HAPTIGO TACTILE NAVIGATION SYSTEM

A Senior Scholars Thesis

by

SARIN REGMI

Submitted to Honors and Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

May 2012

Major: Computer Engineering

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Approved by:

Research Advisor:	Tracy Hammond
Associate Director, Honors and Undergraduate Research:	Duncan MacKenzie

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ABSTRACT

HaptiGo Tactile Navigation System. (May 2012)

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Tactile navigation systems employ the use of ones sense of touch with haptic feedback to communicate directions. This type of navigation presents a potentially faster and more accurate mode of navigation than preexisting visual or auditory forms. We developed a navigation system, HaptiGo, which uses a tactile harness controlled by an Android application to communicate directions. The use of a smartphone to provide GPS and compass information allows for a more compact and user-friendly system then previous tactile navigation systems. HaptiGo has been tested for functionality and user approval of tactile navigation. It was further tested to determine if tactile navigation provides for faster navigation times, increased path accuracy and improved environmental awareness compared to traditional maps navigation methods. We discuss the novel usage of smartphones for tactile navigation, the effectiveness of the HaptiGo navigation system, its accuracy compared to the use of static map-based navigation, and the potential benefits of tactile navigation.

DEDICATION

Dedicated to my family, friends and mentors who have always been a motivating factor for me.

ACKNOWLEDGMENTS

I would like to thank my adviser, Dr. Tracy Hammond, my graduate student adviser, Manoj Prasad and all the other members of Sketch Recognition Lab at Texas A&M University for their help and effort on making this project a success.

NOMENCLATURE

API	Application Programming Interface
GPS	Global Positioning Systems
4G	Fourth Generation
SIM	Subscriber Identity Module

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CHAPTER I

INTRODUCTION

Introduction to navigation

Maps have long been recognized as the key to navigation. They are often coupled with a spoken/written list of directions or additional information about the route. In modern times, we have the option of both paper and dynamic electronic maps, found on devices such as smartphones, GPS devices (both handheld and those integrated into automobiles), tablets, etc. Despite the advancement of these systems to provide users with easy and understandable navigational instruction, visual and auditory navigation may not be the most effective modes of navigation.

Many visual navigation methods, such as maps and GPS displays, require time for the user to orient themselves to the map and interpret it in relation to their surroundings. When referencing a map, either dynamic or static, a user must take the time to decipher the map, and then take the information they have gathered and use it to determine their location and direction in relation to their actual environment.

Auditory instruction requires much of the same; users must spend time searching the

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This thesis follows the style of *Journal of the Association for Computing Machinery*.

area for landmarks to orient them- selves prior to and throughout navigation. Tactile navigation requires no orientation time or understanding of environment on the users part and hence a more accurate method of navigation.

Different forms of navigation

Tactile navigation is a less environmentally intrusive form of navigation than those of visual and auditory navigation. Any kind of visual maps require people to spend time looking at a visual. Even dynamic maps, which are very easy to understand, require an interface displaying a map for users to follow. HaptiGo requires usage of an interface in the beginning of the program to instruct the program where to guide, and beyond that there is no need to look at the Android phone. HaptiGo requires the least amount of usage of an interface compared to other smartphone navigation system.

Tactile feedback also allows for instantaneous communication of instruction. Instead of having to wait several seconds for an instruction to be vocalized or to have to review map displayed on an interface, an actuator will vibrate, giving the same instruction in a fraction of the time. The constant directional feedback combined with minimized mental processing yields more accurate navigation.

Tactile feedback also has potential for those with disabilities. The blind, in particular, would benefit greatly from the advancement of accessible haptic technologies, providing a subtler and more reliable means of navigation than the use of seeing-eye animals, and could be more finely tuned to their needs than an animal.

Related work

Research on interaction systems during the past two decades was focused on visual and audio cues. However, current research has shifted to the use of tactile feedback as a more intuitive and unobtrusive means of interaction. This research focuses more on military applications [Davis 2006; Krausman and Elliott 2005; Smets et al. 2008] and navigation systems [Erp et al. 2005; Erp and Duistermaat 2005; Heuten et al. 2008; Bosman et al. 2003; Tsukada and Yasumura 2004; Pielot et al. 2008]. Various other studies conducted have combined different modes of interactions (visual, audio and tactile) to provide contextual information of the physical world [Krausman and Elliott 2005; Gilliland and Schlegel 1994]. Some interaction systems have integrated augmented reality with tactile, audio and visual aids to create an information-rich system [Thomas et al. 1998; Feiner et al. 1997; Pielot et al. 2008; Rohs et al. 2007; Gilliland and Schlegel 1994].

Krausman and Elliott [2005] expand on benefits of tactile feedback in situations where audio and visual cue channels are overloaded and proposes the use of tactile alerts to provide situational awareness to platoon leaders during high workload military operations. This implementation is further supported by tactile displays used as communication systems for pilots and astronauts, providing directional cues to aid spatial orientation [Gilliland and Schlegel 1994; Jones and Nakamura 2003; Veen and

Erp 2001], as well as being used to aid navigation [Davis 2006; Tsukada and Yasumura 2004; Thomas et al. 1998; Pielot et al. 2008; Erp et al. 2005].

Projects like [Tsukada and Yasumura 2004; Pielot et al. 2008; Erp et al. 2005] presented a tactile-based functional navigation system where a belt is used to provide haptic feedback to users. Van Erp et al. [2005] showed that pedestrians are able to follow a route consisting of waypoints guided only by a tactile belt. However, the limited number of displayable directions caused the users to travel along indirect routes between waypoints in some cases Tactual Wearable Display [Tan and Pentland 1997] attached a matrix of vibrators to the back of a vest, and tried to transmit directions and other information to user. Smets et al. [2008], with the use of a tactile vest forwarded a scenario where it was hard to conclude whether tactile displays made significant effect on situational awareness. It did conclude, however, that the addition of tactile displays to other systems could improve the performance rather than being used exclusively. Bosman et al. [2003] proposed an indoor tactile navigation system via two bracelets. It outputs three commands: left, right, and stop (both bracelets activated). Heuten.et.al [2008] designed a solely tactile based navigation belt with more precision in directing users.

Relation of previous work to HaptiGo

The positions of the vibration actuators were chosen based on peoples natural reaction to touch stimuli. The three vibrators are placed strategically on the right and left shoulders and mid back. Any stimuli to the shoulder will create a natural response to turn in that direction. This makes the placement of the actuators more intuitive compared to other systems.

In the ActiveBelt project [Tsukada and Yasumura 2004], the vibrations are delivered through a belt to the lower torso. The actual usability of the belt is questionable, due to the fact that the vibrators must be relocated on the belt according to waist size. Our haptic harness can easily be worn over most clothing. In addition, the adjustable straps allow it to be fit to users of all shapes and sizes without having to rearrange the vibration actuators.

Smets et al. [2008] designed a tactile vest structurally similar to ours is described. However, this vest is significantly more constraining than the harness we designed. Our vest has an open front, and uses a minimal amount of material, providing for unrestricted movement and increased comfort. Furthermore, the placing of actuators and number of actuators being used make our system more intuitive and less confusing.

Other implementations of navigation systems such as [Thomas et al. 1998; Feiner et al. 1997; Pielot et al. 2008; Wagner and Schmalstieg 2003; Rohs et al. 2007; Krausman and Elliott 2005] use excessive external hardware to receive GPS signal, compass bearing, and other pieces of information. Touring Machine [Feiner et al. 1997] requires a backpack full of equipment, and Wearable Computer [Thomas et al. 1998] requires augmented reality goggles as well as a backpack. Available technologies have since advanced, and HaptiGo requires only a small vest and a smartphone.

The use of a smartphone to provide the necessary information for this technology greatly increases the overall accessibility of the product. Smartphones are rapidly becoming the norm in modern society. Smartphone usage is on the rise; it is predicted that 1 in 2 Americans will own a smartphone by the end of 2011 [Entner 2011]. If desired, one could install the necessary Android application and have it running on their phone in mere seconds.

The minimalistic approach to HaptiGo construction also greatly reduces the cost of production for the harness. All of the components of the harness are also affordable, the most expensive part being the LilyPad at $20. The total cost of harness comes to be under $50 for our prototype, which can be further reduced with mass production. Such affordability could make tactile navigation a navigation method easily accessible to the masses.

CHAPTER II

IMPLEMENTATION

Implementation of HaptiGo

The users objective is to navigate along a course from a starting point to a final destination. The navigation path is broken into segments using waypoints. The course segments are straight paths, and the waypoints are located at the vertices of the segments. The process of navigation consists of navigation to a waypoint until the user is within a set radius of the point, upon which the cycle repeats until there are no waypoints remaining. HaptiGo and the Arduino LilyPad code work together to receive GPS signal, bearing, and deliver a constant stream of vibrations to user to direct them through waypoints to a final destination.

Hardware

The central control unit of the HaptiGo harness, which is shown in Figure 1, is a LilyPad Arduino ATmega328V microcontroller (2). A 3.7V cell phone battery powers the circuit (4). Conductive threads (1) connect the LilyPad control board ports to three Arduino LilyPad Vibe Boards, the actuators used to send haptic signals to the wearer. Signal communications between the Android smartphone and the LilyPad control board are conducted via a BlueSMiRF Silver Bluetooth modem (3). A variety of Android smartphone models were utilized throughout the development. The most frequently used phone was a Motorola Atrix 4G, equipped with a SIM card/data plan, running the

Android 2.2.2 platform. Motorola Milestones were also used, running the Android 2.2.1 platform. These phones were not equipped with SIM cards and data plans. Figure 2 shows the corresponding circuit diagram of Figure 1.

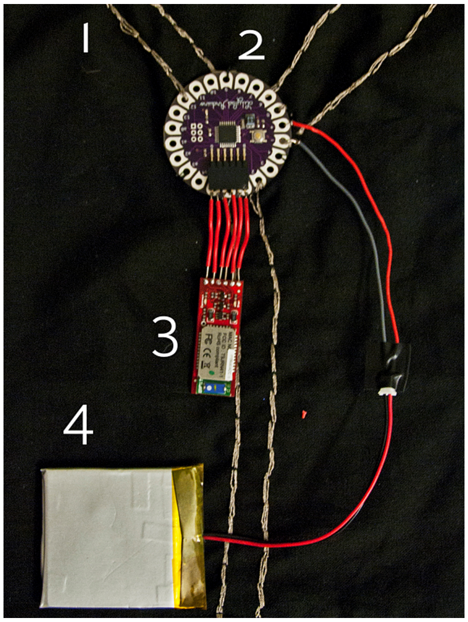


Figure 1. Prototype of Harness

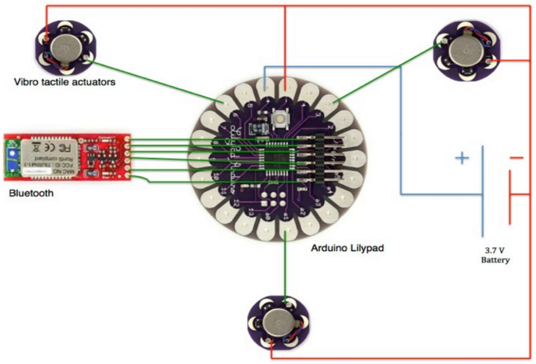


Figure 2. Circuit Diagram

Arduino software

The Amarino toolkit was used to provide a connection between the Android phone and the Arduino LilyPad via Bluetooth, so we could send and receive data between the two.

Navigation with HaptiGo

The Android application obtains navigation waypoints from Google Maps while HaptiGo is running or in the form of a Google Earth KML file stored on the SD card and processes them into Android location objects. These location objects are loaded into a queue, and the program then leads the user to each waypoint in the order that they appear on the path.

There are two pieces of information obtained from the phone that are essential for navigation. First is the user’s current location, which is updated whenever the user travels a distance of two meters, second is the bearing to the desired location. The data is updated every three seconds.

Android implementation

To provide a constant stream of haptic signals, a timer is called in the Android application. This timer sends a signal to the Arduino code every three seconds. The three-second delay is to prevent a build-up of vibrational signals. Once Arduino receives this signal, it sends a signal to the Android Application that triggers the ArduinoReceiver, the method that processes the Bluetooth signal. It is implemented this way because it is necessary for the majority of the calculations to be called from the ArduinoReceiver instead of directly from the timer. If the methods were called from the timer, this would cause lagging in the code, since the timer does not realistically run on an exact time interval if there are a lot of methods called from it. This is why only one method is called from the timer, which sends the signal to the Arduino. In the ArduinoReceiver, methods are then called to calculate and instruct the Arduino to communicate vibrational patterns.

The majority of the activity is called from within the Android code, in the ArduinoReceiver. When first called, it checks to see if the current location of the user is within a five-meter radius of the next waypoint. A five-meter radius allows for the usual two to three meter range for GPS accuracy, as well as some extra space so that it is not necessary to be standing on the exact waypoint. The radius is increased to 20 meters for driving tours, to allow for the width of the road, the size of intersections, etc. If the current location is within the radius, the program registers that the user has reached the waypoint, notifies the user that they have reached a point via a haptic signal, and accesses the next waypoint in the locations queue. If the user is not within the waypoint radius, the program continues to send vibrations to the user to navigate them to the next waypoint.

The program determines the haptic signals by calling a method that determines if the user needs to veer right, left or continue straight to access the next waypoint. This is determined by a turning algorithm, which determines whether a right or left turn is more efficient in a given situation, as well as calculating the necessary turning angle.
The algorithm uses two values: the users current bearing and the bearing to the next destination. The bearing to the next destination is calculated by a method in the Android

library, and is based upon the users current position and the desired location; the method determines the path of shortest distance to the desired location, and returns the bearing of that path (again in degrees east of true north). The turn algorithm is as follows:

- If the bearing to the next destination is greater than the current bearing, check to see if the current bearing + 180 degrees is still less than the bearing to the next destination. That is, if a 180 degrees turn to the right will still not bring the user to or beyond the desired bearing. If this is so, it is more efficient to turn left. If not, a right turn is more efficient. The colored region in which the users current bearing falls into determines whether the user turns, right or left or travels straight. The necessary turning angle also determines the duration of a specific vibration. The larger the angle, the longer the duration of the vibration sent to the user.

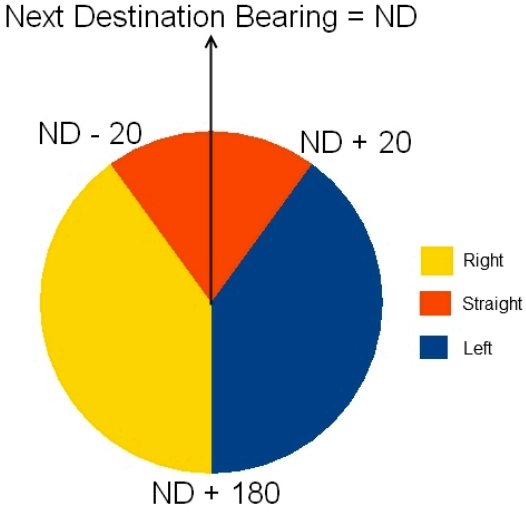


Figure 3. Angle of Turn Calculation

From Figure 3, the colored region in which the users current bearing falls into determines whether the user turns, right or left or travels straight. The necessary turning angle also determines the duration of a specific vibration. The larger the angle, the longer the duration of the vibration sent to the user as shown in Table I.

Table I.
Vibration Frequencies and Angles of Turn

Turning Angle in Degrees	Direction to turn, Vibration Duration (Milliseconds)
Less than 20	Straight
20-30	Left/right - 200
30-60	Left/right - 350
60-90	Left/right - 500
90-135	Left/right - 750
135-180	Left/right - 1s

Limitations

Once the direction of the user, and the frequency of the vibration are calculated, they are sent to the Arduino LilyPad, which then responds with the appropriate vibrations. This process takes place every three seconds. This time is customized for different applications that require faster of slower update times, such as driving applications. HaptiGo encountered the standard GPS issues that all GPS-based applications face. If the user is in between tall buildings, or close to a building with a lot of glass in the structure, the GPS will not send accurate information. The application will not receive any sort of signal inside buildings, and thus cannot function indoors. Since our application is mostly used for walking, and deals with smaller distances between waypoints, it is extremely important for the current location information to be accurate. This limited us to only designing courses in wide-open spaces. Although this was a limitation to our version of the navigation system, as GPS technology improves, the system will be able to be utilized in a greater variety of areas. Sometimes, there were issues with Bluetooth connection and the system had to be restarted from beginning so that the Bluetooth can connect to phone again. To solve that issue, we implemented a shortcut menu, which would let user to reconnect to the Bluetooth anytime the connection went off.

User interface

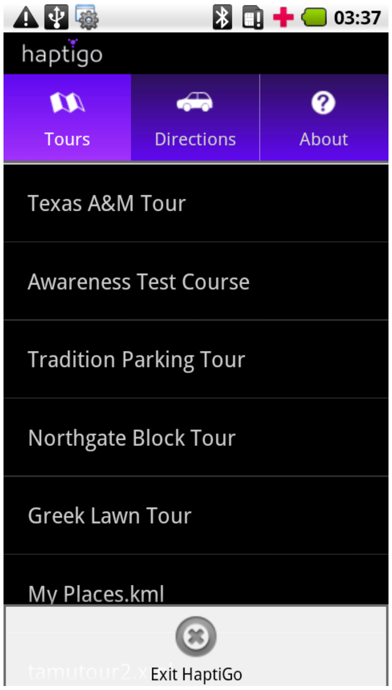
Our Android application, HaptiGo, is capable of performing the following tasks:

1. Retrieve route coordinates, landmark coordinates, and their descriptions from a se of tours that come with the application, as well as from a special Maps folder created by the application on the SD card where users can load their own customized KML files that can be created on Google Earth.

2. Draw a route path, along which all landmarks are identified and marked with interactive pins. When selected, a dialog box appears, which displays information about the selected location.

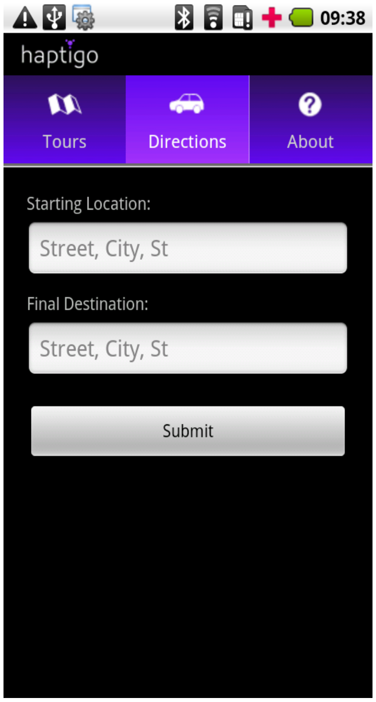
3. Play informative audio files when a landmark is reached.

4. The corresponding layouts of Tours and Driving Direction interfaces are shown in Figure 4 and Figure 5 respectively.



Texas A&M Tour
Awareness Test Course
Tradition Parking Tour
Northgate Block Tour
Greek Lawn Tour
My Places.kml

Figure 4. Tour Listing



Starting Location: Street, City, St

Final Destination: Street, City, St

Figure 5. Driving Directions

CHAPTER III

METHODS

Participant pool

In total, we performed 35 user tests with HaptiGo. Information about the participants, as well as their reactions to HaptiGo, was gathered via online survey. All of the test participants were between the ages of 16 and 30. The majority of the users have completed a high school education. The vast majority of the participants had never heard of tactile feedback before. Those that had were all studying in the Computer Science and Engineering fields. Of all of our users, 58.4 % owned smartphones. Figure 6, shows distribution of participants based on their academic background and Figure 7 shows the preferred mode of navigation among them.

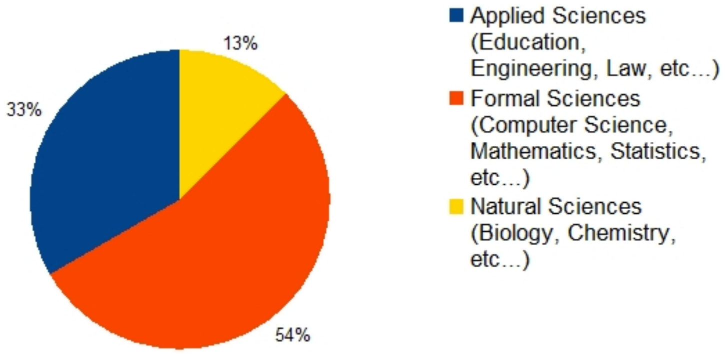


Figure 6. Area of Study of Users

Testing setup

The courses were set on the top level of a parking garage, an area that provided an empty area for the users to walk in, as well as an open space free of sky obstructions, so we could receive the best GPS signal possible. The GPS was consistently accurate to 2-4 meters in this location.

For all of the functionality tests, a Motorola Atrix 4G (equipped with data plan) was used. The data plan provided Assisted GPS, which increased GPS accuracy. Aside from HaptiGo, Google's application My Tracks was used. My Tracks allowed us to document the exact path that the user traveled during the course of the testing, as well as information such as their average speed, time spent traveling, distance traveled, etc.

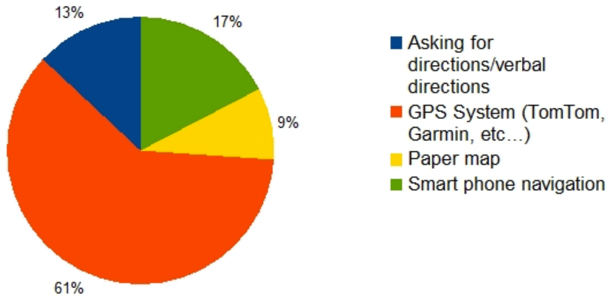


Figure 7. Preferred Methods of Navigation of Users

During the development process, one of the test proctors would follow slightly behind the participant as they proceeded through the course, to keep an eye on the Bluetooth connection (an LED on the Bluetooth modem indicated if it was connected or not) and to ensure that the actuators were still vibrating as planned at regular intervals. Once we re-designed the Bluetooth piece, and implemented a reconnect button into the GUI this became less of a problem. The Bluetooth connection was more stable and users were easily able to reconnect and continue their course in the case of a Blue- tooth connection failure.

Functional testing

We ran a functionality experiment to receive user feedback about our haptic harness, as well as test general responsive- ness to tactile navigation. For the functionality tests, a secondary testing application was used on the smartphone. The application was very basic, a GUI with only three buttons: initiate the walking tour, sever and reestablish the Bluetooth connection, and exit the application. The application ran the users through a set of hard-coded points (points initialized within the application, rather than from an external XML or KML file), and served merely as a method to test the actual harness, rather than the full project. The plotted course was short, approximately 300 feet long, and navigated the user through four waypoints at scattered locations.

Prior to the testing process, the test participants were briefed on the purposes of the HaptiGo project and some basics about the construction of the harness. We explained that the harness was going to use vibrations to navigate them through a course comprised of a series of points. They were told that there were three tactile actuators built into the harness, but we did not explain to them how to interpret the signals, to allow for unbiased results. The participants were then fitted into the harness by the test proctors, with the straps being adjusted to fit the harness as tightly as possible, so all of the haptic signals could be clearly felt. They were told to hold the smartphone flat out in front of them, about level with their navel, and then instructed to simply walk wherever they thought the harness was telling them to walk. The test was ended once the user either reached the final destination point, or when the Bluetooth disconnected.

Efficiency testing

All users were run through a 200-foot training course before the main course consisting of four points, in order to give them time to become accustomed to our tactile navigation system. Those with prior experience were run through the training course once, to refresh their memory. Those with no previous experience went through the training course twice. All users were allowed to ask questions about the navigation system, such as the meaning of the signals, how best to go about turning, and so on. It was at this point in the testing that it was explained that one should veer rather than perform a sharp turn when signaled. It was also here that most users noticed and questioned the vibrations signifying that one has reached a waypoint or a destination.

Once the test participant was comfortable with the navigation system, and the experimenters assured that they had at least a basic understanding of the workings of the system, they user performed the main course (course A or course B) as shown in Figure 8. Both courses consisted of 7 waypoints, and were 650 feet in length, spanning the entire area of the garage level. The waypoints of each course were marked with a chalk circle containing the course letter and the number of the waypoint (i.e. the points of course A were labeled A1-A7). The user was told that there were two test courses, one of which would be navigated by traditional visual methods, one via tactile navigation. They were alerted of the fact that they would be timed; though it was stressed that they need not rush through the course, merely travel at a comfortable pace.

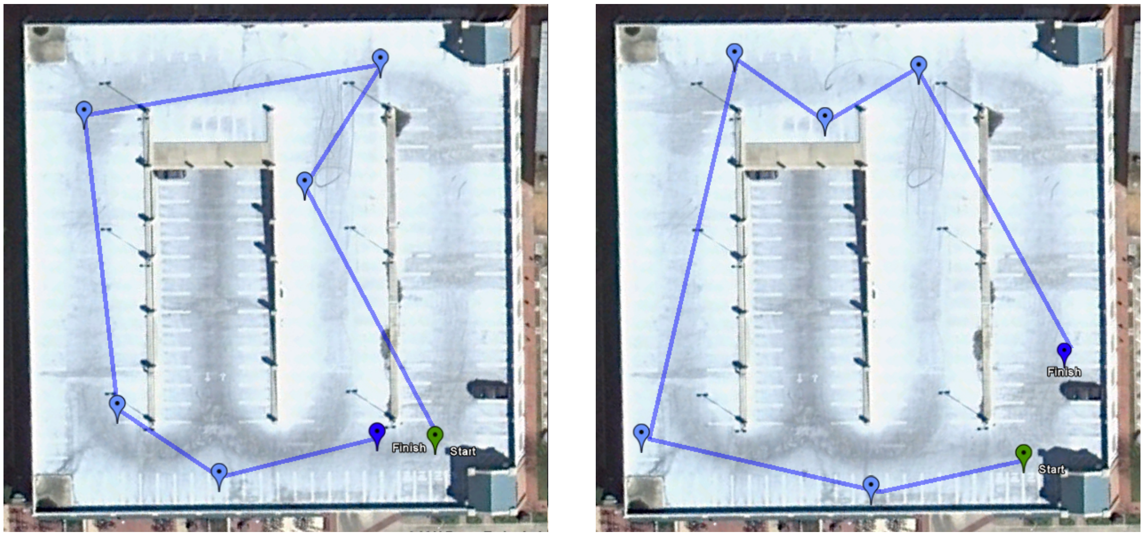


Figure 8. Maps Given to Users for Navigation

A coin toss was used to determine if the user was to go through the first course using tactile navigation or a paper map. The same method was used to decide which course the user was to take, A or B. When proceeding through the map course, the participants used a paper printout of the course (Figure 8). They were instructed to look for the circular markings as a verification that they had reached the waypoints, and told that once they could see the marking and verify that it was the correct point, they were allowed to proceed on to the next point. This allowance simulates the five-meter waypoint radius allowed by the haptic harness. The users were not given the actual map until the timer was started.

When proceeding through the haptics course, they were not told to look at the markings on the ground. They were there to be referenced if necessary, but as there were two sets of course points marked on the ground, the users knew that navigating toward any kind of marking was unhelpful.

If the Bluetooth modem disconnected for any reason during the haptic navigation course, the timer was paused, to give time to reestablish the Bluetooth connection. Once the connection was secure, the timer would be turned back on, and navigation could continue.

Upon successful completion of both courses, My Tracks was turned off, the users times for each course were documented, and the users were emailed a survey asking about their opinions of HaptiGo and commentary on the process and how it could be improved.

CHAPTER IV

RESULTS

User study I

For the functionality testing, many of the users were initially startled when the actuators began buzzing, regardless of being alerted to their function prior to the test. However, all of the participants became accustomed to the vibrations within a very short period of time, and none of them reported finding them uncomfortable. Several of the users commented that they occasionally found the vibrations irritating; however, their comments were directed more at the implemented vibrational pattern. They found the frequency with which the actuators went off to be too high; we decreased the frequency to once every three seconds, and received no further complaints. Since users were using the application while moving at a normal walking pace, the three-second frequency provided fast enough feedback for users to be directed correctly. This time interval is easily changeable for different uses of the HaptiGo. . Table II provides a better illustration of these results.

We noticed that many of the participants reacted to the vibration signals with very sudden, sharp turns. They would zigzag through the course, wasting time traveling back and forth over the designated path rather than continuously progressing forward. After observing this behavior in several successive tests, we began to instruct the participants to veer in the direction that they were being told to go–that is, to continue traveling forward while bearing slightly to the right/left. This instruction kept the participants constantly moving forward, and for the most part put a stop to the zigzagging behavior. An intriguing observation was that many of the users would look at the smartphone for visual indicators, regardless of their being told that there was nothing of use to them on the display.

30 users rated the efficiency of the navigation system to be an average of 6.6 out of 10, 10 being most efficient, with a standard deviation of 1.37. Users gave the vibrational patterns an average of 5.7 out of 10 for clarity, 10 being very easy to understand, with a standard deviation of 1.53.

54% users said they could fairly easily navigate with harness while 38% were neutral and 8% felt it was difficult.

Table II.
Vibration Testing Results

	All the time	Sometime	Not at all
Vibration Pattern Awareness	13%	69%	19%
Irritation due to Vibration	0%	6%	94%

User study II

For efficiency testing, when users were told that the process was timed, they walked at a faster-than-average pace, and some began disregarding the signals in an attempt to complete the course as quickly as possible.

When using the map, we found that the users had trouble orienting themselves. At the beginning of the test, users would often misread the map and walk in the opposite direction of the course. Many missed waypoints, and had to backtrack through parts of the course. Much time was wasted circling an area, searching for the actual waypoints. Users also spent a lot of time simply stopping and staring at the map to plot out their route, a halting behavior not seen during tactile navigation.

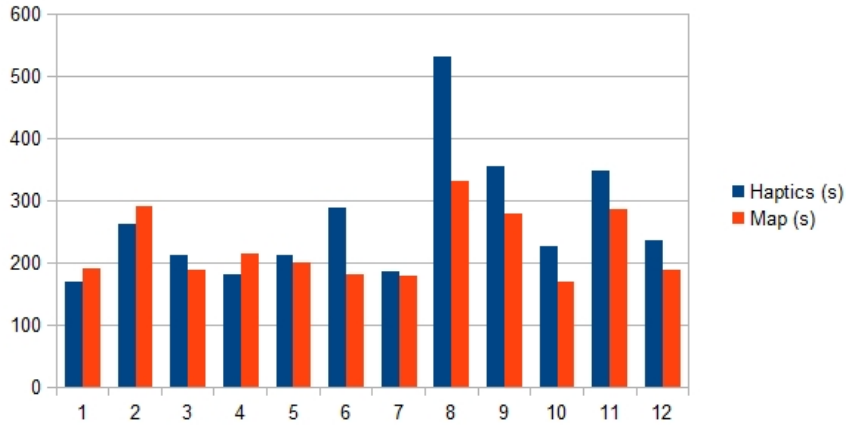


Figure 9. Time Comparison: HaptiGo vs. Maps

The mean distance covered while navigating with HaptiGo was 876 ft. compared to 937 ft. with Maps. However, average time spent on course was 248 seconds for HaptiGo compared to 225 seconds for Maps. Figure 9 and Figure10 show the distribution of data that was used to get those averages for time and distance.

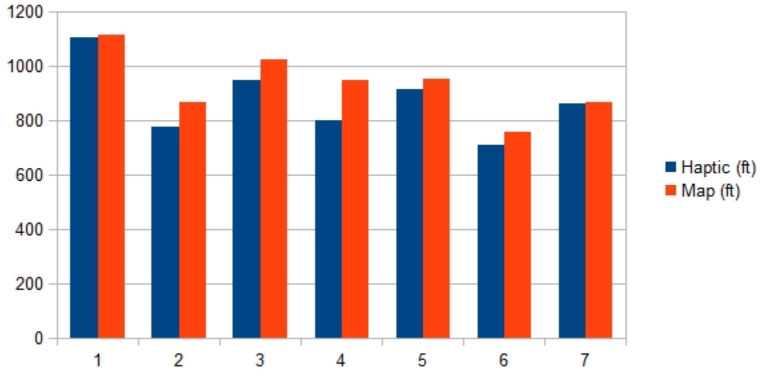


Figure 10. Distance Travelled: HaptiGo vs. Maps

Although HaptiGo did not prove to be more time-efficient than traditional map navigation, it led users along a more accurate path, in terms of total distance traveled versus course length.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Discussion

People wanting to look at smartphone while navigating supports the idea that people are currently more inclined toward visual navigation techniques. People waiting for system to respond, or being shocked with vibrations shows that they are intrigued by the technology itself that they forget its functionality. We believe that with time and continued exposure to haptic navigation, people could become equally accustomed to this form of navigation and hence we can get better results with efficiency and environmental awareness.

When users walked a higher speed they began to miss waypoints. The farther they traveled away from a waypoint, the more confusing the navigational signals became, and oftentimes the test would have to be restarted. However, this issue did not arise when users traveled at a more average walking pace.

Users stated that they wished that were given instruction to veer rather than make sharp turns. They also complained that the straight actuator was placed in such a way that it was difficult to feel. However, this issue was addressed in the next version of the harness. Aside from that, users felt that the system was self- explanatory.

Our data from the efficiency testing supports our hypothesis that HaptiGo is a more accurate form of navigation than the traditional visual navigation. HaptiGo provides a constant stream of instructions via vibration to users. In addition, it responds to every turn and movement that the user makes. Unlike traditional maps, HaptiGo immediately corrects a user when veering off of the course.

Like all new technology, users need to become accustomed to vibration frequencies, turning methods, and so on. Overall people are much more accustomed to using basic visual maps to navigate, and even the training that was given before the user test most likely did not make people as comfortable with using tactile navigation as they are with maps. We feel that the efficiency results were more dependent upon users' experience with the system. Although the data did not show HaptiGo to be more time efficient in our user tests, we believe that with the right user training HaptiGo could be just as time efficient as traditional navigation.

HaptiGo makes use of the Android smartphones internal compass, and thus necessitates holding the smartphone like a compass. During the navigation process, the phone must be held directly in front of the user, pointing in the same directing as the user is facing, to receive correct compass/bearing information.

The addition of an external compass would eliminate this need. An external compass would be an addition well worth investigating in the future. It would allow the option of the user turning on the navigation, and then putting the phone in a pocket or a bag, making the application completely hands-free. HaptiGo would require less of the users attention, allowing for multitasking during the navigation process, and an even more unobtrusive application.

After heavy use of the hardware, parts of the hardware lost functionality, namely the Bluetooth. The connections between the modem and the control board loosened, and thus the Bluetooth would lose power and connectivity upon the slightest shift. Because of this, many user tests were disrupted and required a restart. Even if a user did not complete an entire test course, they managed to walk through at least half of the course, and could give useful feedback. We eventually soldered the Bluetooth modem to the control board via wires, and the connectivity issues were solved.

Conclusion

We have designed a navigation system, HaptiGo, which uses tactile feedback to communicate directional information. We developed a wearable harness, which delivers the vibrational feedback to the user. The positioning of the actuators and the minimalistic approach to the hardware makes this system one of the most intuitive tactile navigation systems created as of yet. The affordable hardware and utilization of smart phone technology for computing makes HaptiGo a more accessible system than previous tactile navigation systems.

We have experimented this system for use with walking tours. Based on our experimentation, we are confident in saying that this systems intuitive and precise nature yields more accurate paths of travel in comparison to traditional forms of navigation using visual aids. We believe that tactile navigation could become more commonplace in the future, if people are given time to become accustomed to such methods.

Future work

In the future, we would work to test our application with visually impaired people. A possible study would be a comparison between the data collected from the visually impaired subjects and the data collected in this experiment. We hope to see visually impaired subjects being able to navigate just as efficiently with HaptiGo, if not more so, than those whose vision is intact.

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