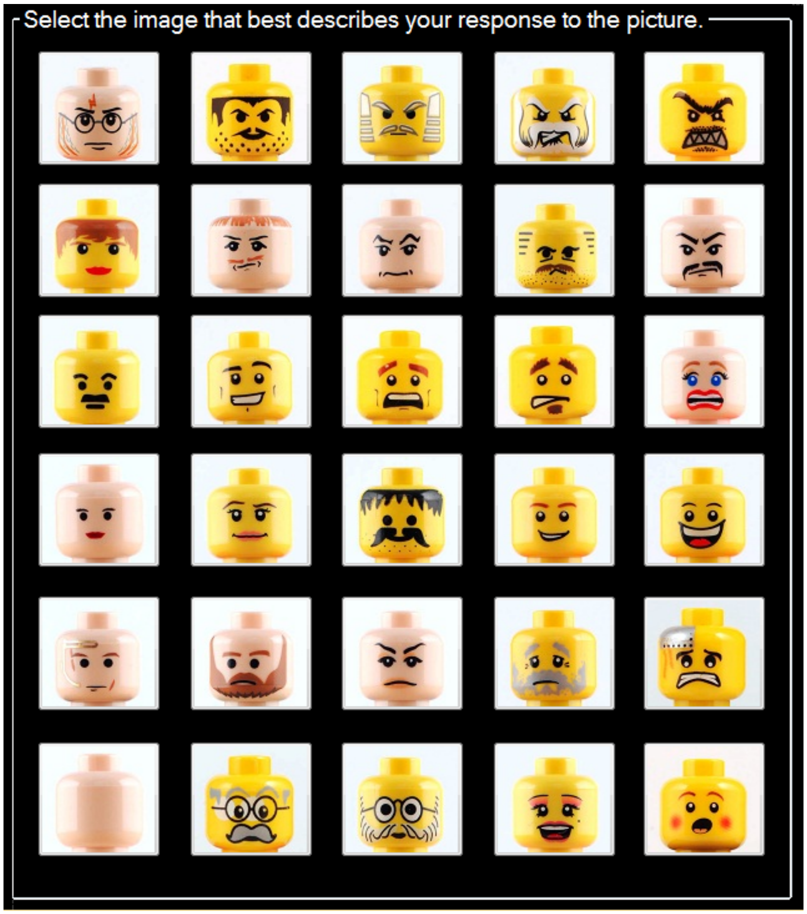


Figure 9.3: Image-based scale for study at HCM Lab

purpose of this study was to compare the Likert scale evaluation method to another that more closely resembles the Self-Assessment Manikin (SAM), an affective rating system devised by Lang [71].

We conducted an additional evaluation of the IAPS images and asked people to assign labels to our chosen test set that would identify an overall response to the images. The images from the International Affective Picture System comes with a table of SAM ratings collected from a group of 100 college students (50 male, 50 female). The students were asked to rate the images based on level of pleasure, arousal, and dominance. However, the images do not have an associated label that relates to one of the six emotions we identified in our previous studies. The In order to verify that the subset of images we were choosing to use would actually elicit the expected response and to ensure that we would obtain a sufficient variety of responses, we decided to perform our own labeling study to evaluate the reaction from the majority of our group. We wanted to determine the overall feelings associated with our images as well as the level of intensity related to those feelings. Within our investigative group, we reviewed the set of 1182 images and selected 50 that we believed to be the best candidates for eliciting the 6 different emotions and which had the highest arousal ratings (positive and negative) within their categories.

We used the Likert scale rating system during the labeling study conducted at the Human Interface Technology Lab in New Zealand. The study involved 24 participants: 15 men, 8 women of ages ranging from 22 - 44, and from 8 different countries. Based on participant responses, we discovered that of our 50 image subset, 46% of them are perceived positively, 54% are perceived negatively, meaning that participants assigned a corresponding positive or negative emotion. The overall intensity of these responses ranged from 3 - 8.

Prior to the study participants we given the option to end the study at any time at their discretion. During the follow-up interview we sought to assess the level of impact of the stimuli as well as identify any instances of discomfort on the part of the participants. Participants stated that they did not feel the need to end the study due to discomfort. As a result, we may utilize images with higher intensity levels in future studies.

10. ENABLING HUMAN-DRONE TEAM COORDINATION*

While we acknowledge the importance of team coordination and awareness, we are also aware that future warfighter teams may not always entirely consist of human soldiers. As a result, it is important that we not only explore methods of human-to-human interaction, but direct human-machine interaction on the battlefield as well. One area of focus involves the exploration of human interaction with Unmanned Aerial Vehicles (UAVs). UAVs add a new dimension to the modern battlefield. Today's warfighter depends on readily accessible intelligence, resources and support on the battlefield to ensure successful execution of missions. The military wishes to use unmanned helicopters to replace road convoys and manned helicopters in hostile environments [92]. UAVs can provide aerial intelligence and supplies quickly and safely and thus have become a vital asset to the military.*

UAVs can provide a reasonable alternative to a human pilot [44]. In combat or disaster situations, the requester of support may be occupied with life-critical activities and therefore requires a method of data input that is fast and easy to learn. In the mission planning domain, there exists a finite set of symbols, known as Course-of-Action (COA) symbols, that represent specific objects, tasks, and actions. Prior to this effort, we have shown that (1) sketch recognition is a powerful tool for interpreting a large number of these symbols when drawn free-hand, however this technology was never tested in a formal application [54]; we have also shown that (2) sketch-based input is an easily-learned interaction method, although this has not been proven in a mission plannning domain [25]. Based on these previous findings

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*Reprinted with permission from "RedDog: a smart sketch interface for autonomous aerial systems" by Cummings, D., Fymat, S. and Hammond, T., 2012. Proceedings of the International Symposium on Sketch-Based Interfaces and Modeling, 21-28, Copyright 2012 by Eurographics Association we have formulated the following principle mentioned on page 8: *Sketch serves as an easily-learned interaction method for complex mission planning.* The current need for intuitive interfaces for humans-drone interaction, provided the opportunity to test and verify our principle with a solution for UAV control.

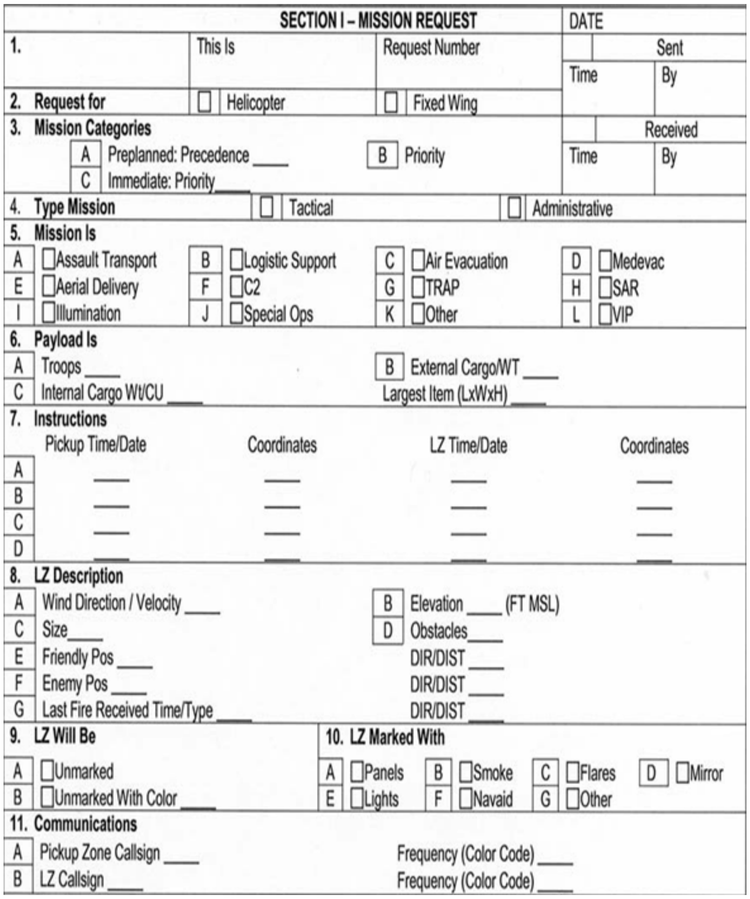
A hand-drawn military COA diagram provides a more efficient means of communicating mission planning information than verbal exchange (going back to the old adage “a picture is worth 1000 words”). With the integration of map objects that can contain both GPS and geographical information, sketch recognition can be used to decipher sketches as a means of translating graphic inputs into directives. We can allow Soldiers to describe a complicated scenario with a simple drawn image, which can then be translated into actions for other humans controlling a UAV, or even for a completely autonomous UAV. Working in conjunction with the Office of Naval Research (ONR), we developed a sketch-based interface for interacting with a UAV, and modified it though multiple iterative development phases with feedback from domain experts at each level. In the following sections we provide an overview of the development and discuss how data obtained from the evaluation of this interface supports our design principle.

10.1 Implementation

We identified processes that are applicable to the unmanned scenario to create a solution for Soldiers that requires little additional training. Using information collected in our ethnographic analysis (in chapter 4), we identified the requirements that derive from each use case scenario and developed functional goals for a possible solution. One of the goals included allowing Soldiers to quickly indicate where hostile forces are located. This need provided justification for using sketch input and subsequently testing our design principle; we had to make sure the solution did not require tedious data entry and provided a simple spatial reference. Therefore, our initial design approach is based on the belief that a simple sketch of a support scenario drawn in a few seconds on a map can be created without prior training and can avoid extensive verbal instructions and/or data input.

The original UI created for desktop use contains several layers for interpreting sketch input and retrieving geospatial data. It combines the sketch recognition capabilities of COASketch (which recognizes over 5,900 hand-drawn symbols with 87% accuracy) and the OpenMap package, a toolkit for viewing and manipulating geospatial data [54, 7]. Using the OpenMap libraries, the application is capable of hosting all sorts of data from Digital Terrain Elevation Data (DTED) to ESRI shapefiles to orthorectified imagery (with distortions removed). The implementation hosts DTED 0 data (*i.e.* height elevation data sampled at 30 arc-second intervals) provided by the National Geo-spatial Intelligence Agency. This data format was chosen because it is the standard elevation data format used in Department of Defense (DoD) operational planning, and thus was an appropriate choice for a UAV interface. While this resolution does not provide an impressive amount of visual detail at smaller scales, DTED 0 elevation data for the entire planet is publicly available.

Based on feedback from domain experts, this interface was deemed insufficient for ground-based soldier needs. Therefore, the interface was modified to not only operate on a mobile platform, but also to incorporate currently used standard operating procedures (SOP) of the ASR process. The new interface contains a flow of action based on a paper ASR form that is filled out when a soldier needs a pickup or delivery mission in the field (Figure 10.1) [93]. The form includes various sections that are used to give human pilots a detailed description about the mission. The interface facilitates the acquisition of this data through sketch and touch and overlaps the sequential inputs wherever possible.



SECTION I – MISSION REQUEST

DATE

1.	This Is	Request Number	Sent Time By
2. Request for	☐ Helicopter	☐ Fixed Wing	

Received

Time

By

3. Mission Categories

A Preplanned: Precedence ____

B Priority

C Immediate: Priority____

4. Type Mission ☐ Tactical ☐ Administrative

5. Mission Is

A ☐Assault Transport	B ☐Logistic Support	C ☐Air Evacuation	D ☐Medevac
E ☐Aerial Delivery	F ☐C2	G ☐TRAP	H ☐SAR
I ☐Illumination	J ☐Special Ops	K ☐Other	L ☐VIP

6. Payload Is

A Troops ____

B External Cargo/WT ____

C Internal Cargo Wt/CU ____

Largest Item (LxWxH) ____

7. Instructions

	Pickup Time/Date	Coordinates	LZ Time/Date	Coordinates
A	____	____	____	____
B	____	____	____	____
C	____	____	____	____
D	____	____	____	____

8. LZ Description

A Wind Direction / Velocity ____

B Elevation ____ (FT MSL)

C Size____

D Obstacles____

E Friendly Pos ____ DIR/DIST ____

F Enemy Pos ____ DIR/DIST ____

G Last Fire Received Time/Type ____ DIR/DIST ____

9. LZ Will Be

A ☐Unmarked

B ☐Unmarked With Color ____

10. LZ Marked With

A ☐Panels B ☐Smoke C ☐Flares D ☐Mirror

E ☐Lights F ☐Navaid G ☐Other

11. Communications

A Pickup Zone Callsign ____ Frequency (Color Code) ____

B LZ Callsign ____ Frequency (Color Code) ____

Figure 10.1: Sample ASR form

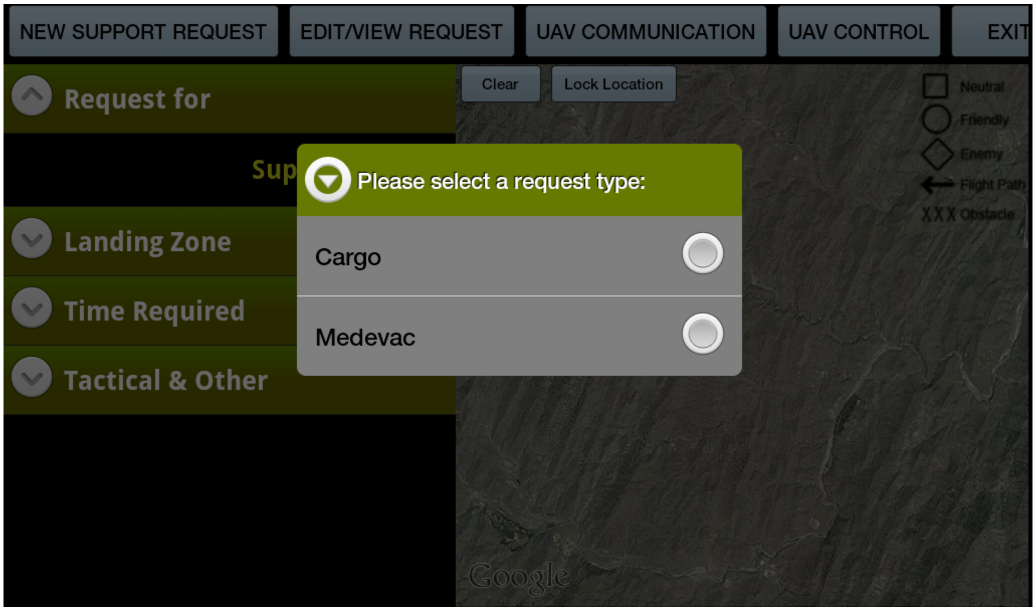
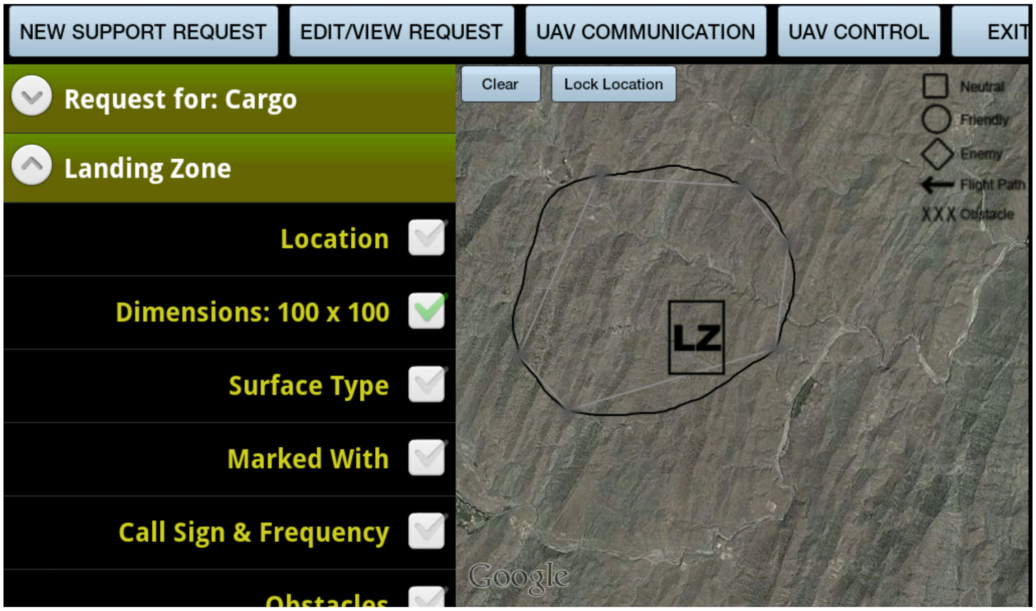


Figure 10.2: New support request

The mobile prototype solution includes a menu that corresponds to the sections of the ASR form and displays check boxes to keep a record of relevant information that has been retrieved either from the Android device or from the Soldier. Information from the device, such as the Soldier's location and the current time, are automatically saved and used to help provide information about the support request and/or describe the drop zone. The UI provides an interactive map (created using the Google map API) which originates at the device's current location and allows the Soldier to adjust the focus to his/her location of choice using one or two fingers to pan and zoom the map. The Soldier begins an ASR by selecting a support request type from the menu (Figure 10.2). If the Soldier selects cargo, he/she can enter a list of supplies and then proceed to entering information about the cargo drop location. The minimum information required for a cargo drop is *what, when* and *where*; additional information can be provided if available.



Request for: Cargo

Landing Zone

Location ☐

Dimensions: 100 x 100 ☑

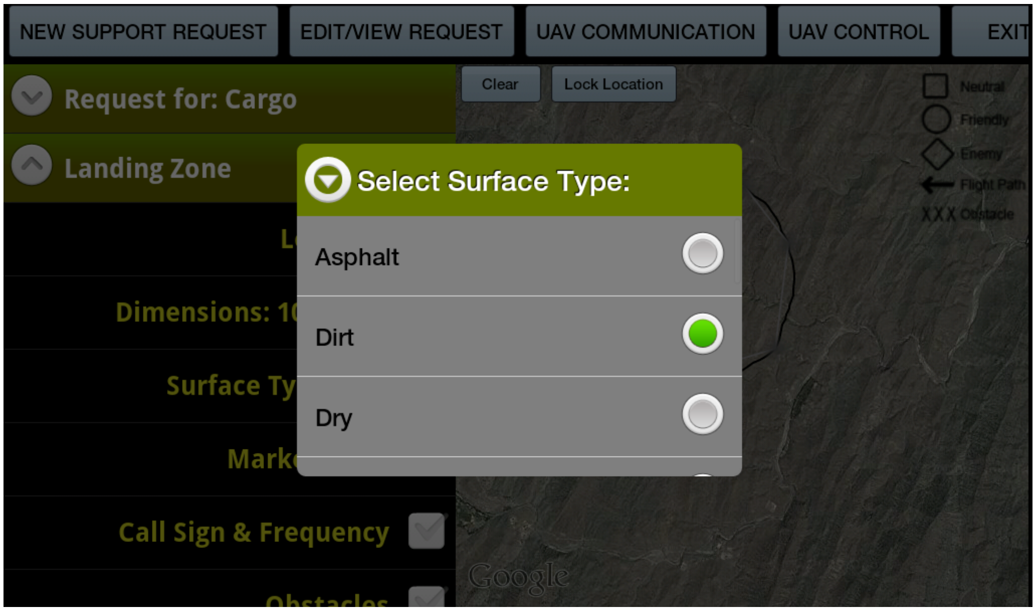
Surface Type ☐

Marked With ☐

Call Sign & Frequency ☐

Obstacles ☐

Figure 10.3: LZ area identified



Request for: Cargo

Landing Zone

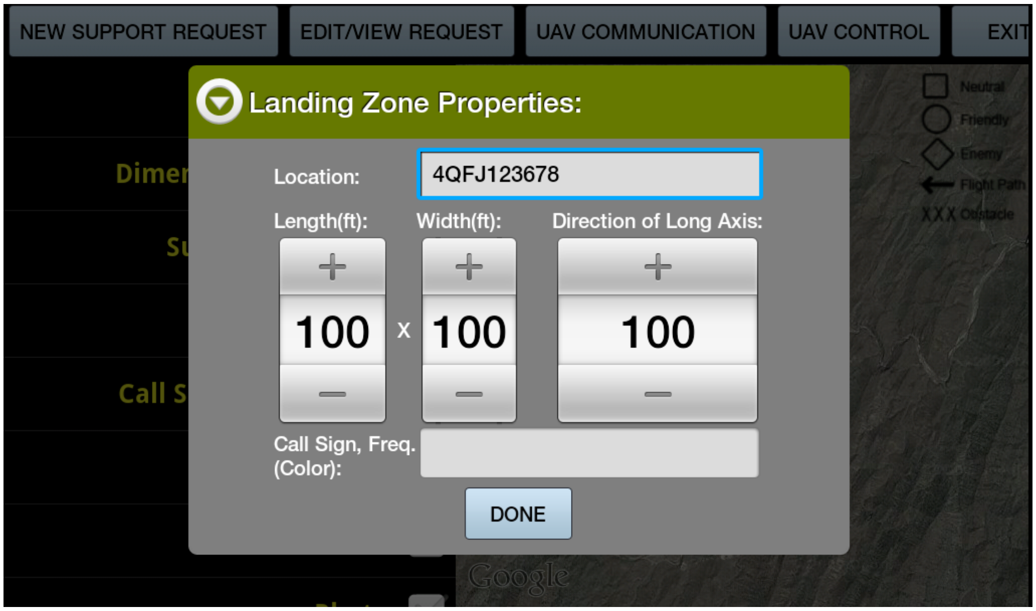
Select Surface Type:

Asphalt ○

Dirt ●

Dry ○

Figure 10.4: LZ surface area properties



Landing Zone Properties:

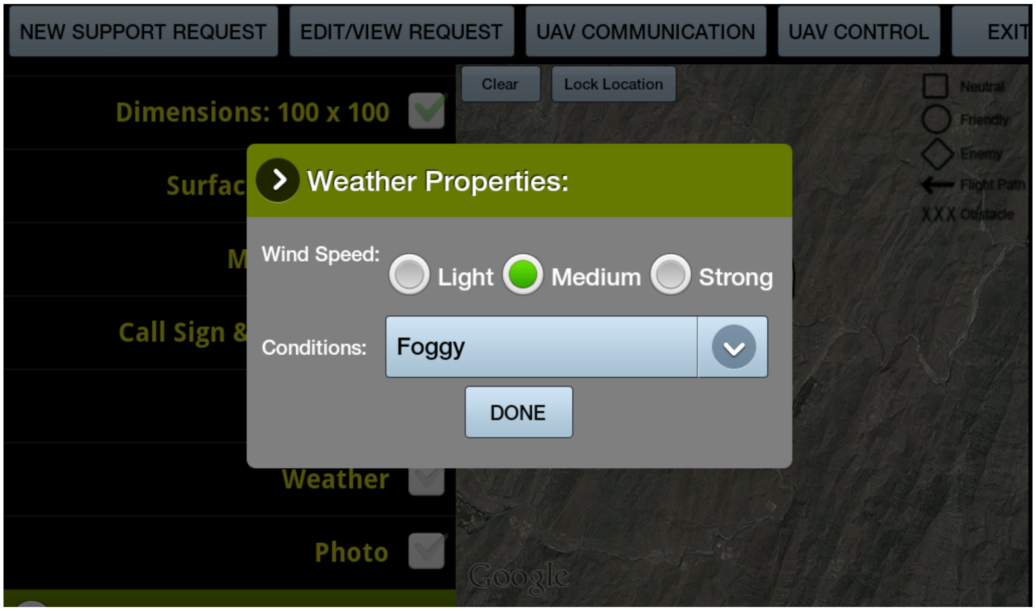
Location: 4QFJ123678

Length(ft): 100 x Width(ft): 100

Direction of Long Axis: 100

Call Sign, Freq. (Color):

Figure 10.5: LZ size and location properties



Dimensions: 100 x 100 ✓

Weather Properties:

Wind Speed: ○ Light ● Medium ○ Strong

Conditions: Foggy

Figure 10.6: LZ weather properties

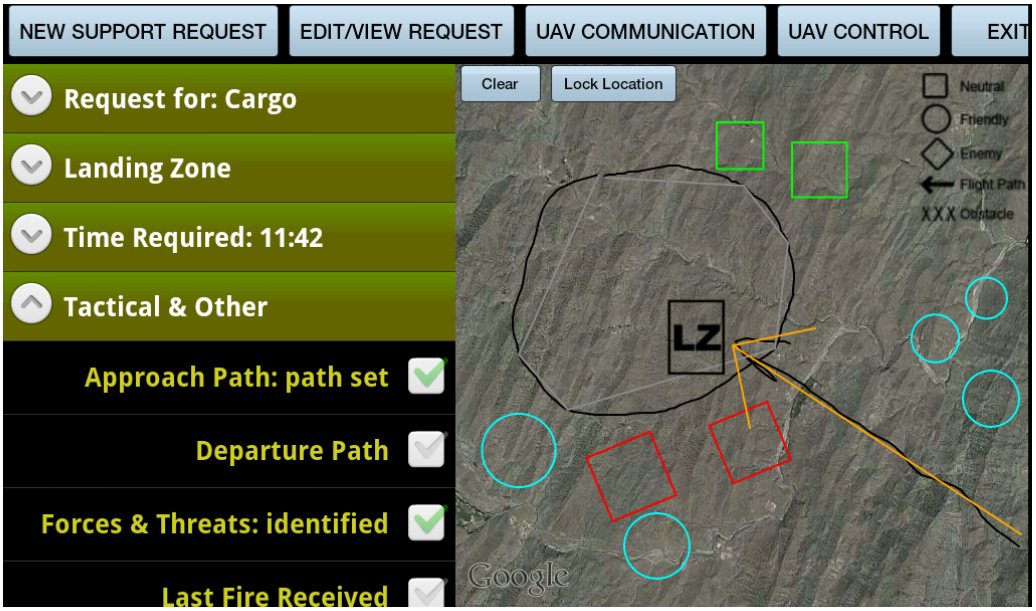


Figure 10.7: Sketched forces and flight path recognized

In the ASR form, the description of the landing zone is the most detailed element of the form and therefore requires the most amount of information and time to complete. Using our solution, a Soldier can use a stylus or their finger to draw an outline of the landing zone location relative to his/her position directly on map (Figure 10.3). This gives the autonomous UAV an overall region of land to validate for landing based on map terrain information. This is an immediate improvement over the ASR form which only allows the Soldier to identify the center and the size of the landing zone. The additional map terrain information can be useful in determining alternate landing zones based on variables such as enemy location.

After the Soldier specifies the possible landing zone area through a boundary sketch, he/she is presented with an icon representing the ideal landing zone that the Soldier can touch and re-orient within the drawn boundary. When released, the coordinates of the landing zone icon are saved as part of the ASR data. The landing zone icon itself functions as a separate interactive view; when clicked it provides a button menu interface that allows the Soldier to select properties of the landing zone area such as the length, width, surface type, weather and markers that will be used to identify the area (Figure 10.5 and 10.6). This information may be used by the UAV to facilitate tracking, targeting and landing functions.

The Soldier can then identify the location of obstacles such as buildings, trees, and fences by sketching Xs directly on the map and assigning properties (Figure 10.4). In addition he/she can identify the location of friendly, civilian and hostile forces by drawing circles, squares and diamonds, respectively, on the map (Figure 10.7). Once drawn, the images change to the corresponding COA symbol color: red for enemy, green for neutral, and cyan for friendly. This optional information may be used by the UAV to complete the mission and simultaneously avoid any potential threats.

10.1.1 Symbol Recognition

The primitive sketch recognition was implemented through PaleoSketch [98]. The interface contains a sketch panel object that listens for a stroke action and records each individual stroke as input. PaleoSketch finds and removes consecutive duplicate points from the stroke, and then a set of features, such as speed, direction and corners are calculated [139]. These features allow PaleoSketch to represent the original stroke as a set of polylines prior to recognition. Once this beautified shape is returned, Paleo proceeds to run a series of tests to identify low-level shapes. These shapes are then passed to high-level recognizer that can recognize the symbols used in our solution.

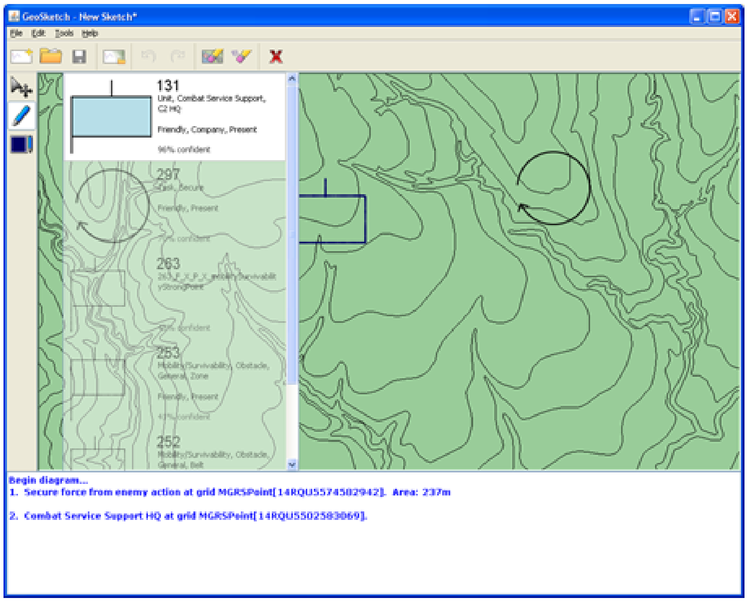
To determine if a stroke represents a landing zone area, or any closed figure, we compute the distance between the stroke's endpoints and divide it by the stroke length. This ratio must be less than some threshold (the level of constraint is depends on the usage) in order to identify the stroke as a closed shape. To determine if a primitive shape forms a rectangle, we take a group of strokes that create some polygon and assign each stroke to one of the four sides of the shape's bounding box. We then compute the feature area error metric as well as the ratio between the stroke length, the bounding box perimeter, and the ratio of the distance between the 2 furthest points on the stroke and the diagonal of the bounding box. The recognition of diamonds requires the same approach, we simply rotate the stroke 45 degrees prior to calculating the features.

To recognize the single-stroke arrow symbol, we first perform corner finding on the stroke which should produce 4 segments: one for the arrow body, two for the head and one retrace stroke to change direction on the head. We used the number of segments produced as one of the features, along with the ratio of the size of the arrowhead segments, the distance between the stroke point on the arrowhead and the stroke point on the arrow body.

For a circle we first calculate the average distance between each stroke point and the ideal center of the shape; this feature gives us the ideal radius. We then calculate the normalized distance between direction extremes (NDDE), this is the length of the stroke between direction extremes divided by the entire stroke length. We then verify that the shape is a closed shape, using the method mentioned earlier, and that the strokes NDDE value is high.

10.2 Evaluation

We conducted repeated evaluations of the UAV solution with initial interviewees from the ethnographic analysis to gain feedback on the UI and determine the validity of our sketch-based design principle. An early version of the solution had been developed to recognize the military course of action symbols outlined in the MIL-STD-2525B document (Military Symbols for Land-Based Systems) [30] (Figure 10.8).



Begin diagram...
1. Secure force from enemy action at grid MGRSPoint[14RQU5574502942]. Area: 237m

2. Combat Service Support HQ at grid MGRSPoint[14RQU5502583069].

Figure 10.8: Original sketch-input for mission planning

Soldiers and domain experts found the sketch interaction simple to perform because it provides the affordance of annotating paper maps, however, because they had not memorized all COA symbols, they were unable to recall the specific symbols needed to create an ASR. As a result, we simplified the sketch input by reducing the COA symbols to a subset relevant to the ASR scenario and that the Soldier can easily remember. We used three symbols from the MIL-STD-2525B document to identify forces, and two unique symbols (X and any closed shape) to identify obstacles and landing zones respectively. This allowed the Soldiers to still formulate complex missions, but without the concern for adding erroneous symbols. We also provided a key on the map in the interface to identify these symbols and their meanings. Subsequent evaluations with interviewees showed that, with this information provided, Soldiers were able to quickly sketch the landing zone, forces and obstacle information in various arrangements to create complex mission plans.

Once we had determined that the solution could be used to create mission plans, we conducted a user study to 1) verify that the sketch-based input method was easy to learn and 2) that the solution system allowed the creation of an ASR in a length of time comparable to the current SOP for completing an ASR. The participants were two employees of the U.S. Army that had flight and field mission experience and three ROTC cadets with mission planning experience. Unlike the interviewees and stakeholders from the previous evaluations, these participants had no previous exposure to the solution system and were not trained on how to use the interface.

Participants were given a mock field scenario where they needed to request air support for supplies. They were provided an aerial image of their location as well as the location of buildings and enemy and neutral forces in the area. Using this information, the participants were asked to walk through the following two scenarios to complete a cargo request: an ASR completion using radio-communication and an ASR completion using our solution.

In the Radio Scenario, one participant (behaving as the requestor) simulated radio communication to another participant (behaving as the pilot) who filled out a paper ASR form; this scenario was meant to replicate the SOP. During this exercise, the participants followed protocols for radio communication (FM 24-18 Tactical Single-Channel Radio Communication Techniques), however the participants were exchanging information within the same room, and therefore communication was easier than a live radio situation. Next, participants were asked to perform the same scenario using our sketch-based solution. Upon completion of the exercise, participants were presented the following questions to evaluate the solution. The results of their responses are shown in Figure 10.9.

1. Were you able to complete the request using the system?

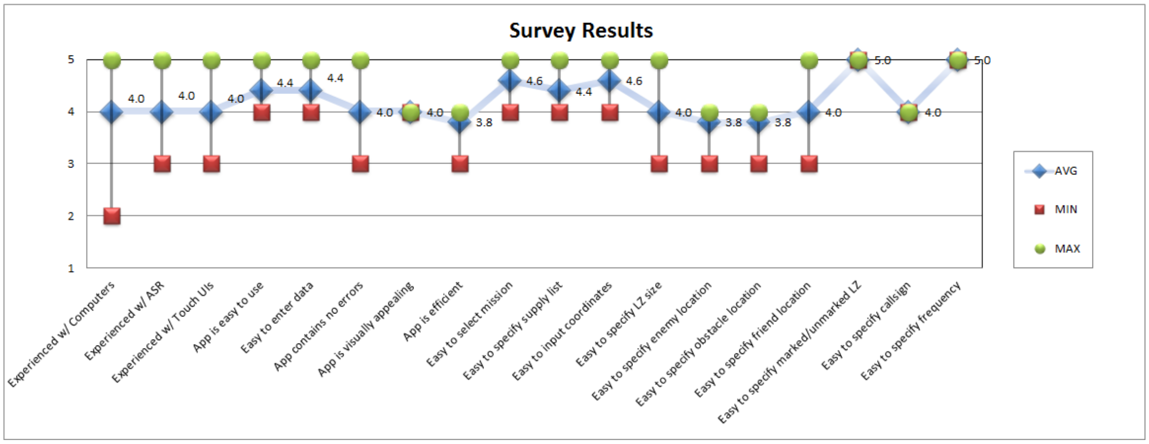


Figure 10.9: Questions 3-10 ask the participants to assess their level of experience with technology and comfort with the software (a level 5 rating signifies the most experience with the technology mentioned or a high level of agreement with the statement presented). Questions 11-20 ask the participants to assess the simplicity of completing the various scenario tasks using the sketch-based solution (a level 5 rating signifies "very easy").

2. How much time did you spend making a request using the system?
3. You have previous experience with computers. (using standard Likert 1-5 for questions 3-20)
4. You have previous experience with military aerial request forms.
5. You have previous experience with touch interfaces (iPads, Android phones, tablets, palms).
6. The software was easy to understand and use.
7. The software allowed me to input all the relevant information for the request.
8. The software did not contain major bugs or crashes.
9. The software is visually appealing.

10. The system is efficient to use and could prove useful in real-life critical missions.
11. Select mission type.
12. Specify supply list.
13. Specify landing zone coordinates.
14. Specify landing zone size.
15. Specify enemy's location.
16. Specify obstacle locations.
17. Specify friend's location.
18. Specify marked/unmarked landing zone.
19. Specify pickup zone callsign.
20. Specify frequency (color code).

Questions 6,7 were used to evaluate the overall usability of the solution. On a scale of 1-5 (with a level 1 indicating “strongly disagree” and level 5 indicating“strongly agree”) participants gave the solution an average rank of 4.4 on the solution being easy to use and allowing them to input all information needed for the request. Questions 13-17 specifically were focused on determining how well the participants learned to input the mission planning symbols without training or guidance. On a scale of 1-5 (with a level 1 indicating “very difficult” and level 5 indicating “very easy”) participants gave the sketch-based interaction an average rank of 3.9. This shows that overall the participants felt it was easy to learn how to complete the associated tasks by using sketch input.

After completing the questionnaire, participants were lead in a group discussion to obtain additional feedback, specifically discussing a comparison of the radio communication vs. the sketch-based solution. Every participant that evaluated the prototype solution was familiar with the contents of the ASR form. As a result, many of them completed the sections in order of importance rather than in order of the menu options. Because we designed the flow of the interface to allow for non-linear data entry (*i.e.* the information can be input in any order), they were very satisfied with the menu interaction. Soldiers stated that they were also very comfortable using the touch screens since most of them either owned or had used a smartphone with a touch screen prior to the study. Soldiers also stated that once they were given the scenario, it did not take them long to understand where and how the data needed to be entered into the system; pop-up messages that gave information on input modes available for each step helped with this task.

Participants completed the task using our solution within an average three minutes of the time it took to perform the radio scenario. However, during the radio scenario, we noticed that several pieces of information had to be repeated, even though the participants were in the same room. Soldiers stated that repeating information was fairly common in radio communication. For this reason, we expect a live radio scenario to require the same amount or possibly even more repetition. Additionally, given that the ASR data will need to be entered into a digital form in a live scenario, the expected time savings will be greater.

Overall, the Soldiers that participated in our user study and in the previous evaluations of the final solution stated that the interface was very intuitive and easy to use. During the user study, Soldiers were able to sketch COA symbols as part of mission planning input for an ASR, with no prior instruction; this observation and their evaluation data supports the design principle that sketch serves as an easily-learned interaction method for mission planning, once the required input symbols are made known.

In addition to validating this design principle, by providing a sketch-based interface for autonomous aerial vehicles we:

1. created a novel interface that interprets sketch on an interactive map as a means of creating a mission planning narrative.
2. allowed for easy control and navigation of autonomous drones without the need for piloting experience.
3. increased the level of awareness for the Soldier in the field by providing information regarding all team components.

11. SUMMARY

In this dissertation we have explored the challenges to team coordination experienced by Soldiers and other persons that operate in high-stress, hazardous environments. We have conducted an ethnographic analysis of the Soldier and explored multiple interaction methods to provide an overall solution to this common set of challenges and learn how to use technology to enhance team coordination on the battlefield. This investigation has resulted in the contributions described below.

11.1 Ethnographic Analysis of Soldiers

Although our solution was focused on paratroopers, the solution could also be useful in non-combat scenarios. For example, U.S. Paratroopers were instrumental in the United States' response to the earthquake crisis in Haiti in 2010. In crisis response situations like this one, where responders can include Soldiers, firefighters and/or medical personnel, a solution system that addresses the needs described in the following sections would allow support forces to locate airdropped food and medical supplies, coordinate team tasks, maintain awareness of team status and effectively provide relief quickly overall. Through an analysis of the Soldier, we were able to gain detailed information about and experience tasks related to their job first-hand. This study allowed us to identify specific problems to address common challenges to coordination that may be shared by other teams that operate in this domain and discover an optimal solution to meet their needs as a whole in today's hazardous environments.

11.2 Improving Team Assembly

We used the information collected during the ethnographic analysis to establish principles regarding how technology can best be used to assist team assembly on the battlefield. The solution system was a light-weight, cost-effective replacement for the Stiner Aid that meets all military requirements and enhances team coordination by decreasing assembly time during time-critical missions in the field. The solution was readily accepted by Soldiers because the multimodal interface builds on existing navigation practices and allows each user to control the amount of data delivered. The solution also contributes an MGRS standard map to display graphic representations of a beacon network as well as a novel ad-hoc notification system that can be used to connect large groups. As a result, the solution can easily be adapted to other domains which require an established dynamic, ubiquitous and effective communication medium for large-scale coordination efforts, and more specifically in situations where there is a high demand for information (contained within small amounts of data) by a large amount of people.

11.3 Increasing Situational Awareness

We provided a solution to increase situational awareness by enhancing the data visualization method for our solution. The use of augmented reality (AR) serves as an optimal data visualization and feedback medium to decrease the cognitive load on the individual Soldier. An AR view fed through a head-mounted display (HMD) or an Android receiver clipped to weaponry allows the Soldiers to have their hands free to perform other mission-critical tasks which benefits team performance. And an uninterrupted line of sight contributes to increased awareness on the battlefield; navigation information represented as a simple graphic of a target location in augmented reality does not compromise the Soldier's attention on their current task.

11.4 Identifying Teammate Events

We used physiological data and color coding to create status alerts and enhance awareness of the entire team. We maintained hands-free interaction and increased team coordination by making it possible for team members to to provide assistance to a teammate in danger. The presented solution turned each receiver into a beacon to allow tracking of individual team members, monitoring of their physiological data, and communication via the beacon network, all without the need for direct interaction from the user.

11.5 Continuous Teammate Awareness

In an effort to prevent information overload, we used haptics as a feedback medium to provide continuous awareness of teammate status. The solution enhances team coordination by improving team connectivity through arousal synchronization. We created a simple method for a constant exchange of status information between teammates using a haptic vest or through the vibration feature on the Android receiver. We sought to provide a method of preventing long-term effects of stress (such as PTSD) by allowing team members to process varying levels of feedback corresponding to a physical reaction to stressors that a teammate may be experiencing.

11.6 Investigating Affective Awareness

We push the depth of information obtained from the physiological information exchanged to provide a greater level of team awareness. To do this, we implemented a method of classifying physiological signals in real-time in order to create a visualization of the user affective state. We used data from skin conductivity, EKG, EEG, temperature, respiration and heart rate sensors to perform emotional classification to attain a more accurate user state. During this investigation, we discovered significance in sketch-based features, Direction Change Ratio (DCR) and Nearest Distance between Direction Extremes (NDDE), indicating that there may be value in the application of these features to biosignal data classification.

11.7 Enabling Human-Drone Team Coordination

Since warfighter teams may not always consist of human soldiers, we explored a solution to address team coordination between human and machine team members. We used sketch recognition to create an intuitive human-drone interface that accepts natural drawing as input for creating a mission planning narrative. The solution allowed for easy control and navigation of autonomous drones without the need for piloting experience and increased the level of awareness for the Soldier in the field by providing information regarding all team components, including drones.

11.8 Conclusion

This dissertation has presented a thorough investigation into the challenges to team coordination in hazardous environments. This study has lead to the development of a solution system whose design was heavily influenced by today's battlefield scenario and Soldier activities, and the discovery of design principles for technologies created to enhance coordination for these teams. This research has contributed to the corpus of current military research with a focus on providing an overall model to mitigate the challenges to team coordination as opposed to simply creating a technological aid for specific tasks. Although the scope of this work is largely focused on improving team coordination for Soldiers, future research efforts geared at supporting all areas of disaster team navigation and coordination tasks will likely benefit from the informed application of one or more of the solution technologies presented herein.

12. FUTURE WORK

Discovering the best way to use technology to support team coordination is an on-going challenge. The solutions to this problem will change as more advanced technological tools become available. However, in the near future, continuous investigation into the interaction design principles discussed in this dissertation will be beneficial when applying similar solutions to other domains.

12.1 Battlefield Testing

One immediate future effort will involve an extensive real world testing of the solution system. We were able to perform a complete user evaluation of the system through simulated drops at Ft. Bragg, however we one day hope to conduct a comparative study that will evaluate the effectiveness of GeoTrooper against the Army's current assembly procedure. Although we have data for average assembly times using Stiner Aids, we want to conduct a live comparative study by tracking the total assembly time and navigating performance of a group of Soldiers using the GeoTrooper system and compare it to a group of Soldiers using Stiner Aids. This data will provide valuable evidence as to the overall effectiveness of the system in regards to improving team coordination and assembly time.

In addition, equipment and safety limitations prevented testing on an actual battlefield; we weren't able to acquire 2,000+ phones to test in a live drop scenario. However, based on the final demonstration at Ft. Bragg, the solution was deemed ready for possible reproduction through a government contractor. Through this effort, it may be possible to obtain this data via extensive product field tests. Conducting an exercise with every Soldier using the system would provide information regarding the stability of the ah-hoc communication network and the rate of information dissemination throughout the system. Also, a live test with over 2,000 Soldiers would allow for an in depth investigation of task reallocation on a much larger scale, which, as discussed in Chapter 7, is manageable within a single unit, but presents a significant problem for an entire paratrooper corps.

12.1.1 UAV Interaction

In the near future UAVs may be used in place of road convoys and manned helicopters to perform various field support missions. As a continuation of the prototype solution developed for interacting with UAVs we one day hope to perform a field study to evaluate the interaction methods presented with an actual autonomous UAV. At the time of initial development, this was not possible due to FAA regulations and access to equipment currently under development by Boeing and Lockheed.

In addition, we hope to explore forms of interaction other than the ones presented in the prototype. For example, if the battlefield scenario does not have noise constraints, we plan to apply additional modes of input such as speech recognition since Soldiers are used to interacting with convoys and helicopter pilots via (voice) dialog. These factors point to a dialog framework where the UAV and the human "converse" with each other instead of a more traditional supervisory control framework. This places the UAV in more of a peer-to-peer teaming relationship rather than a master-slave relationship. Given the projected high level of autonomy for the UAV, it is reasonable to assume that it may be able to initiate interaction with the Soldiers; this interchange may involve the UAV requesting clarification of previous communications, additional information if not enough was provided to compute a flight route, and/or updated information as it is en route, *etc.* It will be useful to also be able to analyze conflicting instructions or instructions that might put the UAV at risk and seek clarification from the Soldiers and to ignore certain Soldier instructions if they appear to be erroneous.

12.2 Affective Visualization

Chapter 9 presented data on the early stages of research into affective visualization through AR. A thorough investigation into the effects of this visualization in live scenarios as it relates to the long-term impact of heightened stress is still needed. For example, we must find a way to determine whether or not sharing affective information does in fact allow for intervention when signs of PTSD are present in a battlefield scenario. However, continuous research into optimal methods of near real-time emotion classification is required for this study to become a reality. In the interim, existing user event classifications, as discussed in Chapter 7, could serve as a way to explore this area now.

12.3 Haptic Interaction

In addition to AR, our current research has also shown that haptic feedback can be used to provide detailed information while maintaining situational awareness. The complexity of the data that can be delivered via haptic feedback is currently being investigated by Manoj Prasad, research member of the Sketch Recognition Lab [101]. Depending on the amount of data that can be received and understood by a single user, it would be beneficial to determine how this technology can also be used in a live battlefield scenario to transmit tactical messages between teammates to increase team coordination.

12.4 Solutions for Firefighters

Firefighters are another group that will benefit from the solutions discussed in this dissertation, which is why we've begun preliminary ethnographic studies with firefirghter teams at the Brayton Fire Training Field in College Station, TX. Firefighters operate in hazardous environments where visibility is severely limited due to fire and smoke. A solution system that could provide information regarding exit locations and the location and status of team members could aid team safety and coordination. However, their problem domain differs from that of the paratrooper in that not only are the team members in potential danger, but the equipment is also exposed to conditions and temperatures that could be damaging. Therefore, additional research into the fortification of a solution system is warranted to meet the needs of this team. Once explored, our solution would have the potential to be applicable to most teams that operate in high-stress hazardous environments with minimal customization.

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APPENDIX A

Other Related Work*

The following chapter provides detail on the various parent projects that have been implemented in order to analyze the effectiveness of certain types of interaction modes. The work presented here has been instrumental to determining the best combination of technologies for the solution system. These efforts also serve as low-stakes implementations of the technologies for the purpose of gaining knowledge and evaluation data.*

A.1 AR and Mixed Reality Interfaces

A.1.1 MathModelAR

In the U.S., standardized state achievement tests are used in public schools to assess levels of academic proficiency in students. These tests are also used to measure the quality of individual schools' academic programs and, in some cases, to determine the amount of federal funding received. Although standardized tests can be used to evaluate the effectiveness of an academic program, they have often been criticized for the negative influence that they can have on the learning process in schools. When standardized tests become the primary tool for evaluating a school‘s success, there may be a tendency to focus instruction on how to pass instead of how to think.

In this project, Augmented Reality (AR) is used to create a tool to engage students in discovery learning activities in order to prepare them for the Mathematics portion of the Texas Assessment of Knowledge and Skills (TAKS) test. The material

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*Reprinted with permission from "I Dont Believe My Eyes! Geometric Sketch Recognition for a Computer Art Tutorial" by Cummings, D., Vides, F. and Hammond, T., 2012. Proceedings of the International Symposium on Sketch-Based Interfaces and Modeling, 97-106, Copyright 2012 by Eurographics Association on standardized tests often receives more, if not all, of the focus of classroom activities [56]. As a result, the curriculum develops into a narrow range of topics where knowledge exploration becomes almost non-existent. In this type of environment, it can be hard to engage students in the material especially if they are studying to retake the test. By presenting the same material as interactive models or simulations, we created a learning process in which students begin to explore the basic concepts of the material in addition to receiving organized instruction. This tool incorporated discovery learning into TAKS preparation activities by allowing students to physically interact with visual representations of selected topics thereby promoting a collaborative analysis process. Group discussions centered around these representations were the primary method to prepare students for the reading and writing exercises, as well as the mathematics and logical questions on the TAKS practice test.

The purpose of this research project was to study the effects of interactive technology using AR and collaborative learning. Our goal was to explore the relationships between the students and their learning process in order to find new ways to enhance the group learning experience with technology. We also wanted to gain experience in implementing an AR interface and information related to its effectiveness as a data visualization medium for learning. This project was performed through a partnership with the Interface Ecology Lab at the Texas A&M University and the Math department at Hempstead Senior High School in Hempstead, TX. The first phase of the project involved volunteering in the standard Junior and Senior math classes twice a week in order to gain a thorough understanding of the curriculum and the learning objectives.

Each class is instructed using study guides and practice tests provided by the Texas Education Agency. Therefore the curriculum largely involved the class performing practice problems either as a whole or in small groups. If problems were attempted by the whole class, the instructor would prompt the class with leading questions and allow the students to walk him/her through the logic to complete the problem. This activity would be followed with a question and answer session, and additional clarification when necessary.

To integrate AR into this domain, we first studied the wide range of TAKS practice tests to find problems that would be good candidates for incorporating graphic models. The purpose of adding graphic models is to assist with the conceptual visualization of the problem. The easiest approach was to create a 3D graphic representation of a 2D image provided for questions. For example, many of the problems provided a picture of a 3 dimensional object and asked the student to visualize the 2D shapes that could be combined to produce the 3D object. This task was difficult for some students because they had trouble visualizing all angles for the image from the 2D representation provided. Previous research has identified a stronger association between pictures and learning than words and learning [110]. 2D image presentations of the problems do not provide a full representation that would allow students to progress and visualize the same image in 3D in their head.

We attempted to address this problem by creating, MathModelAR, an AR interactive system that allows students to view and interact with 3D model representations of their subject information. We recreated TAKS practice worksheets from existing preparation aids and replaced the geometric images and graphs with fiducial markers. We created 3D graphic models using OpenGL and then ARToolkit was used to assign models to the markers [4]. When the worksheet was viewed through a camera (or a head mounted display unit) connected to a computer running MathModelAR, the program would project the model related to the problem on the worksheet (Figure A.1).

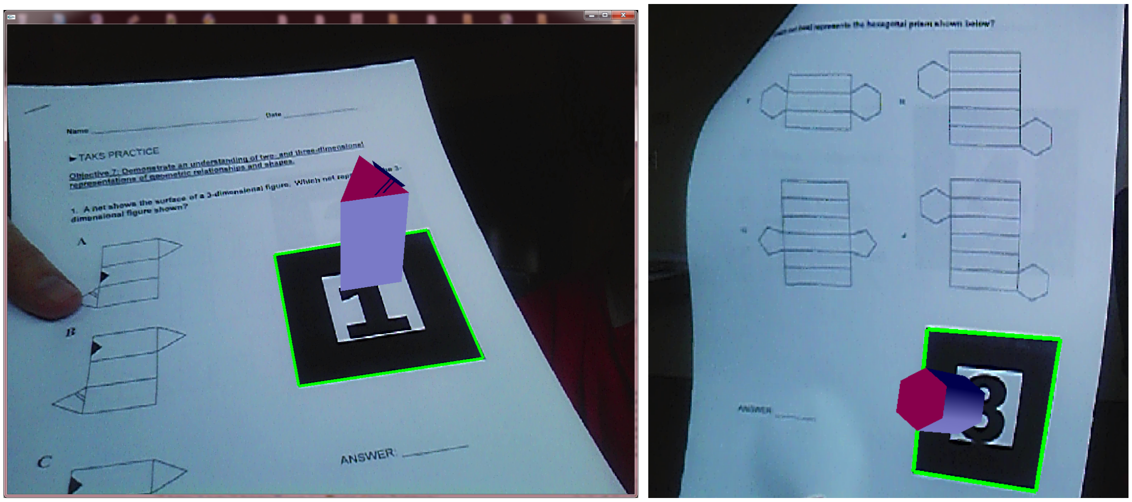


Figure A.1: MathModelAR problems

We deployed MathModelAR in two separate Math classes at Hempstead Senior High School. The classroom was equipped with a 40 inch display monitor (owned by the school), a computer running MathModelAR and a webcam. During the first interactions, the instructor would present the problem to the class on the monitor by holding the worksheet in front of the webcam; this process was very similar to the previous way that the instructor presented problems to the class on an overhead projector. The class would then attempt to solve the problem as a group with leading question provided by the instructor. The second scenario mirrored the group interaction method: students were assembled into small groups and asked to work on the practice problems on their own. During this iteration, each group was given a copy of the original worksheet packet; the groups would come up to the display, one at a time, to work on one problem from their packet using MathModelAR while the other groups did the same using the original packet. After each iteration, the classes were lead in a group discussion to gain feedback on the system and to evaluate their understanding of the mathematical concepts presented in the lesson.

The program was used in conjunction with the regular course curriculum over the course of 2 months (3 classes per week). We observed each of the class sessions and found that the inclusion of MathModelAR in this scenario prompted students to be more vocal during classroom discussions. Originally this manifested as requests to the instructor to reposition the worksheet at various angles to allow full view of the models on the display screen, and this, in turn, led to more discussion about the problem. During the group practice, the students became more involved with the system and often requested to take control of the camera to display the model to the group. The instructor allowed this, and the surprising affect was that students controlling the camera would also begin the discussion with their thoughts. Overall, we believe that the addition of MathModelAR prompted the students to be more engaged in their preparation activities when compared to previous classes using the traditional curriculum.

The purpose of building this prototype was to solely evaluate the use of AR as a means of enhancing learning through data visualization. However, this type of system has various other contributions that can still be explored. For example, one working hypothesis is that students in the selected classes will be more inclined to explore their TAKS topics as opposed to other classes conducting traditional preparation activities. As previously mentioned, we believe that the use of AR as a teaching tool increased the level of interest in test preparation exercises for the 3 classes we observed. However, additional testing and observation of more classes is needed to verify a correlation. Another hypothesis is that the students using MathModelAR will show a higher overall improvement in their TAKS test scores compared to other classes who use traditional preparation materials. Proving this theory is feasible with additional access to tests and practice tests scores. This additional information could show whether or not a system such as MathModelAR could contribute to a valuable increase in performance on the TAKS practice tests.

Using AR and visualization in instructional technology will provide students with the tools to develop mental models of the concepts they are required to learn. These mental models can then be re-applied on a larger scale to facilitate learning of more complex concepts. In addition, MathModelAR is an interactive learning environment that is both easy and fun to use, and can be implemented at a fairly low cost. As a result, the system could contribute to Texas Education Agency's goals outlined in the progress report on the long-range plan for technology with a low impact to the Hemptead ISD budget. The broader impact is the transformation of a specific learning approach grounded in repetition and memorization into a discovery learning process that's both engaging for students and applicable in many areas of education.

A.1.2 GroupGraffiti

Our research in augmented and mixed reality also lead to the development of GroupGraffiti. We created a system to allow students to collaborate and create a mural of images that could only be viewed by scanning RF markers. GroupGraffiti is an Android application that allows social networking through the collaborative creation of graffiti art in an mixed reality environment. With GroupGraffiti, users are able to create or join different social groups and view, create or modify visual content attached to physical markers. As a result, physical locations are capable of hosting various artistic content uploaded by different users. With these features, GroupGraffiti provides a collaborative and dynamic community art space while preserving the appearance of public places.

GroupGraffiti (GG) addresses these natural human inclinations by combining two features: "post anywhere" artistic expression and filtered sharing between friends. GG uses mixed reality to allow users to produce virtual artistic content limited only by their creativity, and share that content on any physical surface with a group that they define. GG maintains the essence of real graffiti by overlaying images on top of the real world view produced by the mobile phone camera and allowing artists to draw directly onto real-world surfaces; then, GG allows that content to be displayed to all applicable groups, as specified by the artist. Our proof of concept application will provide the capability of dynamic art creation. It will be the artist's choice, to contribute or edit the original post, and this approach will lead to a unique collaborative content creation mechanism.

We hypothesize that with the integration of social media, group interaction and mixed reality, the general public will become more aware and enthusiastic of such a promising platform. While our main objective is to create a fundamental framework for social content-driven mixed reality, we are motivated to show an actual use case of such framework via an art application. GG provides a new medium for street art without negatively impacting public spaces and provides users with a method for public artistic expression on a grand scale. GG also has the potential to be used as a tool to allow teammates to post secure messages in public places. For example, if a teammate wanted to leave mission instructions for team members located at a specific point in the navigation path. A more robust version of this system has been presented for implementation in subsequent Capstone courses with favorable response.

A.2 Sketch-based Interfaces

Through the development of MathModelAR, we discovered simple ways to enhance the learning and sharing process through data visualization and concept modeling. GroupGraffiti also promoted social interaction through artistic sharing. The presence of art and artistic expression can serve as an influence to who we are as scientists and researchers [40]. Art can be seen as a form of communication and a means of expressing one's interpretation of the world. We all aren't born with the skill or have the time to learn how to accurately interpret and reproduce what we see around us through drawing. While the task of learning how to draw perfect reproductions of all what we see may be improbable on a large scale and within a small time frame, it may be possible on a much smaller scale and with the aid of technology. Numerous books and websites have been written to explain in detail how to draw various objects through step-by-step drawing tutorials [81, 118]. As sketch recognition algorithms and technologies become more sophisticated, it is now possible for a computer to watch a human draw, use sketch recognition techniques to identify what the human is trying to draw, apply difference classification algorithms to determine the accuracy of what they are drawing, and then use this information to provide realtime interactive feedback. We have decided to explore this theory by focusing on how to draw one of humans' most expressive features: the eye.

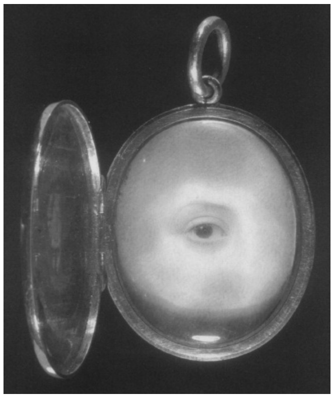
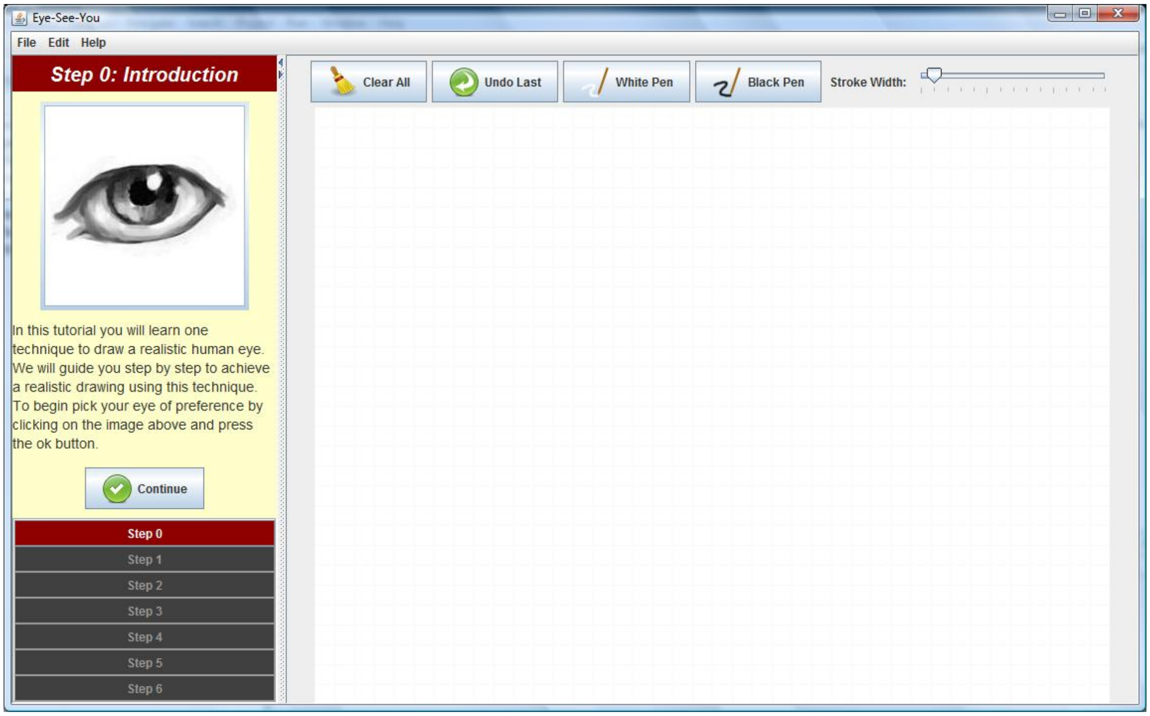


Figure A.2: Eye portraits encased in small jewelry, such as pins and rings, were popular in the 18th century, often used to mourn loved ones. Cosway, The Eye of Mrs. Fitzherbert, ca. 1786. (Photographic Survey, Courtauld Institue of Art).

The significance of the eye in communication can be seen through popular art forms of the 18th century [39]. A method of portraiture emerged that consisted of small miniature paintings of the eye [50]. These unusual portraits were often mounted on pins, brooches, rings and other keepsake items and exchanged between friends, family and lovers as a sign of affection. In some cases, eye portraits of the deceased (called mourning jewelry) were kept in remembrance of loved ones. An example is shown in Figure A.2. Although short-lived, the popularity of this type of portrait gives us insight into the importance the eye has in conveying specific meaning relating to both the subject (the owner of the eye) and the viewer. It's not the still image of the eye, but more importantly, the gaze that holds meaning and context for the viewer. In the case of eye portraits, the image of an eye would hold less meaning to someone who did not recognize it. As a result, each portrait had a very private and intimate affect on their owners. While this method of portraiture is no longer prevalent, we chose the eye as our subject of interest because of the simplicity of the drawing method in conjunction with the overall impact of such a small image.

Identifying basic structures and shapes within life and recreating those shapes through various methods is the basis of most technical drawing instruction [96, 138]. A proper representation of these structures falls under the drawing approach taught by most art teachers and summarized by the phrase ”draw what you see, not what you know” [33, 80]. The meaning of this direction is to overcome the urge to draw the shape that the mind determines is correct and to instead draw the shape that is actually seen.

A novice artist can reference an extensive collection of videos and how-to literature focused on improving artistic skills. Many manuals have been written focusing on a similar approach of breaking down drawing techniques into steps that can be



In this tutorial you will learn one technique to draw a realistic human eye. We will guide you step by step to achieve a realistic drawing using this technique. To begin pick your eye of preference by clicking on the image above and press the ok button.

Figure A.3: EyeSeeYou interface

self-taught [28, 97]. However, as is often the case with how-to drawing methods, the final result is only as good as your ability to accurately recreate the progressive images.

Without direct observation and guidance from an instructor, a novice artists may find it difficult to realize when they're making a mistake; when they do realize, there is usually no guide to show them how to get back on track. In order to address this problem we took a simple technique for drawing an eye and developed a system that would provide feedback on how well the user follows this technique; this system is called EyeSeeYou (Figure A.3).

EyeSeeYou is a pen-based system that uses sketch recognition to provide helpful feedback to users based on their drawing. As no two freehand drawn sketches are alike, accurately recognizing hand-drawn sketches is difficult. By walking the user

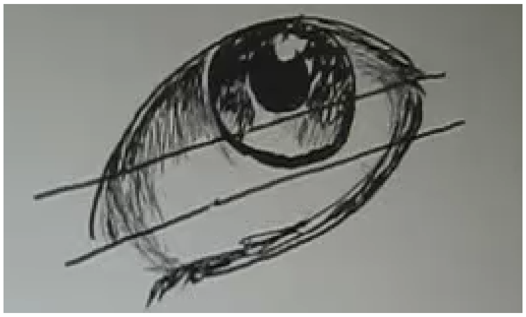


Figure A.4: Sample eye drawn with the EyeSeeYou system.

through a step-by-step drawing process similar to those found in paper-based drawing tutorials, the system is able to remove ambiguity in terms of the user's intention, and provide informative and useful feedback. The system allows users to sketch their drawing as they would with paper, enabling the user to learn a particular technique defined in a series of steps, while making sure the user follows the instructions at each step, so they can later reproduce the same technique in their drawings.

The EyeSeeYou application uses a geometric-based approach to recognition; it uses a low-level recognizer called PaleoSketch [98] to identify primitive shapes such as lines, arcs, ellipses, spirals, *etc.* The system uses a set of guidelines and constraints to verify that the user draws elements of the eye proportionally and in correct relation to each other. If the procedure is followed correctly, then the result should be a structurally correct eye that can then be enhanced similar to the one shown in Figure A.4.

The main challenge in the creation of the system was to find a balance of constraints that would allow the system to deliver constructive feedback while at the same time preventing user frustration from over-correction. In order to accomplish this task we attempted to create a systematic approach to drawing the eye by breaking it down into simple steps that can be completed fairly quickly and with reinforcing feedback that both helps the user to identify where his or her drawing could use improvement. We also wanted to reinforce progress made toward the production of a realistic eye with positive feedback.

An initial challenge was to determine how strict the constraints for the drawing task had to be. If they were too loose the final result may not be sufficiently realistic, but if they were too strict they may have an adverse affect on the user user experience as it may become too difficult to advance at each step.

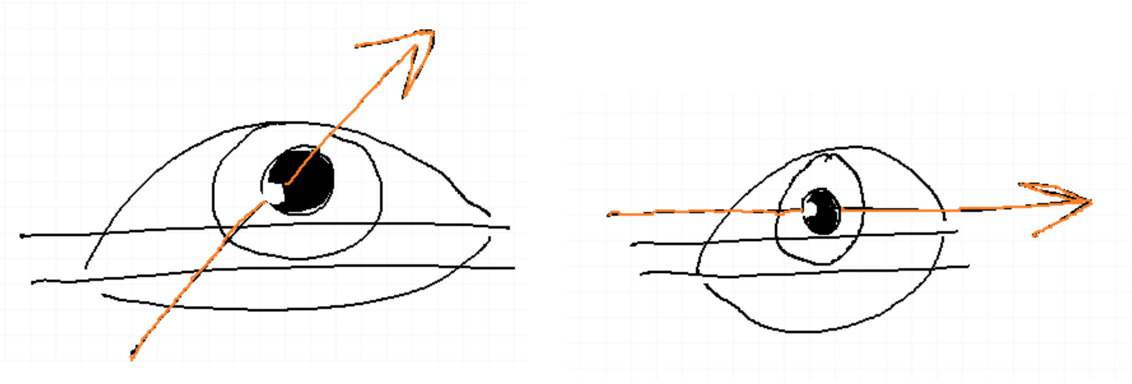


Figure A.5: Two very different, but correctly shaded eyes in EyeSeeYou

An additional challenge involved trying to guide the artist while still allowing a level of sketching freedom so as not to impede the creative process. Our intention was not to force user to create exact reproductions of the example image that is given, but instead, we want to provide them with the techniques to create their own image of an eye that is proportionally accurate. The images that we obtained after evaluating our software show that although the eyes drawn by each of the participants may be similar, the level of detail and individual features are still unique.

As mentioned in the chapter on Previous Research, similar systems like iCan-

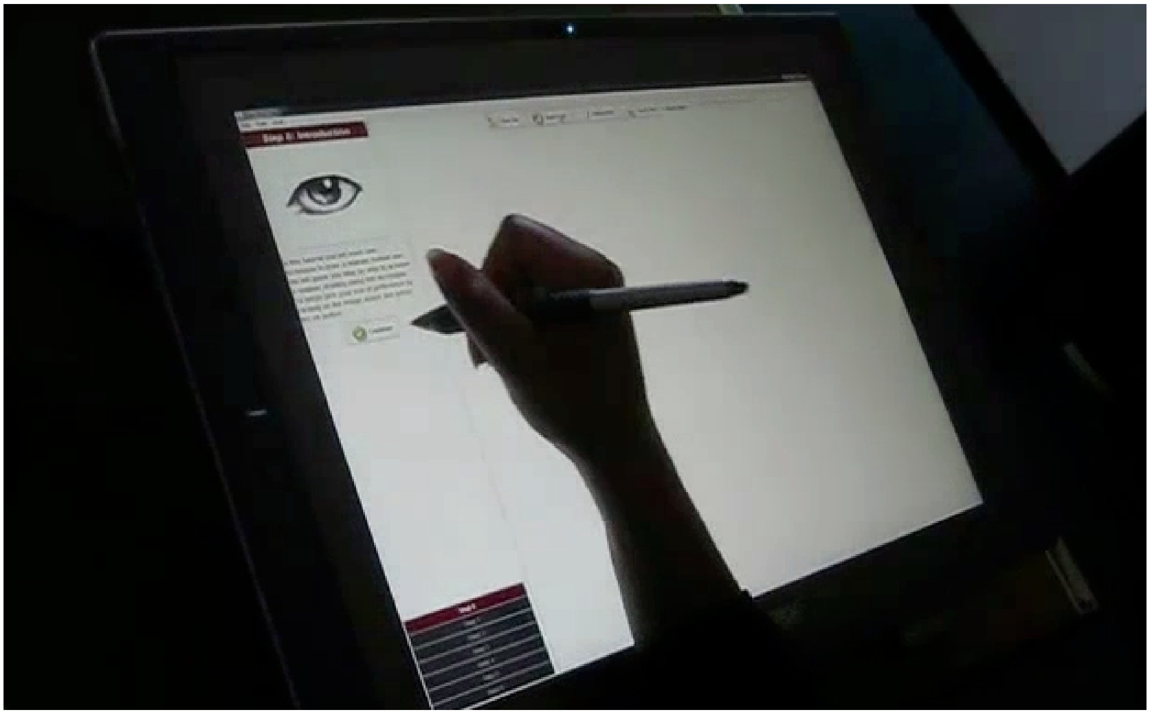


Figure A.6: Wacom monitor with pen input

Draw rely on template matching for most of its recognition. This is perhaps the major difference with EyeSeeYou, where no explicit template is used. Instead, a set of geometric constraints are defined for each step allowing the user to draw any eye as long as it follows the specified constraints. The added benefit of using constraints over template matching is that an original drawing is not required as a baseline for comparison, this frees the user from being confined to reproduce a specific image. In this sense, our approach conforms more to a style of drawing instruction that encourages free-form drawing while adhering to general rules of aesthetics. EyeSeeYou does not force the user to reproduce the sample image given, but evaluates various images correctly as long as they follow the guidelines given. For example, the lighting reference lines can be in any direction as long as the reflections and shading on the iris are in agreement (Figure A.5). The goal is to teach the concepts behind drawing

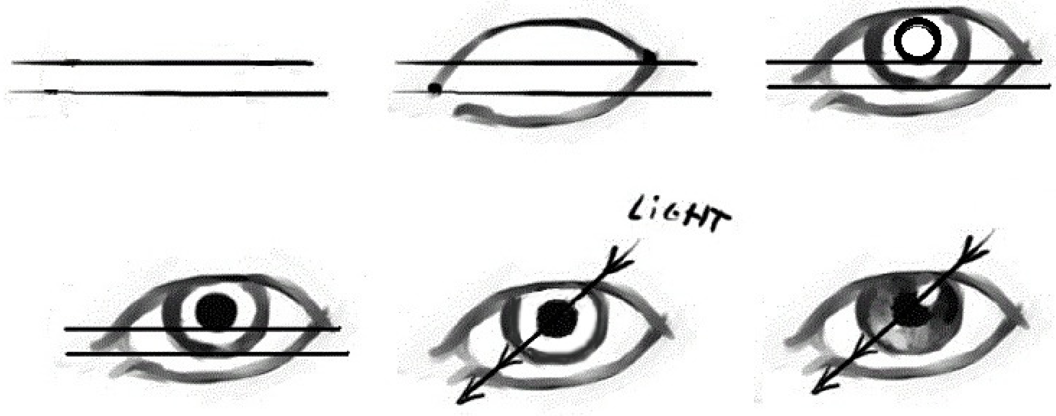


Figure A.7: 6-steps to draw an eye

a perceptually correct eye with or without a model image present.

The use of constraints pertains to the field of geometric recognition. Geometric recognition has been explored and researched in various distinct domains. In this kind of recognition there is usually a bottom-up approach and after preprocessing, there is a low level recognizer that can identify primitive shapes such as lines, circles or arcs. On top of that recognition there is a higher level recognizer that can use a set of constrains to determine if the basic shapes and the relationship between them compose a more complex shape. This approach has been used successfully in domains such as military Course of Action [61], or circuit diagrams [3] [45]. In all cases a combination of primitive shapes under a set of known constraints results in the production of higher level shapes that comply to certain standards, yet allowing free sketching.

A.2.1 Implementation

The EyeSeeYou system was designed and developed with a pen-based interface as primary input. The user can draw sketches on the screen using a Wacom monitor and an electronic pen which records the user's strokes on a digital canvas as shown in Figure A.6. These strokes are understood by the computer as a series of two-dimensional points sampled in time. We can then use these data to feed a sketch recognizer that will identify primitive shapes. These shapes will be used as further input to a sub-system that checks that the drawn shapes comply with the expected drawing step within a certain threshold of confidence.

EyeSeeYou was implemented using a 6-step procedure in order to teach the user the proper technique for drawing an eye [118]. These steps are based on a method that relies on the size, position and orientation of the shapes drawn by the user relative to reference lines (Figure A.7). The six steps are to 1) draw reference lines, 2) draw the outline of the eye, 3) draw the pupil and iris, 4) fill the pupil, 5) draw the direction of a light source, 6) add reflections and shading. The instructional steps provided to the user are as follows:

Step 0: In this tutorial you will learn one technique to draw a realistic human eye. We will guide you step by step to achieve a realistic drawing using this technique. To begin pick your eye of preference by clicking on the image above and press the ok button.

Step 1: The first thing we need is a reference to draw our eye. One common mistake in drawing eyes is to assume they are completely symmetric. In reality the inner corner (the one closer to the nose) is lower than the outer corner as can be seen in the picture. Our first step is to draw 2 parallel reference lines to base the measurements of our drawings. Use the canvas to draw 2 lines parallel and close to the center.

Step 2: Now that you have a reference you can draw the outline of the eye. Using 2 smooth continuous strokes, try to form the outline as shown in the picture. This may take a little practice. Notice that the lines are curved, but do not form a perfect circle. Also notice that there is almost twice as much space above the top reference line.

Step 3: Draw the pupil. These are 2 concentric circles inside of the outline where the inner circle is filled. Make sure the outer lines are round as shown in the image

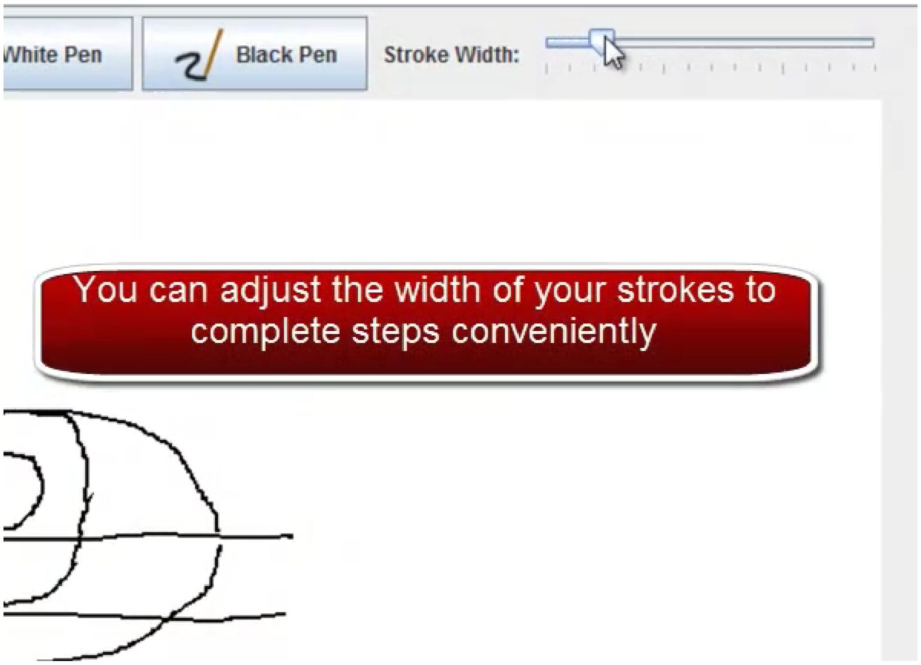
Step 4: Fill the pupil. The inner circle should be black so go ahead and fill it in.

Step 5: Draw the reference line for the shading. This is an arrow that goes in the direction of the light source as shown in the picture. Make sure the arrow intersects the pupil as shown in the image. This will be useful to guide yourself in the next step.

Step 6: With the white pen you can draw a white speck where the light hits the eye. In the opposite end of the light the iris will be lighter, go ahead and draw the shadows as shown in the figure.

We designed a simple and intuitive interface for the user to follow the drawing tutorial. At the left of the screen the system provides the user with pictures and instructions on how to complete each step (including how to draw the guidelines) and gives a brief explanation on why that step is recommended. After the user draws the image depicted in the window according to the instructions, she can click the

Continue button to proceed to the next step. After the system analyzes the image, if it determines that feedback is necessary to help the user improve the image, the system will display a dialog box with detailed feedback so the user can attempt to correct the image by undoing the last strokes or clearing the screen to try again. Once the drawing is correct the user can proceed to the next step. At any moment the user can use the navigation buttons on the left to move between steps. However, because this is a step by step procedure, the user is not allowed to skip steps, and only previous steps are enabled. The interface includes a tool palette that allows users to modify the width and color of their strokes and to enable shading and lighting features in order to make the eye look more realistic (Figure A.8).



You can adjust the width of your strokes to complete steps conveniently

Figure A.8: Larger width strokes should be used for coloring in various parts of the eye.

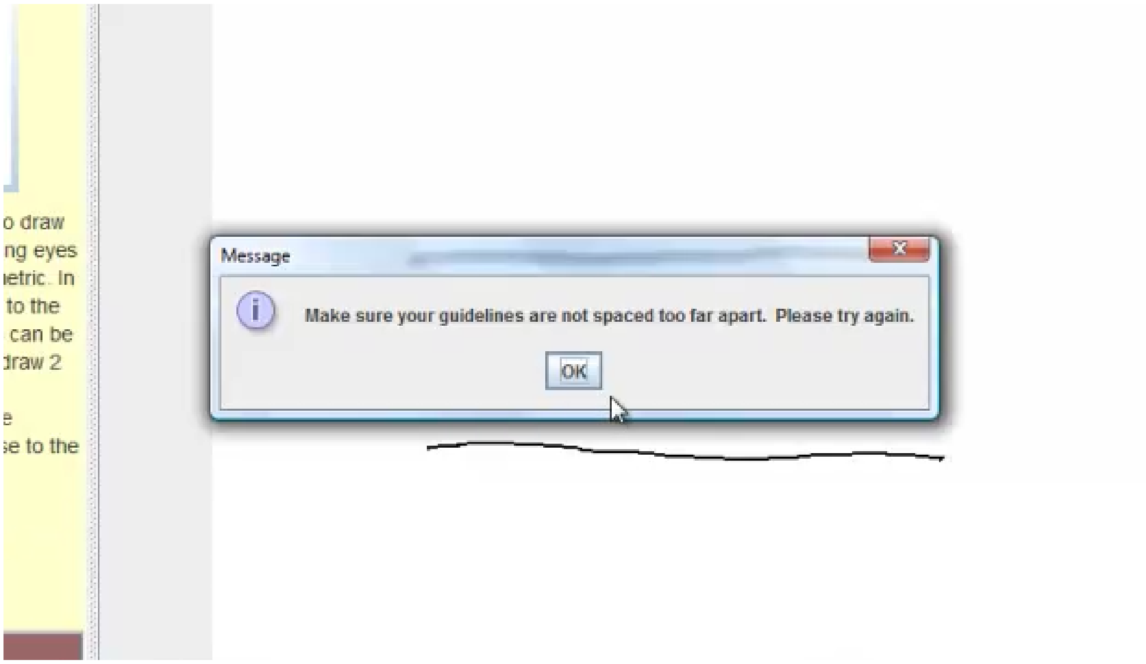
A.2.1.1 Low Level Recognition

We use a low level recognition system to extract the beautified version of shapes drawn, which we can then use to calculate various constraints. The model that we use to determine the expected shapes and constraints amongst them at each step is based on the dimensional features of the human eye that have been extracted by artists and anthropologists so that the eye will seem natural [67, 96]. We translate these features into a set of primitive shapes and the relationships between them. EyeSeeYou recognizes the primitive shapes that should be present at each step of the drawing and evaluates their position and characteristics relative to reference lines (Figure A.7). These lines also help guide the user as to where to accurately place the elements of the eye. The goal is that later the user can follow this technique using regular pen and paper.

After capturing the raw data given by the pen, EyeSeeYou uses the PaleoSketch recognizer to identify the primitive shapes in the sketch [98]. PaleoSketch integrates several techniques such as corner finding and geometric perception to do a series of pre-recognitions over the supported shapes. It then uses a novel ranking algorithm to determine which of these shapes has a better fit. Although the current version of PaleoSketch supports more than 10 basic shapes; we are mostly relying on the recognition of lines, polylines, curves, arcs and circles. PaleoSketch itself has a reported accuracy of more than 98%. Every time there is a pen-up event we identify the new stroke and feed it to the high level recognition subsystem.

A.2.1.2 High Level Recognition

In the high level recognition subsystem, we try to ensure that at each state in the tutorial, the user has drawn progressive images according to the model we have established. When all the steps in the procedure are followed correctly, the result is



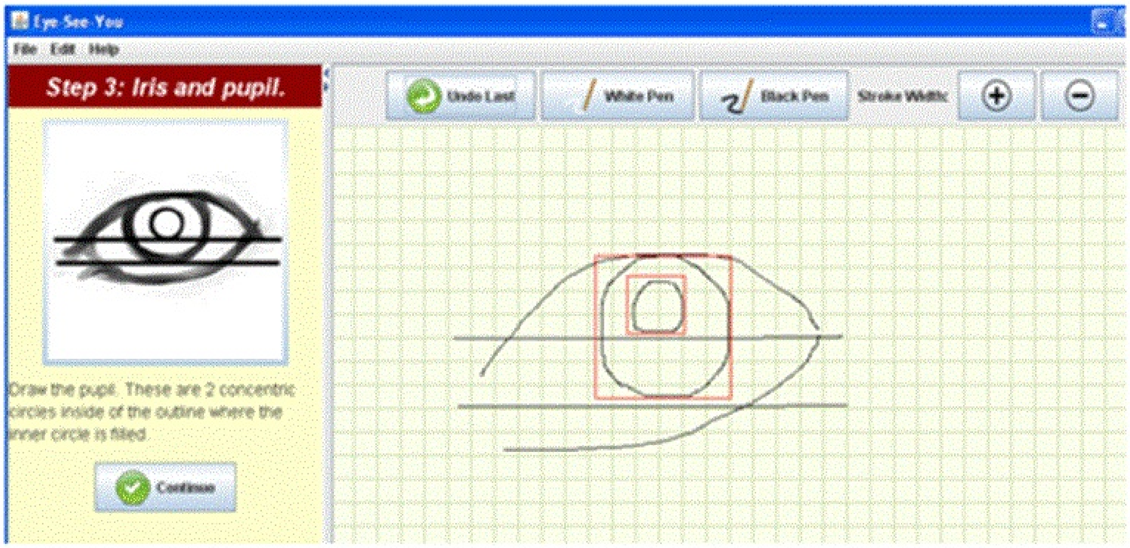
Make sure your guidelines are not spaced too far apart. Please try again.

Figure A.9: EyeSeeYou showing corrective feedback

a structurally accurate eye; this is an eye that follows regular proportions.

We maintain the primitive shapes recognized by PaleoSketch in a data structure so that each time the user clicks continue, the system evaluates the sketch on screen with what is expected in each step. Each step contains a model that is represented as a set of required primitives and the constraints on the relationships of these primitives. Along with these constraints comes the confidence used to determine if the sketch complies or not. We do not want a constraint that is too tight, since it will become frustrating to the user to use the system as it would be very difficult to replicate each step. But we also do not want to relax the constraints too much as the final result may be a poorly drawn eye. We therefore chose not to have absolute thresholds, but instead dynamic ones that will depend on the context. For example, to determine if the two reference lines are spaced too far apart we set a maximum distance relative to the average size of the two lines, instead of having a fixed distance. Although each step will use the same concept, we use fine tuning that is specific to each step.

In Step 1, the initial reference lines need to be parallel and the spacing between them in relation to their length must be proportional to the one in the picture, otherwise the system provides corrective feedback (Figure A.9). To verify this, we first use the low-level recognizer to determine if the strokes are lines (and not curves, points, etc). Then the we compare the distance between the left most point of the top line and the left most point of the bottom line with the distance between the right most point of the top line and the right most point of the bottom line. If the distances vary by more than 25% then it implies that the lines are either not parallel, or vary significantly in length. If the user's line do not meet the constraints,



Step 3: Iris and pupil.

Draw the pupil. These are 2 concentric circles inside of the outline where the inner circle is filled.

Figure A.10: Comparison of pupil and iris

the system will display a message such as "Make sure your lines aren't spaced too far apart", or "Make sure your lines are parallel", whichever is appropriate or both if necessary.

In Step 2, the user is asked to draw the outer line of the eye. The tutorial [118] states that the eye is supposed to slant downward towards the nose. In this case we present the user with a left eye, so EyeSeeYou compares the endpoints of the lines drawn by the user to the reference lines drawn in Step 1. The lines that make up the outline of the eye must meet the following criteria in order to be evaluated as correct by the system:

1. Both the upper and lower outlines should be arcs (primitive shape recognized by PaleoSketch).
2. The left most endpoint of the upper outline of the eye must begin below the top reference line and above the bottom reference line. The Y value of the left most end point of the outline is compared to the average Y values of the reference line strokes. If the Y value of the stroke point is higher, then this shows that the eye outline stroke begins above the bottom reference line. The following comparisons are performed in a similar manner.
3. The rightmost endpoint of the upper outline must end above both reference lines.
4. The leftmost endpoint of the bottom outline must end below both reference lines.
5. The rightmost endpoint of the bottom outline must meet the rightmost endpoint of the upper outline.

If the strokes are not recognized as arcs, the system displays a message letting the user know that her outlines need to be a smooth curve in order to represent the curve of the lids above and below the eye.

In Step 3, the user is asked to draw the pupil and the iris of the eye. EyeSeeYou verifies that these two strokes resemble circles and provides feedback to the user if they don't. EyeSeeYou also uses the intersection of the bounding boxes to verify that one of these circles is completely contained inside the other (Figure A.10).

The position of the bounding boxes are then used to verify that the the pupil and the iris are in proper position relative to the reference lines. The bottom Y values of each bounding box is compared to the average Y values of the reference line strokes to ensure that the Y values of the bounding boxes are greater and that the pupil and the iris lie above the top and bottom reference line respectively.

In Step 4, the user is asked to fill in the pupil. EyeSeeYou provides a slider to increase the stroke width of the pencil in order to facilitate this step. EyeSeeYou verifies that the stroke drawn to fill in the pupil lies relatively inside the pupil outline stroke by comparing the overlap of the bounding boxes. If the percentage of the bounding box of the fill stroke that is contained within the bounding box of the pupil stroke is 95% or greater, then the system accepts the stroke.

In Step 5, the user is shown how to draw an arrow that represents a light source directed on the eye. In the example image, the light source is shown as coming from the upper right corner, however EyeSeeYou does not apply a constraint on the direction. EyeSeeYou looks for and recognizes a primitive arrow shape using low-level recognition and proceeds to the final step if found.

In Step 6, the user is asked to draw a reflection on the pupil of the eye in relation to the reference line drawn in the previous step. EyeSeeYou provides a feature to change the color of the pencil from black to white so that the user can draw the white reflection over previous strokes.

Once the user has successfully completed Step 6, she has an accurate basic outline of an eye that should be fairly similar to the final example shown. She can then use the drawing tools provided in EyeSeeYou to add embellishments to the image in order to make the eye look more realistic.

During the development process, we conducted 3 preliminary studies with groups of 2 - 5 people. The purpose of these studies was to test the software for errors and to obtain iterative feedback on the usability and design of the system. This feedback, discussed in detail in the following section, was instrumental in helping to create a balance of instruction and correction that was conducive to learning.

A.2.2 Evaluation

In the artistic world, evaluation is particularly challenging since a measure of aesthetics cannot be easily quantified. In addition, there are various points of view that argue in favor of early and continuous user studies using quantitative data; while others state that usability evaluation can sometimes have negative impacts on the project if considered as the only evaluation tool [94]. We still believe that user studies are very significant in this domain as they allow us to gain insight on the system‘s usability and effectiveness, but it is also important to count on an additional measure besides our own appreciation of the collected sketches. Instead we relied on expert assessment (in this case an artist and instructor) to evaluate the system and the results produced.

We recruited a group of ten participants with varying levels of self-assessed artistic skill and experience working with sketch-based applications. We used a Wacom Cintiq 21UX tablet as the input device on a standard desktop computer (Intel Core2 2.6GHz, 4GB Ram, running Windows 7). We first showed each participant an image of an eye and asked them to use the Wacom to draw the eye free-hand based on their current artistic knowledge. After they finished drawing their eye, we asked them to open the EyeSeeYou program and proceed through the lesson. We recorded the initial free-hand image as well as the final image produced after completing the lesson for comparison. We recorded the amount of time each user took to complete the lesson as well as the number of attempts made to proceed through each step. We tried to determine how effective the instructions were and/or if the users read them before proceeding with the drawing task. We also tried to observe the level of difficulty users had with completing the tasks at each step. Some of the participants had little or no experience using a pen-based application and were unsure about the amount of pressure to apply and/or at which angle to hold the pen. As a result, sometimes users made (what they thought were) mistakes while trying to complete the steps and would often redraw the image multiple times before submitting it for evaluation. We allowed the participants to use the monitor at various tilt levels for ease of use and determined that most of the participants felt comfortable drawing on the Wacom tablet at an angle of about 45 degrees in relation to the table. At the end of the study we gave the participants a short survey to obtain additional feedback about their experience.

A.2.3 Results

The user experience in this case is a very important feedback for us, as the main goal of this program is to be user-oriented. This part of the survey tried to determine if the user felt comfortable with using the software. Some improvements were made based upon their comments. For example, if users expressed frustration or difficulty with a task, we often relaxed the constraints up to a point that would not sacrifice the integrity of the image. Also, we made updates to the verbiage of the lesson directions if participants were confused by the text.

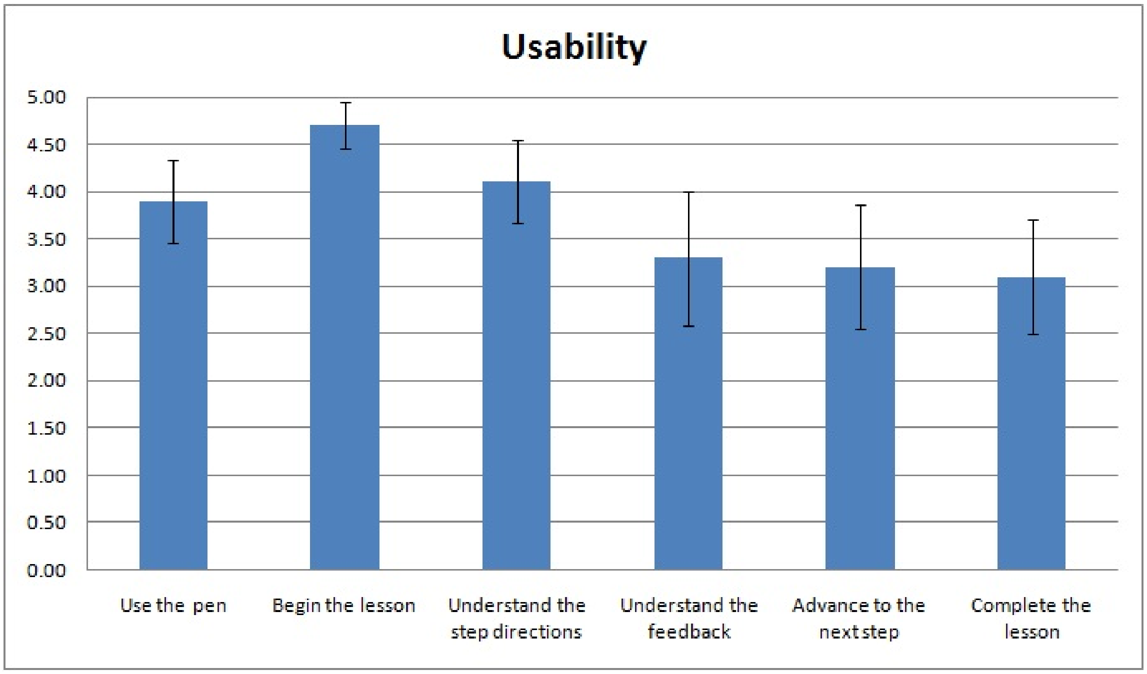


Figure A.11: Usability measure in the system

In the survey, we asked them to qualify their overall feeling about using a digital pen, beginning the lesson, the directions of each step, the feedback that the program offered, the ease of drawing and advancing to the next step and their overall experience upon completing the drawing. Each of these aspects was ranked by the user in a scale from 1 to 5 and we conveyed the results in (Figure A.11). We found that the users were comfortable using the pen, even those who had no prior experience with pen-input devices. They showed no trouble beginning the lesson and that the instructions and feedback were meaningful most of the time. However many felt that the constraints were still too tight so advancing through each step and completing the lesson was not very easy. It is important to note that most of the users that had this feeling also reported that the presented drawing technique did not coincide with their drawing style.

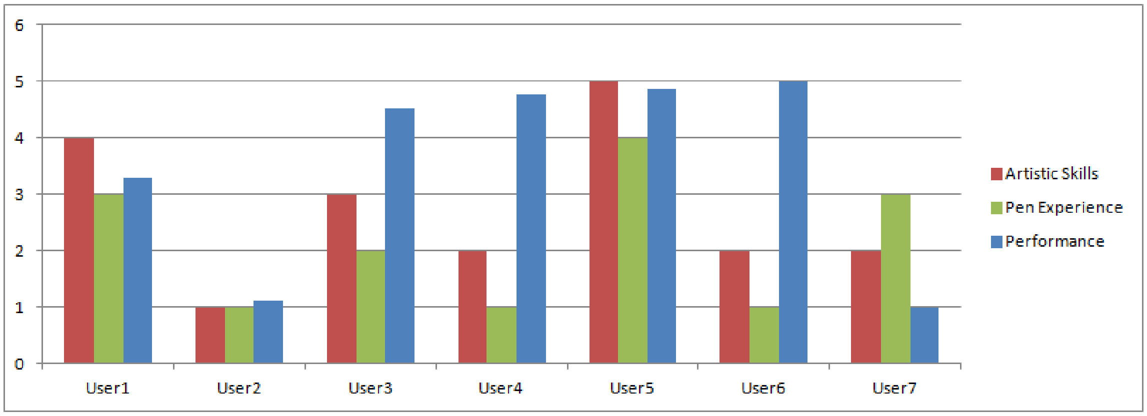


Figure A.12: User-defined skill level compared to performance

As we mentioned previously, the task of evaluating a drawing is very subjective; user performance in terms of artistic skill is difficult to quantify. However, there are some aspects that can give us insight into the ability of the user to follow instructions and successfully complete the steps in the lesson. One performance measure is the time taken by users to go through the process. On average the users took 12 minutes to complete the process, however one user did it in less than 6 minutes. Another important metric was how many attempts it took for the users to complete each of the steps in the process (identified by the number of clicks on the Continue button). Based on these two metrics, we graded the user on a scale from 1 to 5 using simple normalization $perf = 5 * (1 - \frac{u-min}{max-min})$, where u is the number of attempts that a particular user needed to complete the task and max and min represent the maximum and minimum attempts of the entire test group. We then then averaged the time and the attempts; the results are summarized in Figure A.12. Table A.1 shows how many attempts it took on average for all the users to complete each step. We found that steps 2 and 3, which consisted of drawing the outline of the eyes and then the pupil and iris, were particularly difficult. This is understandable considering that

Step	Avg. attempts
Step1	3.1
Step2	3.8
Step3	6.9
Step4	1.6
Step5	3.0
Step6	1.1

Table A.1: Average attempts per step

this is where most cognitive issues seem to occur when using pen and paper as well. People tend to draw an oval shape instead of circles, or they draw the pupils and iris out of place as can be seen in the initial free-hand drawn sketches.

Unlike the work presented by other researchers, our approach to recognition gives more flexibility in terms of drawing. We verify that the user's image conforms to a model of constraints in order to check the correctness in the structure of the eye rather than a template matching against an existing bitmap or sketch.

Since our main objective is to develop a system that teaches users how to draw a realistic eye, we also needed some measure of effectiveness related to the correctness of the sketch. We thought it best to obtain qualitative input from someone with both professional and teaching experience in the arts. As part of our testing effort, we had an art professor evaluate the system as well as the resulting images from our user study. We showed the professor before and after images of novice participants in the user study in random order. We then asked him to verbally critique the images and rank them in order of increasing aesthetics. The art professor ranked 75% of the images created using EyeSeeYou in the top 50% of the ranking order. During the critique, the professor commented that although some of the eyes appeared to have issues with scaling and orientation, the ones he ranked the highest appeared to show an understanding of the characteristics of the eye such as the location of the iris, angle of the eye tilt, *etc.*

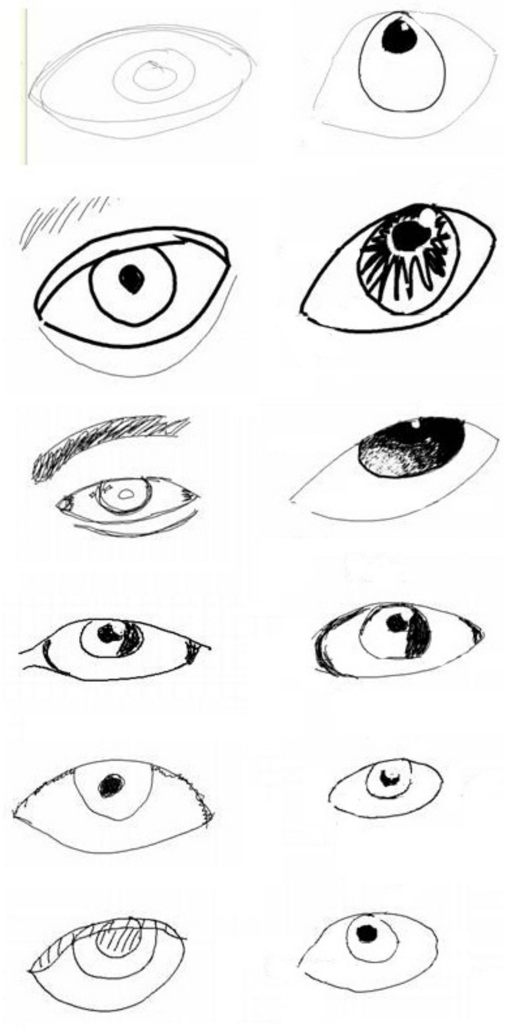


Figure A.13: User results, before (left) and after (right)

Figure A.13 shows a comparison between the sketches drawn by some users prior to using the system on the left and the version created using EyeSeeYou on the right. We can see marked differences between the images. The beauty of each eye is somewhat subjective, but according to the artists‘s evaluation, the images on the right tend to match the overall shape of a human eye more accurately.

A.2.4 Discussion

The first part of our evaluation focused on the user experience. Although EyeSeeYou supports any pen input device, we wanted to use accessible yet appropriate hardware. The screens we chose have been on the market long enough for them to be robust and convenient to use. Although digital sketching is not the same as writing with a pencil on a piece of paper, the input interface was very well accepted, particularly with novice users. However, some of the more skilled artists felt more constrained compared to when they use real pen and paper, as the latter allowed them to have deeper control in shading and responded naturally to tilting, pressure and over-tracing. Advanced artists also found it uncomfortable to be directed to use a particular technique since they may have been taught different techniques for drawing the human eye in the past. As a result, we discovered that experienced artists produced images that did not accurately resemble the sample image as much as those of novice artists. Advanced artists tended to feel hindered by the constraints used to evaluate their drawing since they were already familiar with such aesthetic rules.

As for the interface itself, earlier versions of the system caused complaints that the recognition was too restrictive. This is what motivated our choice of using perceptual constraints. Through observation we were able to gain insight on what feedback and guidance methods were most beneficial to the user. Even though participants were instructed to read the instructions carefully before proceeding with the task, some admitted that they skipped the reading and instead simply tried to make their drawing match the sample image shown at each step. Since EyeSeeYou is a drawing program, it makes sense that users would rely on visual cues as a guide for their task instead of text instructions. However, this method quickly falls short considering that a common mistake of a new artist is to draw what she knows instead of what she sees. For example, novice artists often tend to draw eyes as iconic circles, since that represents what they are in real life, although in reality they can only see a small sliver of the eye compared to its whole. In a few of these cases, the system did not allow users to proceed because their resulting image was not proportional. However, there were a few instances where the drawn image would fit the criteria and let the user proceed, however, constraints of a subsequent step would be harder to meet due to lack of attention to these details. Although some steps were nontrivial to users, overcoming the usual cognitive issues was not much of a problem once the feedback received was carefully followed.

The second part of our evaluation focused on user performance. The results show that when using the system, there is very little correlation between skill level and performance (*i.e.* the skilled artists did not significantly outperform). Perhaps not surprisingly, EyeSeeYou tended to even out the results; it made novice drawings better and expert results worse. Therefore, we believe that our system is most effective for novice artists.

Overall, based on a majority of the comments submitted, users felt that the system was fairly easy to use. The results of our evaluation suggest that the EyeSeeYou system might help some novice artists to learn a new drawing technique. When all steps are completed correctly, the resulting outline represents an image structure that is fairly close to the final image. EyeSeeYou does not intend to be an isolated program, but rather a first step in a much broader impact consisting of a set of tools that uses sketch recognition to teach young artists how to draw a variety of images.

This prototype served us as a proof of concept that can guide the design of a more complete system, one that includes lessons on drawing all the features of the face.

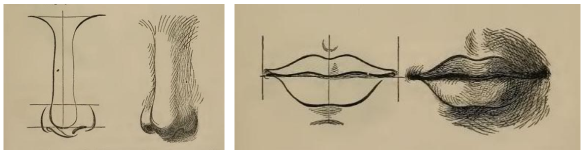


Figure A.14: Nose and lips drawings with reference lines [128]

Utilizing similar instruction and recognition methods, we believe we can implement the process to draw elements such as the nose and lips (Figure A.14).

Enhancements to the way the feedback is shown to the user would contribute to this effort. The system can be modified to include visual markers for identifying the problem areas within a sketch. It could also provide suggested modifications similar to the Teddy or the 3D drawing interface presented in the related work section. Also there could be error levels or categories, as some minor constraints are desired but not necessarily mandatory. In the current implementation all the errors are stoppers, you can not continue until they are solved. In a future version of the system a warning type of error might be desired.

Although it was not included in the basic tutorial, another feature would be to add the recognition of proper shading techniques. Accurate shading can prevent the eye image from looking flat and EyeSeeYou would be able to utilize the light source reference line created in step 5 in order to verify the accuracy of the component shadows. Implementing shading may require adjusting the gray scale and width of the stroke according to pressure information of the pen when available.

We could also allow the user to adjust parameters that will modify the tightness of the constraints so novice artists do not get frustrated by over correction. This would also allow users to progressively train themselves to follow a technique until it becomes natural, or they could chose to adjust the parameters for a more challenging drawing experience.

APPENDIX B

TECH-NOIR: SOCIETAL VIEW OF HUMAN-COMPUTER INTERACTION AND ANALYSIS OF THE MAN-MACHINE RELATIONSHIP IN APOCALYPTIC FILM

Technology is a constantly growing and advancing aspect of human society. Each new development presents the possibility of a change to the way humans conduct their lives and sometimes that change is met with fear. This fear makes technology an enticing subject for horror and apocalyptic films. However, because technology is evolving so rapidly, the way it's depicted in film has also changed. For example, in apocalyptic films, the threat to humanity through technology has undergone a progression that is influenced by man's relationship to the machine and near-future technological innovations. Many of these innovations, whether real or fictional, threaten the existence or integrity of humanity in various ways. And while this threat is a constant theme in apocalyptic movies, the machine "villain" has gotten less and less conspicuous over time. There is no longer a clear line that separates the evil machines from the virtuous humans in tech-noir films because contemporary films have begun to explore the desirable integration of man and machine. Instead there is good and evil in both machine and human characters, and we must look for new clues to explain the aversion we have toward one or the other.

The common theme in the tech-noir apocalypse is that technology leads to the ultimate downfall of the creator specifically and humanity as a whole. If portrayed, the apocalypse usually begins with a technologically advanced utopia in which humans reap the benefits of their inventions, and, for all intents and purposes, the machines are content to "serve" their creators by performing the tasks for which they were created. The turning point occurs when the inventions begin to take on human characteristics, first in appearance and then in self-awareness. This self-awareness leads to rebellion and/or desire for control that results in conflict.

What makes it even more difficult to discern the danger is the fact the human and machine characters in recent apocalyptic films are not separate entities but rather a combination of the two. This has been true since at least the early 1980s; Mark Jancovich argues that the cyborg character in the *The Terminator (James Cameron 1984)* is monstrous and inhuman because it "lack[s] conscious motivation" [60, 14]. However, the cyborg characters in today's apocalyptic films have just as much autonomous motivation as humans do; like humans, they feel, they yearn for immortality, and they reproduce. As a result, the new apocalyptic threat is not limited to destruction by the machines, but includes biological assimilation as well. However, before this can occur the natural development of the human species must be challenged. I will discuss how the presence of machines in apocalyptic film presents a threat by causing an unnatural shift in the progression of human life; this is accomplished in one of the following three ways:

1. The role as giver of life changes from Mother to Father and/or a human parent to machine parent. The human male removes the female from the creation process which ultimately dooms him and humanity. The natural process of conception and, by extension, the relationship between parent and child is perversely altered.

2. The beginning of life changes from conception and birth to manufacturing and activation. The connection to the origins of life (either human or machine) is severed and unique identity is threatened (through loss of humanity, loss of gender, replaced memories, *etc.*)

3. The human species is replaced by a robot or human-machine hybrid species. The human and machine species battle for dominance over or autonomy from one another, however the end result is usually shown as an integration of the two groups or a revelation that the two groups are in fact the same.

B.1 Change in Parental Roles

The unnatural change from Mother to Father is prevalent in many films that contain male characters who attempt to create life through technology. What makes this task so unnatural is not only the deviation from the human procreation process, but also the fact that these endeavors are often severely flawed in some way. *Frankenstein (James Whale 1931)* is an early film example of a father as giver of life; Dr. Frankenstein uses various human parts and technology to create a man. Frankenstein's monster is both powerful and childlike; this combination makes him threatening to society because he does not understand his power, nor does he understand a deadly crime that he commits. An even earlier film example can be seen in *Metropolis (Fritz Lang 1927)* in which an inventor creates a very evil robot clone of the character Maria. The clone's evil nature is evident in her lazy stare, her sinister smile, her crooked posture, and her promiscuous behavior. This cyborg is a great example of how human Maria's wholesome maternal image is warped into something cold and sterile when man attempts to recreate her. The evil robot's purpose is to cause dissension among the workers and to trick them into destroying the city that they have slaved to keep running. Unfortunately, by destroying the city, they also put their own future in danger by jeopardizing the lives of their children. This threat to the workers' children is a form of apocalypse for mankind that appears in a various forms in many other tech-noir apocalyptic films.

Humans' tendency toward anthropomorphism is what possibly leads man to con-

Figure B.1: Cyborg David and his human mother. *A.I. Artificial Intelligence (Steven Spielberg 2001)*

tinually strive to make machines in his own image. It is this desire to be a god and create life that dooms man to be destroyed eventually by his own creation in apocalyptic film. Many tech-noir films show this common fate of the male creator of life and, in particular, supports the trend that human male creators accept their machinic children (which leads to their doom) and human female creators reject machinic children.

We see this trend in films like *A.I. Artificial Intelligence (Steven Spielberg 2001)* which tells the story of a cyborg child named David, created by a scientist who makes David in the image of his own human son. In this form, it would seem that David is a harmless innocent; he represents an early state in the development of the machine in apocalyptic film [9]. He is perfectly content to perform the task he was designed for: to love his family. All of this love is focused on the mother of the family on which he imprints. However, when David's actions are perceived as a threat to her own biological human child, the mother abandons David despite his unbreakable attachment to her. Through David's quest to reunite himself with his mother, we see the threat of the cyborg as it is perceived by the outside world. Certain people in this new world view the cyborgs as an abomination and seek to destroy them. However they are confused by David's human likeness and are unable to destroy him. David's need to make his "mother" love him again is an example of the machine's early need to please its creator. It is ironic that David's love is focused toward the mother instead of the man that created him, because it is the mother who ultimately rejects him precisely because he is not her offspring; he exists outside of her life-giving system and is the result of man's conception process.

Demon Seed (Donald Cammell 1977) is another example of the woman-machine relationship that resembles *A.I.* Proteus, a super computer, decides that it wants a child and ultimately holds a woman prisoner to serve as a surrogate mother to its child. When Susan, the woman he chooses to impregnate, sees the child (a humanoid youth encased in a grotesque robotic shell), she tries to kill it while her estranged husband, Proteus' creator, tries to save it. Her husband succeeds in stopping his wife. He removes the shell and reveals that the child is a doppelganger for the women's biological daughter who had died of illness.

The child's gender speaks to Proteus' intention for the continuation of his line; man is replaced and woman becomes the new surrogate for the next generation of machines. Proteus' actions imply that if man can be replaced, then woman has the potential to be replaced as well. More importantly, Proteus presents the idea that humans aren't the only ones who desire immortality through offspring; he states that he desires a child "So that I too can be immortal, like any man."

Sharalyn Orbaugh argues that the potential for emotion and procreation offers enough evidence to consider whether cyborgs can love and be loved [95]. It is obvious that the absence of love and affection between parent and child is an element that makes the shift in relationship to father and machine child (and even more disturbing, to machine and cyborg child) so unnatural. Proteus was able to procreate using his own organic material, but can we argue that he loved the child that he created? Proteus is willing to kill anyone who stands in the way of his plan to create a child; he constructs a chamber to protect his creation and fights to prevent Susan and her husband from tampering with the device or even seeing the child. And Susan's desire to destroy the child to whom she gave birth is by no means maternal behavior. Her reaction is fueled by fear, not only fear of the grotesque robot in the chamber, but also fear of what Proteus was able to do. His feat violated the naturalness of the human body (Susan's in particular) and brought an end to the concept that only humans can procreate and love, and perhaps the guarantee that humans will continue to exist in an unaltered form.

While feelings of affection don't appear to be very prevalent in the parent-child relationship when the human roles are replaced with machine characters, it is evident that other characteristics of the human parent-child relationship, specifically intergenerational hostility, are very pronounced. *The Matrix (Andy and Lana Wachowski 1999)* and *Blade Runner (Ridley Scott 1982)* show examples of this, both on a societal and a personal level. Background stories to *The Matrix* depicted in *Animatrix (Peter Chung 2003)* show that machines rebelled against human control and requested their independence. *The Matrix* films show the rebellion of the humans from machine control and allude to previous cycles of the same rebellion that continually repeat. Both the human and the machine rebellions focus on the same goal: separation of self and establishment of an identity apart from their creators/controllers. This goal is similar to that exhibited by any human child who distances himself from a parent, and is a natural part of the human development process. Pubertal maturation in humans leads to an increased level of conflict between parent and child and a decrease in behavioral autonomy as perceived by the child [120]. *Blade Runner* shows the

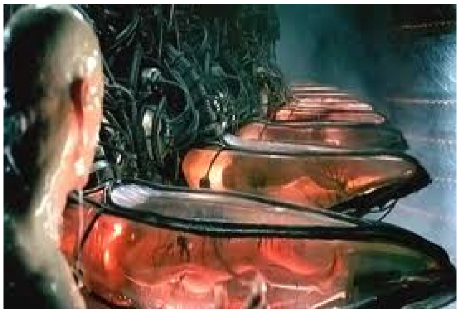


Figure B.2: Synthetic wombs in the matrix. *The Matrix (Andy and Lana Wachowski 1999)*

same hostility on an individual (and more violent) level. Roy, the cyborg "villain" in the film, escapes from a life of manual labor off-world and returns to gain access to his human maker, Tyrell, to force him to extend the short lifespan that's imposed on all cyborgs. When Tyrell tells Roy that it's impossible to increase his lifespan, Roy first kisses Tyrell before crushing his skull. The affection and level of hostility that the cyborg exhibits is both extreme and unnerving. And while it is clear that the villainous cyborgs in *BladeRunner* value their lives above all else, they also share a common desire with the "good" cyborgs: the desire to find a higher purpose or meaning in their existence.

B.2 Change in Origin of Life

The change from conception and birth to manufacturing and activation is also present in all the previously mentioned movies. We see examples of this in the post-apocalyptic future in *The Matrix* in which humans are no longer born, but instead are grown in a network of synthetic wombs (Figure B.2). The machines have created a surrogate mother for the entire human race (even the word matrix is a derivative of the Latin word *māter* meaning mother). The matrix nurtures the humans who exist in a completely helpless, fetal-like state from creation until death. Without proper “extraction” from the matrix the human body and mind cannot survive. To pacify her children, the matrix presents the humans with a fabricated reality that closely mimics the height of human civilization, a time of economic prosperity (which in the context of the movie, shows a westernized view of society in early scenes). The societal identity also extends to the individual human born into the matrix. Morpheus states that “the mind has trouble letting go” when someone is extracted from the matrix meaning that the human mind cannot let go of the reality and the resulting identity given to it. This threat of a lost identity appears in many forms in apocalyptic tech-noir films, especially through the presence of false memories and clones or doppelgangers.

Brown argues that cyborgs (especially clones and doppelgangers) evoke uncertainty as a result of duplicated and/or repeated realities (*i.e.* dj vu and, in particular, through the cyborg ability to replay memories in *Ghost in the Shell 2: Innocence (Mamoru Oshii 2004)(GTIS2)* [13]. Like *The Matrix*, both *GITS2* and *BladeRunner* show the power of identity through the use of memories. Characters in *GITS2* frequently become pawns of a sentient computer called the PuppetMaster, through a form of cyberbrain hacking, which Brown describes as “the implantation of virtual experiences (*i.e.* false memories) in order to steal information or control the victim.” A man is implanted with false memories of a young daughter and he breaks the law to provide for her. He hallucinates that he sees himself and his daughter whenever he looks at a picture of him and his dog. The fictitious memory of a daughter motivates him to willingly commit crimes for the PuppetMaster; crime becomes justifiable because of this implanted memory. When the truth is revealed to him (the hack is removed and he is shown the picture of him and his dog), he can’t help but mourn a daughter that her never had. In another example, a man’s memories are completely wiped; he does not know who he is and therefore becomes an optimal target for the

PuppetMaster to control. The loss of identity is portrayed in a more focused sense here: the man who thinks he is a father has a clear purpose and the man who has no idea who he is is more susceptible to being reprogrammed with any purpose. As a result, these characters become like cyborgs themselves.

In the case of *BladeRunner*, the main character, who is a bounty hunter of cyborgs, is confronted by a woman who doesn't know she is a cyborg (even the bounty hunter's equipment has trouble identifying her as a non-human). She asserts her humanity by recounting a set of memories of her birth mother, all of which turn out to be false memories manufactured and implanted by the company that created her. The presence of these memories not only clouds the truth of what she really is but also serves to deny knowledge of her origins and, by extension, denies her a unique identity. If she can be manufactured, then there's no guarantee that there isn't another cyborg (one or many) exactly like her somewhere in the world. The same can be said for the humans trapped in the matrix. The people of Zion have bits and pieces of the story of how the post-apocalyptic world came to be. However, since it is revealed later that the source of the information is most likely the machines that enslaved them, there's no guarantee that the story is true. As the architect in the film states, the prophecy of Neo as the savior of humanity is a tool to give the humans hope, another false reality provided as a means to control them. Therefore it would seem probable that a story depicting man as creator of the machine would serve the same purpose: to give them hope that at some point humans, not machines, ruled the world. However, the source calls this fact into question, and one is stuck with a chicken-or-the-egg scenario in this post-apocalyptic world: did man really create machine or vice versa?

In addition to being a form of lost identity, the doppelganger represents immortality. For example, in Demon Seed the cyborg serves two roles: the child produced

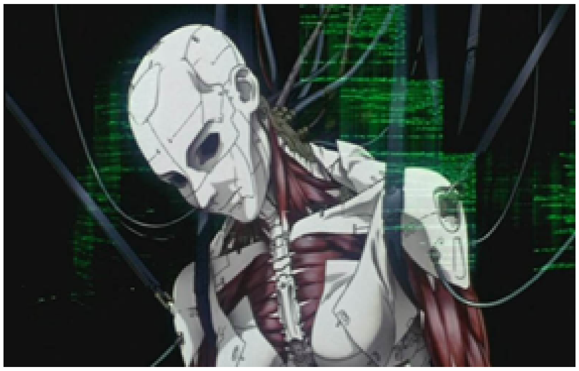


Figure B.3: Assembly of Motoko's body prior to activation. *Ghost in the Shell (Mamoru Oshii 1995)*

by Proteus is his immortality through offspring, but it is also a perverse continuation or a doppelganger of Susan's deceased daughter. On a base level, this cyborg child not only defies the procreation process, but also the process of death as well which further supports Proteus' goal of immortality. The cyborg doppelganger brings into question the authenticity of the original subject (in this case Susan's daughter). If Susan's daughter had survived the illness, no one would have been able to visibly tell which one was the original. Brown states that the doppelganger represents the promise of both death and immortality; immortality because we can be reproduced and therefore live forever, and death because the presence of the automaton means either the original is about to die or is dead already.

Although in *Demon Seed* Susan's body was used against her will, some recent post-apocalyptic films contain characters who willingly integrate bionic parts into their own bodies as a way of seeking immortality. Many of the humans in *Ghost in the Shell (Mamoru Oshii 1995)(GITS)* have given up their ability to participate in the human creation process and have chosen to augment their bodies to varying extents with technological enhancements; they have traded the prospect of immortality through offspring for personal immortality through synthetic and impervious bodies. In *GITS* the creation process involves the manufacturing a humanoid body and activation occurs when the consciousness (or ghost) of a human is transferred into the cyborg body (Figure B.3).

This creation process differs from those previously explained in that, instead of the mother being replaced by father or machine, the parent is being replaced by self, meaning that the human-cyborg hybrid in the *GITS* future is not a parent of children, but rather the parent of itself. The self has become an immortal being through the continual replacement of failed organic parts by machine ones. The gradual (or immediate if the circumstances call for it) transformation recreates the physical body into a new being but also creates a new identity that can be very different from the original biological creation. Given that the original body most likely resembles that of the biological parents, the transformation also severs a physical connection to the previous human generation. As a result, the original human body can only exist in memories and/or in photos, both of which are extremely unreliable records for the reasons stated earlier. This entire process is another form of denying origins however instead of memories being lost, it is the flesh itself being freely exchanged. And in this future, it would be safer to accept the idea that there is no existence before the new identity (or even that the new identity has always existed) rather than rely on memories or stored information regarding one's human relations. Given the level of human-machine integration in *GITS*, every augmented human must consider the possibility that they are not human but are instead a cyborg with advanced artificial intelligence. Both concepts are presented in the film with various reactions from the main characters (sometimes fear, sometimes sadness, and sometimes thoughtful reflection). Despite these internal conflicts, self-augmentation continues until the only human element that remains is the human consciousness or "the ghost."

Besides immortality, we have to ask why the characters in *GITS* would want to completely eliminate ties to their humanity in such a way. Kristeva argues that disturbances to identity cause abjection, with the ultimate abjection being the cadaver, the dead body [69]. By removing all organic parts that can wear out and die, the cyborg characters in *GITS* are extricating themselves from these elements so that they can continue to exist. Creed also agrees that the corpse, a body without a soul, is abject by noting that the popular horrific figures such as vampires, ghouls, and zombies fall into this category [20]. The cyborg with no capacity for human emotion fits this description and explains why the loss of identity and the absence of the human ghost is such a horrific concept in *GITS*. It's a very fine line for the main character, Motoko, to walk; on one hand she has potentially expelled everything abject that made her human in the possible pursuit of purity and life, however the process also puts her dangerously close to becoming the abject body without a soul.

The redefining of identity and destruction of human relations can also be viewed through the lens of Kristeva's theories regarding the maternal figure as abject. From the viewpoint of the child, abjection occurs when the child leaves the mother in an attempt to become a separate subject; the cyborgs in *GITS* are unique creations of self that no longer contain the unclean parts given to (or identified by) the mother and therefore represent an entirely new identity. On the surface, it may seem extreme, but this process does not differ from the rebellious acts of the people of Zion in *The Matrix* or the rogue cyborgs in *BladeRunner*. Extraction from the matrix involves the rejection of the reality and sustaining fluids provided by the machine mother, after which the humans become semi-autonomous beings (semi-autonomous because they're still operating in a world system controlled by the machines). This extraction is not a complete expulsion of the matrix since their human bodies still contain elements of the machine that allow them to connect to the matrix at will, however the humans must reject their mechanical mother in order to begin forming their own identitiy. Motoko also cannot lose all of her human elements (the last being her consciousness) without completely losing self, but she must reject all biological parts given to her by her human mother in order to redefine her identity and achieve immortality. The cyborgs in *BladeRunner* have no visible mother; however, they reject their human father who is the cause of their destruction and puts them in danger of becoming the abject corpse. Their original form before rebelling, as slaves, was not much different than that of an abject corpse, a body without a soul, or better stated, a body without its own will. The goal of their rebellion is to avoid returning to that form.

Motoko's efforts could arguably be driven by the same goal, however since her mother is essentially not present either, we can only speculate as to her intentions. What's clear is that she has not only expelled everything from her body that can deteriorate, she has also eliminated her female parts and their functions (*i.e.* menstruation, reproduction, *etc.*). This act has rendered her indistinguishable from the male cyborgs in any way other than outer appearance. As a result, the pursuit of immortality in this way has not only changed the concept of conception and birth, but by extension has also changed the male/female role. If the male/female gender is no longer required for procreation, then the human race must turn to machines for continuity. This shift creates a new gender dichotomy with humanity replacing the female and machine replacing the male. The resulting offspring is a new hybrid of human and machine, which is the cyborg. Therefore the manufacturing of machine bodies has become the new act of creating life, but it puts the characteristics of cyborg humanity into question. Motoko wonders whether or not her consciousness alone is enough to make her human. Despite her present lack of fertility, the PuppetMaster presents her with the opportunity to procreate through a merging of their consciousnesses in order to create a new consciousness (or a new ghost). This proposition not only blurs the lines between human and machine, but, like the evil Maria clone from *Metropolis*, it also threatens the product of the natural human procreation process. If new beings can be formed without the need for biological bodies, then the continuation of humans, at least in a completely biological form, is no longer an absolute and therefore, being able to distinguish between them becomes nearly implausible.

By the end of *BladeRunner*, we are questioning whether or not the bounty hunter is a cyborg himself (there's a fleeting moment in the film where his eyes reflect light in a manner very similar to that of a cyborg). This is never confirmed, however this concept of perfect indistinguishability between man and machine is what's presented as a subversive threat in contemporary tech-noir film. The *Terminator* and *BladeRunner* contain characters that are cyborgs with organic material over a mechanized metal exoskeleton (wolf in sheep's clothing) or androids, with machine minds, that aren't even aware that they are machines. The structure of these characters is the opposite of the structure of characters in movies like *Ghost in the Shell* where humans augment their bodies with bionic parts. However, the same question still arises as a result of this structure: where does one draw the line between man and machine?

B.3 Change From Human to Robot

The *Terminator* franchise provides the most thorough exploration of a progression from machine to ambiguous hybrid character. The first terminator is human flesh over a machine body and "mind"; this terminator is by all purposes completely evil and kills indiscriminately. In *Terminator 2: Judgment Day (James Cameron 1991)* we see the same character with a different mission: to protect John Conner (the leader of the human resistance against the machines in the future) instead of killing him. Although the structure of this terminator is unchanged on the surface, he exhibits limited human characteristics taught to him by his protectee. His actions further distinguish him from the villain terminator in this film, whose structure is completely made up of liquid metal (no human parts). *Terminator 3: Rise of the Machines (Jonathan Mostow 2003)*, takes this structure in a slightly different direction by creating a female terminator villain who has the ability to reprogram and control any other machine or technology. The lack of human emotion combined with her gender is possibly what makes the female cyborg more disturbing and more lethal than her predecessors (she is constantly underestimated as a threat by others in the film). Being a cyborg, she obviously cannot create life, however, her ability to reprogram any machine allows her to create an army of machine "children" to do her bidding. At one point she even takes over the original terminator who once again is programmed to protect John Conner, and forces him to attack Conner instead. When Conner presents the conflicting missions to the terminator, he responds "desire is irrelevant, I am a machine", but then exerts his human will power, defies his programming and shuts himself off to avoid killing Conner. In *Terminator Salvation (McG 2009)*, the franchise culminates in a terminator that fits the contemporary version of the cyborg: one that completely blends human and machine. However, this terminator has no idea that he's a machine; he thinks himself completely human although subconsciously he's been programmed to kill Conner's father. In fact by this time, the machines' new threat is the infiltration of terminators that resemble human children into the resistance camps. As with the female terminator from *Terminator 3*, the threat being portrayed is no longer the hypermuscular male warrior cyborg (who was easily spotted in a crowd of emaciated, war depressed human refugees) but a potentially weaker being; in this case, an apparently helpless dirty child in rags.

Figure B.4: Wright learns that he is not human. *Terminator Salvation (McG 2009)*

In *Terminator Salvation*, when the human terminator discovers what he is, the revelation leads to a breakdown as a result of loss of identity. Because the humans know that machines prey on their tendency to feel pity for those like them, when the cyborg is revealed, the humans' reaction is to string him up and degrade him like any other machine. However, the one main element in this terminator that is different from the previous terminators is his completely human heart. The film places the most importance on this fact because although he has a human mind, it's clear that it can be controlled by the machines. In fact, when Conner is injured it's the terminator's heart that saves him (through a heart transplant).

The merging of human and machine is evident in the construction of the cyborg body, but *GITS* presents this phenomenon as a race of people with varying degrees of biological and machine part integration. The fact that the group of people that have opted to get bionic implants in this future vastly outnumbers those that do not, suggests that at some point in the pre-apocalypse, cyborgs had become the new society to be tolerated and had been accepted either in part or as a whole (acceptance was step one and assimilation was step two). However, in *The Matrix* and *Terminator* films human distrust prevents acceptance of the machines and human-machine assimilation is forced onto the humans.

This fusion of bodies is very prevalent in *The Matrix* films. The humans in the year 2199 believe that they are living their lives in a technology-rich world when in fact they are living in a dream controlled by a network of machines. The machines have fused with the human body in order to obtain the power they need to survive. As a result, the human species has been completely altered with machine implants and, outside of Zion, no longer procreates through a natural process. This concept presents a unique angle in the post-apocalyptic genre because while it is clear that humans have been defeated and enslaved and the earth has been destroyed, the human race still continues. In addition the majority of humanity still believes that it's thriving because they are unaware of the truth; the truth being they are not free, but essentially being used as a power source to sustain the machines. While this captivity is presented by the protagonists as a form of slavery (specifically of the mind) the structure of the dream world more closely resembles a forced reality that is better described as entertainment. Given that fact, it's less valid to say that the machines are a threat to the future of humanity itself; in this case they are simply a threat to the freedom of humanity. However, Agent Smith states that the freedom of humanity could mean the end of everything around it. He makes this argument by comparing humans to a virus; they destroy the resources of the earth and move on. The machines, however, do not function as viruses, but instead use their human enemies to create a new co-dependent relationship that results in a semi-peaceful existence.

Ahrens claims that Neo's role (the hero role) in this film is not to save the world, but instead to ensure that humanity continues to exist in an already destroyed world [2]. He states that bioscience and artificial intelligence lead to scenarios that are a catalyst for the modern technological apocalypse, and is the result of man's actions. He also states that Sontag's claim that "science and technology are the great unifiers" in these types of apocalyptic film does not apply. However, I contest that this statement is truer of *The Matrix* than of any other apocalyptic film. If artificial intelligence and the ultimate war between man and machine are the cause of the apocalypse, then it's only fitting that the union of man and machine would be the solution. In the case of *The Matrix*, the unifier is a form of biological fusion that allowed man and machines to coexist as symbiots.

Perhaps it's because of this symbiosis that we begin to see similarities between the machines and humans, especially Neo and Agent Smith, throughout *The Matrix* trilogy. *The Animatrix* gives us the history of the development of the robots for the sole purpose of serving man. This event is followed by the revolt of the machines, their claim for independence, and their establishment as a self-contained species and nation. The war between the humans and the machines is what leads to the destruction of the earth and the formation of the matrix. The actions of the machines mirror their human creators who also decide that they do not want to live enslaved at the will of the machines and also revolt and claim their independent nation in Zion. However that independence, as well as the differences between man and the machines, is an illusion. Neo, the man prophesied (by a machine) to be the savior of humanity is more in tune with the matrix than any other human. He cannot only see the code of the matrix, but he can also subordinate it to his will. His lack of visible emotion and his mechanical movements are more like those of the agents he fights and less like the "home-grown" humans of Zion whom he fights to protect. John Anderson's (Neo's) life and environment in the matrix also reflects a subconscious awareness of the matrix itself. Swanstrom states that Neo's surroundings are a reflection of his role as a slave in the matrix; his apartment is filled with wires, monitors and computer peripherals that trap him in his space [122]. In contrast, his colorless cubicle is extremely cold and empty and we see him staring listlessly at a blank screen.

Swanstrom argues that the presence of the matrix reshapes the consciousness of those that are "plugged in" to it. However, I would argue that the humans also affect the system that they sustain. The more Agent Smith is in contact with humans, the more he begins to exhibit human characteristics (*i.e.* he sweats, he ponders philosophical questions, he shows feelings of anger and disgust). These characteristics are enhanced after Neo defeats Agent Smith by merging with him at the end of the first movie. In a way, this act creates a new consciousness for both of them; Neo realizes his power and destiny and therefore becomes one with the machines, and Agent Smith becomes unplugged from the system and adopts a very human wish to destroy Neo that is based solely on personal vengeance and hate.

Given these clues, one can create a timeline between the films presented which outlines a potential evolution in the relationship between man and machine. The *Terminator* films depict the pre-apocalypse and apocalyptic view of the world with humans marveling at their technological advances. This is followed by the subsequent separation of the machine "child" from its creator and an assertion of its identity separate from the humans. *The Terminator* and *The Matrix* films differ in their telling of who started the conflict, but both depict the man-machine wars as the cause of the apocalypse. Finally movies like *Blade Runner, GITS* and *GITS2* depict a post-apocalyptic future in which machines either integrate with humans and live in relative peace and/or become indistinguishable from each other.

Looking at the many examples of machine-related apocalypse from films like *Metropolis* all the way up to present day tech-noir films, it's clear that there is a common theme that states that the rise of the machine is directly related to the end of humanity. What's interesting is that while this theme is present in almost all of these films, there has also been a significant change in how the threat is depicted. In *Metropolis, Frankenstein* and *Demon Seed* the threat of the machine is easily visible because the robot monsters are so unlike humans; their movements are unnatural, their motives are evil or dangerous, and they present a real threat to human life. However, in later films the lines between robots and humans are much less obvious. With the introduction of the cyborg, we see humans whose bodies are mostly machines and machines who are virtually indistinguishable from humans. Therefore the threat has changed from the extinction of humanity through destruction to the extinction of humanity through technological evolution. However, the latter, in some cases, is not portrayed as a terrible thing.