UNMANNED COOPERATIVE FIRE-SEEKING AND -FIGHTING ROBOT WITH BLUETOOTH COMMUNICATION AND STAIR-CLIMBING CAPABILITY

A Thesis

by

YING-CHIN CHAO

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

MASTER OF SCIENCE

May 2010

Major Subject: Mechanical Engineering

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Approved by:

Chair of Committee,	Won-jong Kim
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	Steve Suh
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ABSTRACT

Unmanned Cooperative Fire-Seeking and -Fighting Robot with Bluetooth Communication and Stair-Climbing Capability. (May 2010)

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Chair of Advisory Committee: Dr. Won-jong Kim

This thesis presents a prototype of Unmanned Cooperative Fire-Seeking and -Fighting Robots (UCSFRs) which have a new way to climb up the stairs or traverse over obstacles with a ball screw. There are three unmanned vehicles (one Mother Vehicle (MV) and two Daughter Vehicles (DVs)) presented in this research. The MV can carry two DVs to climb stairs. They can communicate with each other using Bluetooth communication modules. The core system of the UCSFRs is a PIC 16F877 microcontroller on a 2840 development board. The software is written in C language and the interface is established through Hyper Terminal built in Windows XP. UCSFRs are low cost unmanned vehicles compared with other commercial ones. The double-deck structure is applied on the DVs. The body of the MV can be extended for special purposes. In this research, there are three tests used to verify the functionality of the UCSFRs: (1) MV's finding and stopping fire, (2) Communication between the MV and the DVs, and (3) the MV's climbing stairs. In the second test, the DVs run in the opposite direction to assist MV detect fire. By cooperative work, they can save time finding the fire. The MV will go to the high-temperature area according to the data sent by the DVs. Because of the features mentioned above, UCSFRs can be used to perform dangerous tasks instead of fire-fighters.

ACKNOWLEDGMENTS

First of all, I would like to take this opportunity to express my sincere appreciation to my advisor, Dr Won-jong Kim, for his patience and help. I also want to thank him for his invaluable time and guidance that I received. He really helped me a lot. I also want to thank Dr. Steve Suh for his encouragement. Dr. Suh was always kind and gave me his help and suggestion. I really appreciated his invaluable time. I also would like to thank Dr. Shankar Bhattacharyya for his patience, help and invaluable time. Dr. Bhattacharyya always gave me many invaluable ideas.

Special thanks go to my good friends Hung-Yi Liao and Xuele Qi for providing help. They always helped me whenever I need it. I really appreciated their time.

Most of all, I would like to thank my parents and my girlfriend. Without their support, understanding and encouragement, this thesis would never have been completed. I really appreciated my parents' support and encouragement at my every step in my life. Because of my parents, I had this opportunity to study abroad and learn more.

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CHAPTER I
INTRODUCTION

In the real world, people may have some experiences of awaking from sound sleep due to the wailing of fire-engine sirens. When they read the newspapers, they would find that there are many accidents about fire such as wildfire, fire in the factories or apartments. There are many people dead in these accidents including firefighters. Fire damages properties of people and wastes social resources. Firefighters are always the first group of people to arrive at these scenes except the residents. When firefighters get a 911 call, they need to depart for the location right away. Sometimes they need to rescue people and search for the survivors. There is a latent hazard for these heroes: they do not know the situation inside the building and are also not familiar with the environment of the building which they are about to get in. At some scenes, firefighters know that there is a fire in somewhere around the building and need to send someone to check it out and find out where it is. In other cases, after firefighters extinguish the fire from the outside of the building, they still have to check out the inside of the building to make sure if there are the embers of the fire or not. This part is another danger for firefighters because the structure of the building may be unstable after big fire. The building may collapse at any time. Whatever reasons there may be, it is dangerous to let firefighters get in an unknown building, unknown environment, or unstable structure.

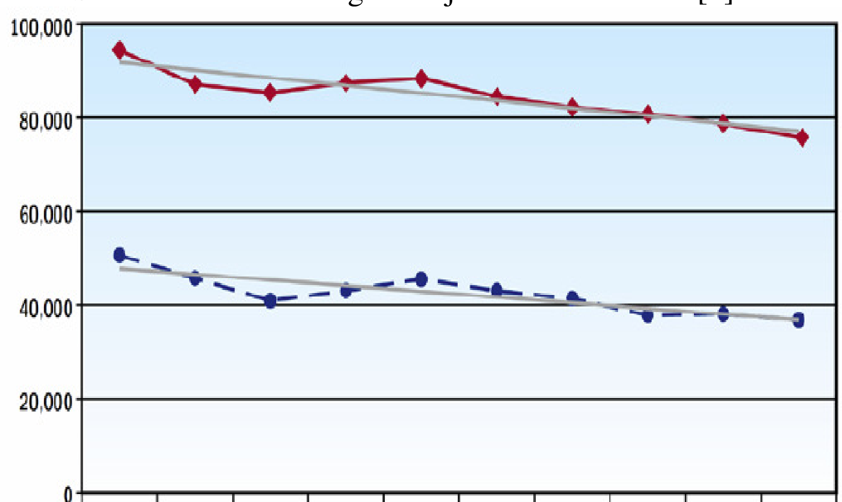
A. Statistics

There are many firefighters injured when they try to extinguish the fire or rescue survivors. Table 1 shows the statistics of the firefighter injured at fire scenes from 1995 to 2004. The following data shown in Table 2 are the accidents of fire from 1998 to 2007.

This thesis follows the style of *IEEE Transactions on Automatic Control*.

Figure 1. Firefighters check the inside and roof after the fire is extinguished. (http://www.silive.com/news) (Advance Photo/Bill Lyons)

Table 1. Statistics on the firefighter injured in fire scenes [1].



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
All Injuries	94,500	87,150	85,400	87,500	88,500	84,550	82,250	80,800	78,750	75,840
Firefighting, fireground	50,640	45,725	40,920	43,080	45,550	43,065	41,395	37,860	38,045	36,880

.

Table 2. Statistics on fire accidents [1],[2].

Year	Fires	Deaths	Injuries	Direct Dollar Loss In Millions
1998	1,755,000	4,035	23,100	$8,629
1999	1,823,000	3,570	21,875	$10,024
2000	1,708,000	4,045	22,350	$11,207
2001[1]	1,734,500	3,745	20,300	$10,583
2001[2]	*	2,451	800	$33,440
2002	1,687,500	3,380	18,425	$10,337
2003	1,584,500	3,925	18,125	$12,307
2004	1,550,500	3,900	17,875	$9,794
2005	1,602,000	3,675	17,925	$10,672
2006	1,642,500	3,245	16,400	$11,307
2007	1,557,500	3,430	17,675	$14,639

*1. Excludes the events of September 11, 2001.

*2. These estimates reflect the number of deaths, injuries, and dollar loss directly related to the events of September 11, 2001.

Note: The decrease in direct dollar loss in 2004 reflects the Southern California wildfires in 2003 with an estimated loss of $2,040,000,000 that occurred. The dollar loss estimate for 2007 includes the California Fire Storm with an estimated property loss of $1,800,000,000.

B. Objectives of the Thesis

It is unnecessary for firefighters to expose themselves under the dangerous condition. The motivation of this research is to improve the situation which is mentioned in the previous part of this chapter. The objective of this research is to build three unmanned vehicles to find a source of fire by the cooperation over Bluetooth modules. There are three unmanned vehicles, one Mother Vehicle (MV) and two Daughter Vehicles (DVs), cooperating with one another, finding out the flame and extinguishing the fire. The MV will carry her DVs and a fire extinguisher. It can search for unknown environment. If needed, it can also climb stairs from one floor to another. For the purpose of this mission, MV can let her DVs out from her "abdomen" and help her find out the flame. With two or three robots working together the time to find the fire will be cut down to half at least. To find out the flame is not the only purpose for these vehicles. They can be placed in the factory to prevent the fire or burglary.

C. Contributions of the Thesis

There are two modes of operation. (1) Under the full autonomous mode, the unmanned vehicles do not need to be controlled by a human being. All actions are pre-programmed controlled by microcontrollers and sensor systems. (2) Under the semi-autonomous mode, the unmanned vehicles are controlled by a human being. People just need to have a laptop, and RS232 and Bluetooth modules.

There are several significant contributions made in this research as listed below:

1. A novel ball-screw mechanism along with two micro-switches enables MV to climb the stairs.
2. Integrated circuit (IC) motor drivers can be substituted by the relay circuit. Relay is considered a switch; however, in this research it is used to complete a circuit to implement the same function as IC motor driver.
3. Another contribution is the design of MV. To achieve the capability of climbing stairs for MV do not need to consider the CG as mentioned in Chapter II or consider the size of the wheels.

4. There is a very important thing, that is, MV and stairs do not need perpendicular. Even if MV does not approach the stairs at the ninety degrees, it can adjust its position and then climb stairs.
5. Because UCSFRs are remotely controllable with Bluetooth, they can be easily used to perform dangerous tasks. So far, all fire accidents still need firefighters to extinguish fire or deal with house-fire accidents.
6. UCSFRs are low-cost unmanned vehicle compared with the Packbot family or other commercial robots, and they easy to construct. They reduce firefighters' chance to be exposed to an unexpected dangerous environment.
7. UCSFRs are 3-D fire-fighting robot. So far, all fire-fighting robots is 2-D. UCSFRs can work from one floor to another but others can only work on the same floor.
8. More importantly, if necessary, the Mother Vehicle's body length can be extended.

In the future, UCSFRs can be used in the fire-fighting, expedition, military, security-system, or rescuing purposes. For commercialization, the weight needs to be optimized. The cost is an important part so it need to be considered as well. The following are possible applications of UCSFRs:

1. For a fire-fighting system, the function and equipment can be the same as this thesis.
2. For expedition, the structure of the vehicles needs to be modified further. It depends on the task and environment. UCSFRs can be like Negotiator, Spirit, or Opportunity.
3. For a military purpose, UCSFRs can substitute people to be put in a minefield to search mines.
4. For a security system, UCSFRs can like a guard to patrol in a house or a factory without requiring taking a rest.

D. Thesis Overview

The structure of this thesis is the following. Chapter II is an overview of unmanned vehicles. In this chapter, there are several well-known unmanned vehicles introduced in Chapter II.A. There are some comparisons between these unmanned vehicles and UCSFRs in Chapter II.B. In Chapter III, there are also some comparisons about these well-known wirelesses. The wireless communication and cooperative robots will be discussed and introduced in Chapter III.A and B separately. In Chapter III.C will introduce UCSFRs' communication module and cooperation. The main system of UCSFRs and components which are used on this research will be discussed more in details in Chapter IV.A and B separately. Chapter V is the most important part which is about UCSFRs' structure and design including the circuit design. Chapter VI is operation and testing. In Chapter VI, some assumptions will be discussed in part A and operation step will be introduced step by step in part B. The Chapter VII is conclusions.

CHAPTER II
UNMANNED VEHICLES

With the development of scientific and technological progress, robotics is an emerging research area. There are many different types of unmanned vehicles such as Autonomous/Unmanned Underwater Vehicle (AUV, UUV), Unmanned Aerial Vehicle (UAV), and Unmanned Ground Vehicle (UGV). These researches of unmanned vehicles cover ground, ocean, and air. There are some well-known examples such as the Packbot family, TaLon family, Remote Minehunting System [3], and Predator RQ-1/MQ-1/MQ-9 Reaper [4].

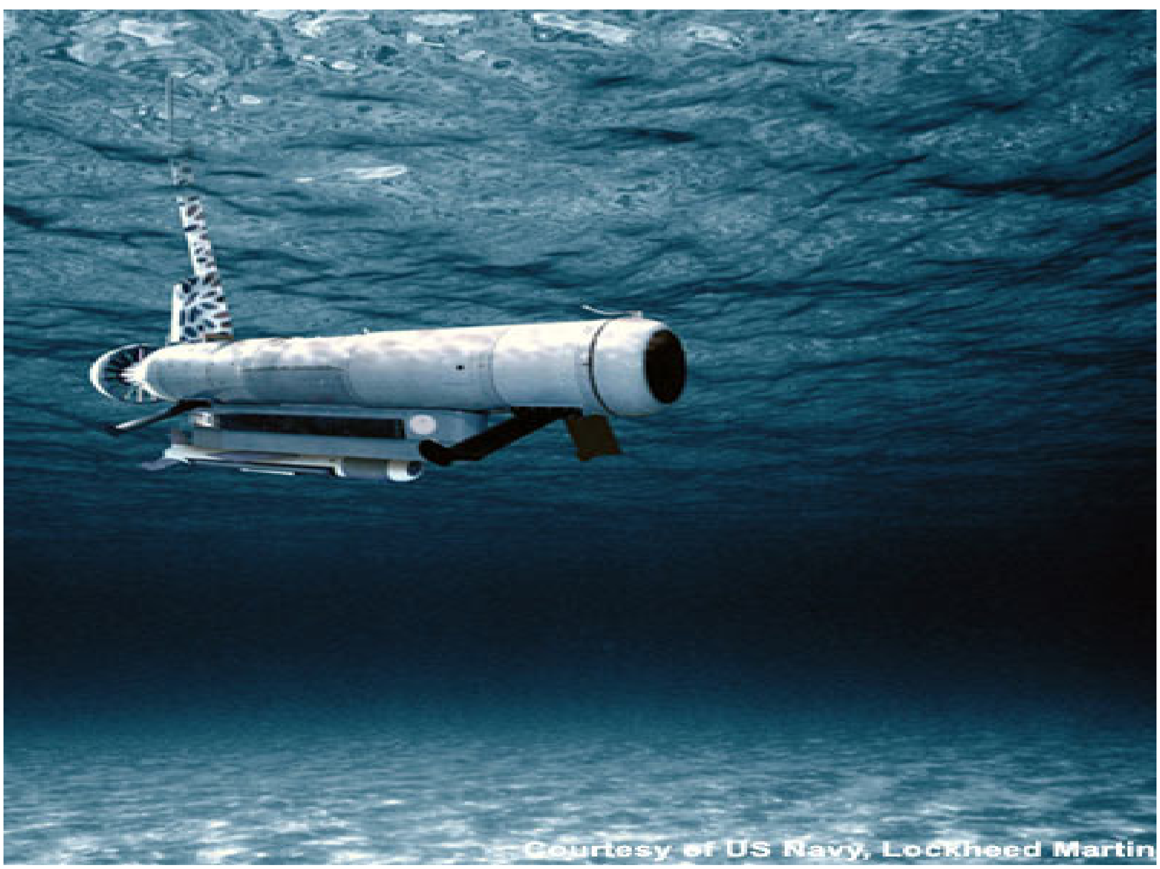


Figure 2. AUV remote Minehunting System, is made by Lockheed Martin [5].

Figure 3. UAV predator, which belongs to Air-Force, USA [4].

In this research, Unmanned Cooperative Fire-Seeking and -Fighting Robots (UCSFRs) are UGV so we will focus on unmanned ground vehicles and have more discussions between UCSFRs and other well-known vehicles.

A. Unmanned Ground Vehicle

Most of unmanned vehicles are used to implement dangerous tasks or work in an unknown environment where people may not be able to reach. So far, scientists and engineers have already developed advanced technologies related to unmanned vehicles.

In the early twentieth century, the National Aeronautics and Space Administration (NASA) used the unmanned vehicles to gather rocks on the moon. It may be dangerous for people to go to the unknown world so the unmanned vehicles were sent there first by humans. Recently, NASA sent many different types of unmanned vehicles to Mars to accomplish different missions. Instead of going at risk, people use unmanned vehicles to complete the tasks and explore the unknown places. NASA has already sent two unmanned vehicles to Mars. They are Spirit and Opportunity [6] which have already worked on Mars. In 2009, they will send a new generation rover which is made by Mars Science Laboratory (MSL) to execute new missions.

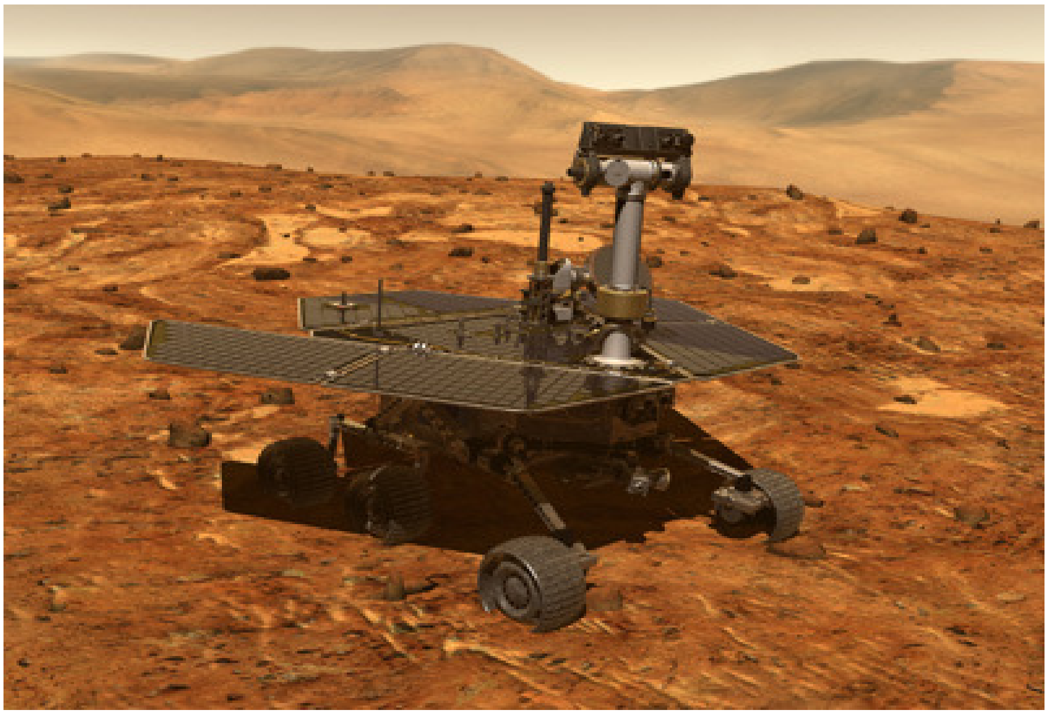


Figure 4. Mars Exploration Rovers- Spirit/Opportunity [6],[7].

The Bomb-Remover/Bomb-Disposal is another application area. These robots have the same purpose as the rover, that is, to help human beings implement dangerous tasks. This type of vehicle is commonly used by the police to remove a suspicious object or bomb. As a matter of fact, these kinds of vehicles are not really “unmanned” vehicles because most of them are remote control vehicles. There are also many unmanned vehicles used for military purpose [8]. For example, the Talon Family from Foster-Miller, Inc. [9] are armed robots, and Small Unmanned Ground Vehicle (SUGV) are multi-function unmanned vehicles from the iRobot company. Both Talon Family and SUGV are semi-automatic robots. Most of them are controlled by soldiers or police. In addition, SUGV can be used to be a security system. It is capable of patrolling in the houses and factories. These cases are common applications for unmanned vehicles. Another good example is Packbot developed by iRobot incorporation [10].

Figure 5. Packbot which belongs to a series of iRobot [10].

The Packbot family and the Talon family are light unmanned vehicles. However, Lunar Rover and Mars Science Laboratory (MSL) Rover are heavy unmanned vehicles. In this thesis, UCSFRs are light unmanned vehicles. The kind of light unmanned vehicles will be perfectly suited at the areas of the small size or medium size such as houses, apartments or factories to carry out the tasks. In the following section, there are comparisons between UCSFRs and some well-known unmanned vehicles.

B. Comparisons

There are several differences on the mechanical structure among these unmanned ground vehicles. In this thesis, MV uses tracks instead of wheels to move around. There are two reasons for using tracks. First of all, tracked vehicles can run on the most terrains. They can run on the rugged terrains easily even though there are crevices on the ground. Second, we do not need many motors to drive the whole vehicle. In MV, the front two wheels are driving wheels so two DC motors are needed to propel the whole vehicle. On the bumpy ground, the whole tracks may not contact with the ground or surface all the time. However, the vehicle can keep moving as long as there is a point contact on the ground. Basically, compared with the vehicles with wheels, the speed of MV with tracks is slower. Nevertheless, this shortcoming does not make significant effect in this research as the working environment of UCSFR is usually at small or medium areas. The other downside is that the tracked vehicle cannot be kept horizontally on the horizontal status if there is a big drop. Under this situation, vehicles might be turned over.

MV can climb stairs depending on the length of ball screws. This feature is different from the methods of climbing stairs of other vehicles. In MV, we do not need to consider the CG (Center of Gravity) if we want to climb up the stairs or climb over an obstacle. No matter how high the obstacle is, we can always climb over it as long as the height of obstacle is less than the length of the ball screw.

Figure 6. Ball screw [11].

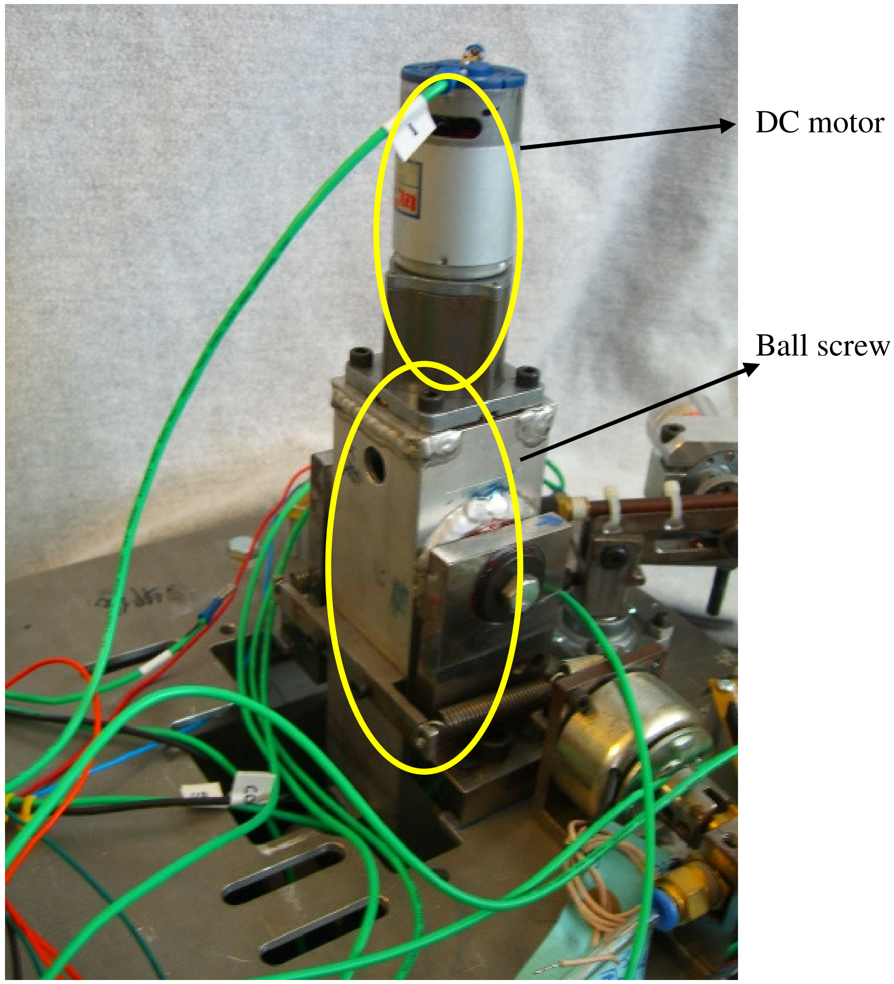


Figure 7. The ball screw on the MV.

As to Spirit and Opportunity, they are designed to use wheels. Mars Exploration Rovers (MER) can traverse over 0.25 m (a wheel diameter) of obstacles. There are six wheels on each rover [12]. Each wheel of the rover is independently driven. It means that there are six DC motors on the each rover. The drawback is power consuming. Rocker Bogie Suspension [12] and six wheels are used by the engineers of NASA to work together. By doing this, all wheels can be in contact with the ground all the time even though the rover climbs on the uneven terrains. Besides with the rovers, there need not be concerned about turning over. In addition, Spirit/Opportunity can run on sloped terrains of 16º tilt and are able to withstand a 45° tilt in any direction without overturning.

There is another similar research from the Rochester Institute of Technology. In that research, it is called Hybrid Locomotion Robot [13]. The robot owns four Leg-Wheels. The Hybrid Locomotion equipment is similar to the combination of MER's Rocker Bogie Suspension and wheels. The robot has the ability of posture control so it can adjust the length of leg to keep the body in horizontal status. This is another design to traverse over an obstacle. If the concept is the same, the ability to traverse over obstacle is also limited by the wheel diameter.

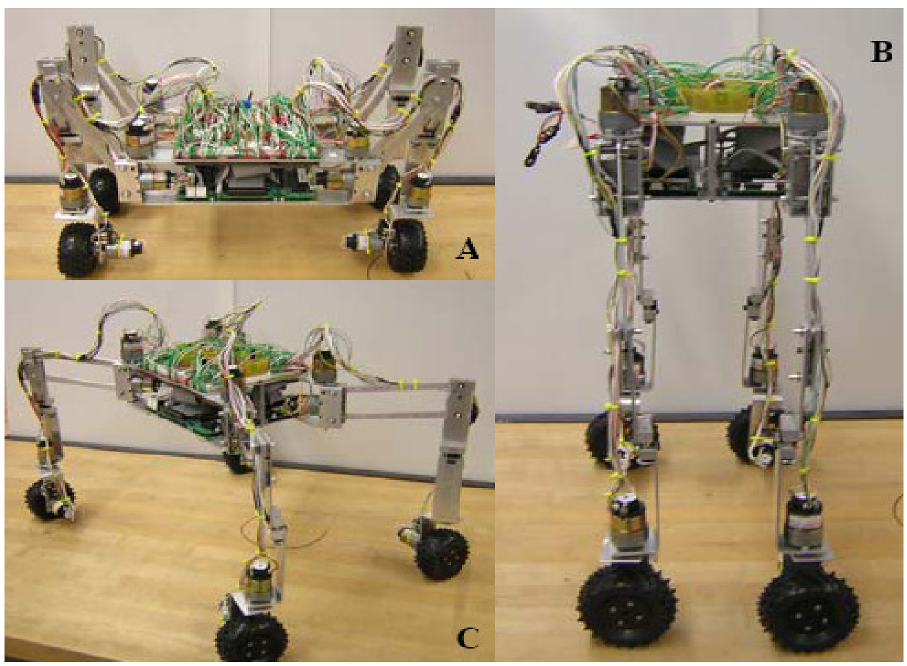


Figure 8. Hybrid locomotion in different status [13].

For Packbot type robot, they can traverse over obstacles or climb up stairs if the CG (center of gravity) is higher than the highest position [14]. Because there are two small flippers, this type of robot can climb up stairs by the rear wheels. At the end of this section, there are basic comparisons between UCSFRs and other famous applications.

Table 3. Basic comparisons about Mother Vehicle, Mars Exploration Rover, and iRobot family robot [5],[6].

	UCSFR Mother Vehicle	**Spirit/Opportunity**	**Negotiator 200**
Length	88 cm include switch sensor	150 cm including solar panel	63.5 cm
Width	43 cm	230 cm including solar panel	53.3 cm with flipper
Height	42 cm include ball screw	150 cm	19.3 cm
Weight	39 kg without battey	155 kg without payload	15.4 kg with two NiMH Robot Batteries
Length Adjustable	Yes	No	No
Communications	Bluetooth over USART	N/A*	Two way audio communication Video 2.6 GHz
Communication Range	Up to 50 m line of sight	N/A	Up to 244 m line of sight
Driver	DC motors	DC motors	N/A
Transmission	Tracks	Wheels	Tracks
Climb Stairs	Yes	N/A	Yes
Withstand a tilt ability	45°	45°	N/A
Climb over Obstacle by Rear Side	No	N/A	Yes

* N/A means that there is no data available.

CHAPTER III
WIRELESS COMMUNICATION AND COOPERATIVE ROBOTS

People are starting to focus on the emerging research, that is, cooperative robots. There are some advantages in the multi-robot system such as time-saving in completing tasks. If engineers want to make robots cooperate with each other, the key technology, wireless communication, can not be ignored. So far, there are several popular wireless communication methods used on industry, health, exploration, security, and so on. In the following sections, there are more discussions and comparisons among these well-known wireless communication technologies.

A. Wireless Communication

The wireless communication is one of the key ingredients for a multi-robot system. So far, there are several well-known wireless protocols such as, Bluetooth, ZigBee, Wibree, WiFi, Wimax, Rubee, and IrDA. Each protocol owns its feature to meet different applications. However, for outdoor robots, Wireless Local Area Network (WLAN) is not useful for them. For example, WLAN needs an access point to get on a network. Like WiFi, the hotspot is needed for users to access the network. For multi-robot vehicles, WLAN will not be the first choice if the working environment is outside the building. Especially, as to the multi-robots for the rescue and explorative purpose, there is no possibility for them to carry equipment of LAN, Wimax or WiFi. The equipment could be expensive, heavy, or big for robots which emphasize mobility.

For the applications of multi-robots, most researchers adopted Wireless Personal Area Network (WPAN)/ Personal Operating Space (POS) namely the short distance wireless communication such as Bluetooth, ZigBee, Wibree, Rubee, and IrDA. POS means 10 m radius and allows for mobility which is defined by Institute Electrical and Electronics Engineers (IEEE) [15]. Table 4 shows the definition of WPAN, and WLAN and the data rate.

Table 4 Definition and range of the wireless technology [16].

Regarding wireless network topologies, there are three types, namely Peer-to-Peer, Star and Mesh. Peer-to-Peer means that one device connects to the other one directly. For Star, one master hop connects to multi-hops, and all data have to go through master points. For Mesh, there are multiple transmission paths and Multi-hop [15]. As shown in Table 5 is the basic comparison of wireless communication including WPAN, WLAN, Metropolitan Area Network (MAN), and Cellular.

1) *Basic Background and Information of WPAN*

Among these WPAN, the Infrared Data Association (IrDa) is the most popular and common one for institutions, universities and personal hobbies. IrDa protocol used infrared to transmit data or catch the signal. There exists a serious limitation, that is, line-of-sight. If robots want to transmit data and receive the data, there must be no obstacles between two robots. The real world is a complicated environment. It is not suitable for IrDA protocol working in the most environments.

Table 5. The comparison of wireless technology [16].

	Typical Range	Freq. Range (Hz)	Network	Cost of Data	Application
Bluetooth	< 10 m	2.4G	P2P	Free	Cable replacement
UWB	10–30 m	3.1–10.6G	P2P	Free	Sync. and Transmission of video/audio data
ZigBee	70–100 m	868/915M 2.4G	Mesh	Free	Sensor networks
802.11a/b /g	100 m	b/g-2.4G a-5.8G	IP & P2P	Free	LAN, Internet
802.11n	100 m	2.4G	IP & P2P	Free	LAN, Internet
Proprieta ry	10 km	915M& 2.4G	P2P	Free	Point to point connectivity
602.16a	50 km	2–11G	IP	Free	Metro area broadband Internet connectivity
2G/2.5G/ 3G	Cellular Network	869–894M	IP	Monthly Charge	Celular telephones and telemetry

Bluetooth was originated and invented by Ericsson in 1994. After four years, there are several companies such as IBM, Nokia, Intel and Toshiba joining into Ericsson to form SIG (Bluetooth Special Interest Group). Bluetooth is 802.15.1 standard. The range of Bluetooth is from 10 to 100 m. The maximum value is possible when special kits like antenna or outdoors is available [15]. The important feature of Bluetooth is the data rate which can be up to 1M bps. The high data rate allows Bluetooth to carry many different types of files.

ZigBee is an emerging wireless protocol compared to the Bluetooth. ZigBee originated in 1998. It is started by Motorola and the members of ZigBee Alliance are Motorola, Phillips, Invensys, Honeywell and Mitsubishi [16]. The motivation to develop ZigBee protocol is that people need lower cost, better latency, and lower power consumption which can not be found in the Bluetooth. The downside of ZigBee compared to the Bluetooth is data rate. The data rate on ZigBee is only 250 kbps [17]. The transmission range is 10–100 m and could be up to 400 m. The significant feature for ZigBee is low power consumption. The battery used on ZigBee could be up to years but the same battery used on Bluetooth is only days [15].

Wibree is introduced by Nokia in 2006. The protocol of Wibree has some similarities such as the transmission range and data rate with Bluetooth. The feature of Wibree is that Wibree can be integrated with Bluetooth [18].

RuBee is a special WPAN. It is supported by Metro, Motorola, IBM, Sony, Panasonic and NCR. Its feature is that it can work in the harsh environments such as water, near steel or around corners [18]. This special working environment is not applicable for ZigBee. The transmission is from 10 to 50 ft and RuBee can use a battery of tags up to 10 years [18].

2) *WPAN Comparisons*

In this section, there are some basic comparisons among these WPAN which is mentioned above. Since Bluetooth was adopted in this research and ZigBee is an emerging and popular WPAN, there will be more comparisons and details between these two popular wireless communication protocols.

Table 6 The comparisons of short distance wireless [19].

	Operating Band (Hz)	**Typical Range**	**Bnadwidth (kb/s)**	**Battery Life (day)**
IrDA	Infrared	75 m	16000	730
Bluetooth	2.4G	10 m	720	7
ZigBee	2.4G/915M/ 868M	75 m	20–250	1000
Wibree	2.4G	10 m	1000	70
RuBee	<450K	15 m	9.6	3650

ZigBee is considered as a potential threat to Bluetooth. There are some elements including cost, range, power consumption, wake up & transmission time, and network topologies.

As to the cost, Bluetooth was $3 and ZigBee was$2 in 2008 [16]. For the transmission Range, ZigBee is longer than Bluetooth. ZigBee is 10–400 meters and Bluetooth is only 10–100 meters. Additionally, the power consumption is one significant difference between ZigBee and Bluetooth. The same battery used on ZigBee could be for years of life but used on Bluetooth only for days. Also, “sleep” and “wake-up” are the reasons causing this significant difference. ZigBee always sleeps and it only wakes up when it needs to transmit or receive data. On the contrary, Bluetooth is always awake to wait for joining a new network or transferring data. Besides, the time ZigBee and Bluetooth take from sleeping to waking up is different. ZigBee takes only 15 milliseconds, but the same action for Bluetooth needs 3 seconds. Another big difference is the network topology. Bluetooth belongs to Star topology or called piconet. The 8 slaves are the maximum for Bluetooth. For ZigBee, it is hybrid. ZigBee could be Star or Mesh so it can connect to others up to 65,000 [15–18]. All data showed that ZigBee is better than Bluetooth. However, it is not true at all. We can see from the following reasons. Since the cost of Bluetooth is becoming cheaper and cheaper, there is no big difference between these two popular wireless communication devices. In addition, Bluetooth owns the significant advantage, namely, Data Rate. The data rate of Bluetooth is up to 1–3Mbps [16]. However, ZigBee is only up to 25–250 kbps. The high data rate means that Bluetooth is capable of carrying many types of files. Table 7 shows the comparisons between ZigBee and Bluetooth.

B. Cooperative Robots

Cooperative robots are the emerging research fields. They could be used in many areas to help human beings. Multi-robot system owns some advantages such as time-saving and the rate of completing tasks. For example, regarding the assembling line, it will take more time for one robot assembling all components to produce one product than three robots responsible for different parts of the same assembling line to produce the same product. The other example is that it will be more effective for the rescue team to search for survivors in the wreck of earthquake. Usually, rescuers have to find out the survivors as soon as possible. Therefore, multi-robot system can save time than single-robot system. In a similar way, it is necessary for firefighters to save time to rescue survivors or extinguish fire. Besides, the environment of our real world is very complicated so a single robot under this environment could be collided with other objects or out of order. Nevertheless, multi-robot system can increase the rate of

Table 7 The comparisons between Bluetooth and ZigBee [15–19].

	Bluetooth	**ZigBee**
Frequency	2.4 GHz	2.4 GHz/915 MHz/ 868 MHz
Range	10–100 m	10–400 m
Data Rate	1 Mbps–3 Mbps	25–250 kbps
Sleep to Active time	15 ms	3 s
Topology	Peer to Peer, Star	Hybrid
Number of devices per network	8	2–65,000
Power Profile	Days-Months	Months-years
Security	128 bit Advance Encryption Standard	128 bit Advance Encryption Standard

completing tasks. If there is a robot not working, other robots can keep performing and finishing the rest tasks without any problem.

Robot-Cup Robot Soccer is a famous application. All of the robots need to be well aware of the relative positions to avoid colliding with each other, to chase the ball or to know where the boundary of field is [20]. Some researches use GPS (Global Position System) to get absolute positions, but some use sensors such as ultrasonic sensor to get relative positions between two robots [21–22]. The relative positions are of importance for robots. With knowing the positions to each other to avoid any collision, robots can be used to perform tasks in the warehouses, factories, libraries, or traffic. For warehouse management, Robots can assist people with the categories of a variety of materials. Under this working environment, there could be many robots working simultaneously. That is the reason the robots need to be aware of their relative positions precisely. It is a similar application in the libraries. Robots can help people put the books back to the shelves on their own.

C. UCSFRs' Communication and Cooperation

A LAN does not meet the requirements of this research. It is impossible for robots to have the access to the network in case there is no access point and hotspot outdoors. After fire, the LAN equipment could be damaged so we need to use WPAN instead of WLAN. Due to the advantages of data rate, penetration and transmission range, Bluetooth is adopted on UCSFRs. Bluetooth on UCSFRs are manufactured by A7 Engineering Inc. The topology of A7-Bluetooth is simply peer-to-peer. The antenna is needed if robots need the long transmission range.

On the A7-Bluetooth, there are two power supply models, that is, 3.3 V and 5 V. About the firmware, there are two modes, namely, Easy-Connect Mode and Command Mode. For Easy-Connect Mode, it means that Bluetooth has been already ready to do some simple things such as the transmission of text. For Command Mode, it is needed to key in some specific commands to ask Bluetooth to do something such as connection of cell phone or the search of all Bluetooth devices.

Each Bluetooth own one specific address so users can tell the manufacturer by the address. The address of the Bluetooth is twelve digit numbers. When the commands of the CCS C compiler send the address over Universal Synchronous Asynchronous Receiver Transmitter (USART), it needs to consider the buffer of USART. It is necessary to give some delay time to complete the address. In general, three milliseconds are enough for the delay time. For this Bluetooth communication module, datasheet does not mention that antenna is needed to use; however, the SMA antenna is necessary for enhancing the strength of the signal. If the SMA antenna is not used, A7-Bluetooth can not find each other even though one is behind the other one. When the Bluetooth of the A7 connect to another Bluetooth of the A7, the indicator LED will blink. When LED shows that they have already connected to each other, it does not mean that it can transfer data right away. It is needed to wait 1 or 2 second and then transfer the data or commands. If users write a code about connection in the microcontroller and use the code to connect other microcontrollers over A7 Bluetooth, users have to consider "carriage return" and "line feed" to get in the Bootloader of the microcontroller. If two A7 Bluetooth modules are used to connect with each other, there is a specific command for cutting the connection off. To make a connection with code which is pre-write in the microcontroller and get in the Bootloader of the microcontroller, the only way to cut the connection is turning the power off.

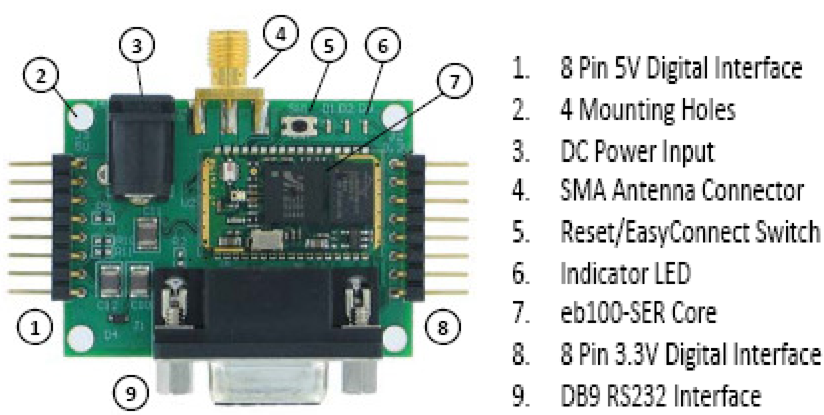


Figure 9. Bluetooth module on UCSFRs [23].

The cooperation on UCSFRs is not so complicated and there are some assumptions in the environment. The details about the assumptions will be discussed in Chapter VI. There is a temperature sensor on MV. If MV detects an abnormal change of temperature, she will let her DVs out. There are two DVs in this research. These DVs are pre-programmed and they will go to the opposite direction to search the flame. If one of DVs find the flame and send the signal for MV, MV will tell the origin of the signal and move toward that direction.

CHAPTER IV
SYSTEM DESCRIPTION

The whole system of Unmanned Cooperative Fire-Seeking and -Fighting Robots (UCSFRs) includes two important parts. One part is the main system which includes software. Second part on UCSFRs is the hardware part which includes the sensor system. In the main system, PIC 16F877 is used as the brain of these robots. It is an 8 bit microcontroller which is manufactured by Microchip, Inc. The microcontroller controls the whole system and makes the decisions for the actions of UCSFRs. The 2840 development board is manufactured by Basic Micro. About the sensor system, there are many sensors used on UCSFRs for different purposes. For example, infrared (IR) sensors and ultrasonic sensors detect distance. An UVtron detects flame. The temperature sensor on each vehicle detects heat. The digital compass can point out the direction. The next section includes the details about each sensor.

A. Main System

1) *Microcontroller-PIC 16F877*

PIC 16F877 is a 40–pin and 8–bit CMOS Reduced Instruction Set Computing (RISC) microcontroller with operating frequency up to 20MHz. The PIC 16F877 includes three timers (one 16 bits and two 8 bits). There are 8 A/D channels on PIC 16F877, and PIC 16F877 also owns 256 bytes Electrically-Erasable Programmable Read-Only Memory (EEPROM). There are two Capture/Compare/Pulse-Width Modulation (PWM) modules and 14 interrupt options. On PIC 16F877, it owns SSP (Synchronous Serial Port) with SPI (Master Mode) and I2C (Master/Slave). PIC 16F877 also owns Universal Synchronous Asynchronous Receiver Transmitter (USART) with 9-bit address detection [24].

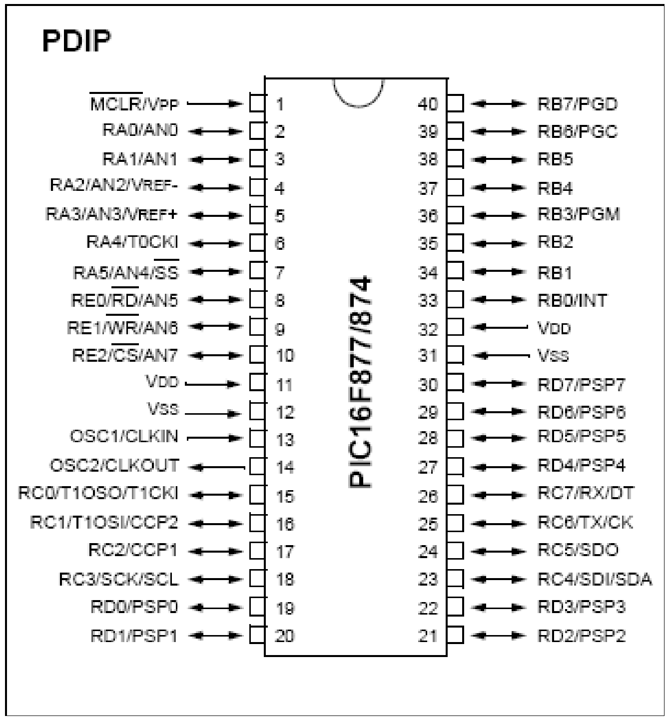


Figure 10. PIC 16F877 pin diagram [24].

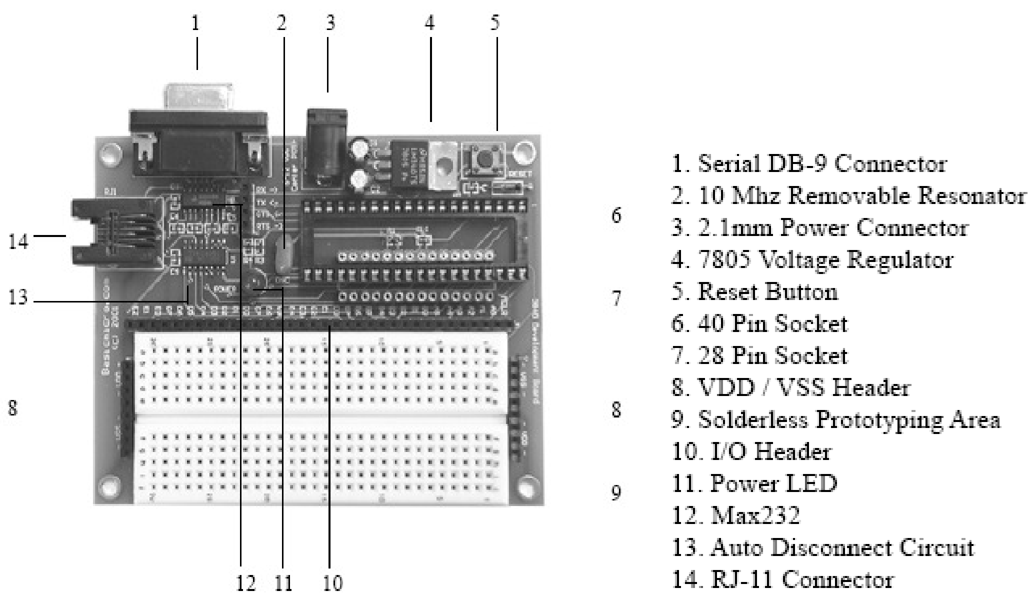


Figure 11. 2840 development board overview [25].

2) *2840 Development Board*

2840 development board is designed to support PIC 28/40 pin microcontrollers. There is a built in RS-232 serial port and a built in power supply. There is a 2840 development board overview in Figure 11. As shown in Figure 11, there is a 40-pin socket for PIC 16F877.

3) *Software*

To complete the software of this research, C compiler, MPLAB, and Hyper Terminal are needed. In this research, C is the only one programming language. The third party compiler which is CCS C compiler [26] is used to edit the all program of UCSFRs. MPLAB is the software designed by Microchip to work with the third party compiler. The version of MPLAB in this research is 8.10, and the version of CCS C compiler is 3.222. People need to write the code on the edited window of MPLAB and compile the code with CCS C compiler. Finally, people need to "burn" the code into microcontroller over RS232. The Hyper Terminal is the tool transferring the code into the microcontroller. Hyper Terminal is built in Windows XP.

B. Hardware and Sensor System

1) *Power Supply*

A 12–V battery and four 9–V batteries are used on MV. The 12–V battery offers power for the whole system of MV. Four 9–V batteries offer power for 2840 development boards and microcontrollers.

Another four 9–V batteries are used on DVs. Two Batteries are used to offer 2840 development board including all sensors, communication module, and microcontroller power. The other two 9–V batteries offer power for the motor gear box.

2) *Relay*

There are two different types of relays. One is LM Series (8-pin) and the other one is RY Series (8-pin) [13]. The LM Series is used to control all the motors on MV.

The edited window of code

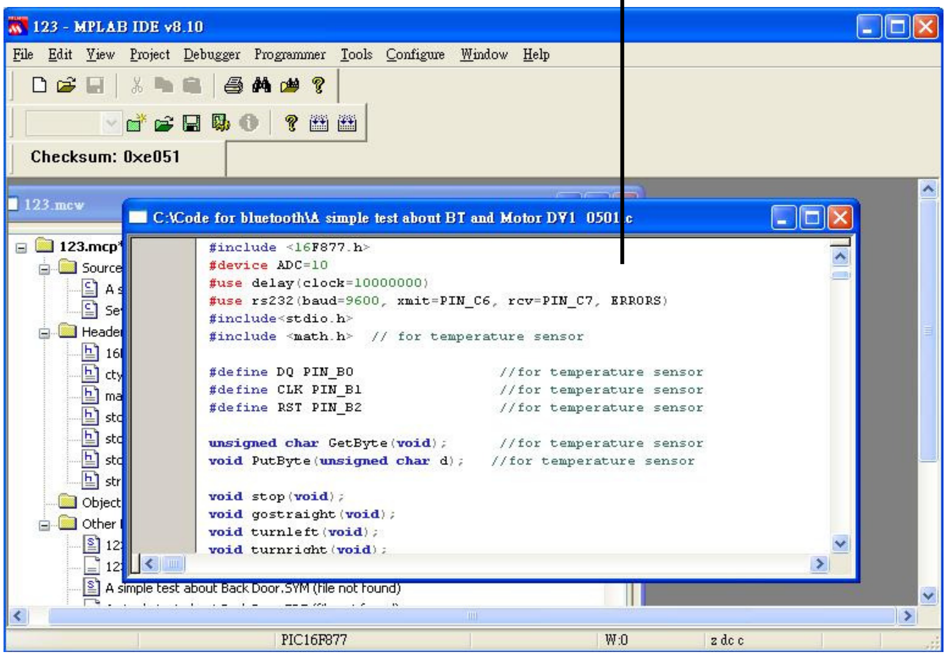


Figure 12. The working window of MPLAB.

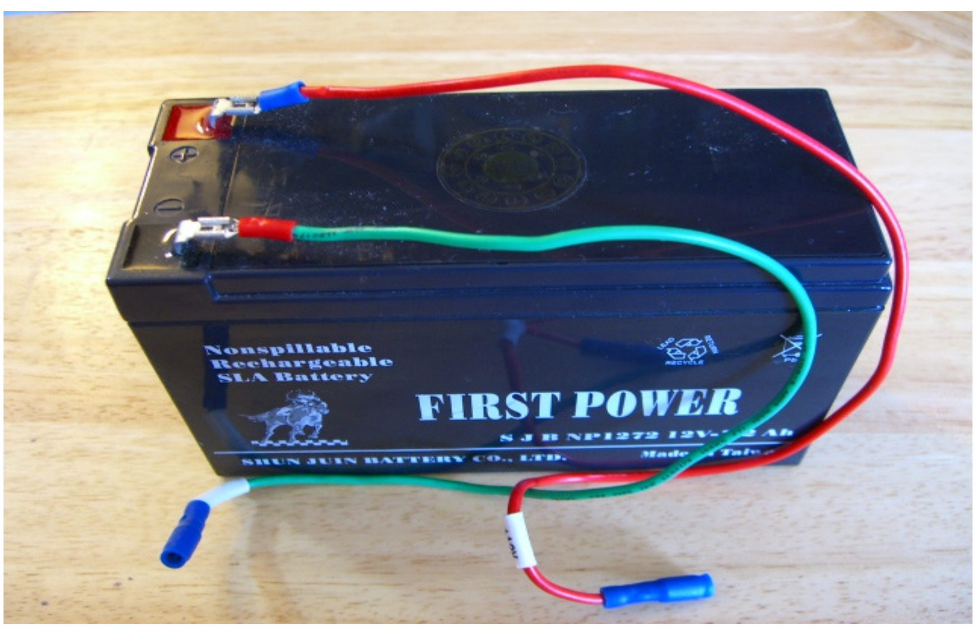


Figure 13. Power supply for the whole system of the Mother Vehicle.

The RY Series are used to control the communication module and control LM Series relay on MV. Each relay has two columns and each column takes care of one set of one NC (normal close) point and one NO (normal open) point.

Figure 14. The LM series relay for 12 V [27].

3) *Navigation Sensor*

1490 compass is a low-price digital compass mounted on each vehicle [28]. The purpose for the compass is to let the vehicle know which direction they are heading. Through the compass, they can send their direction or location data to another vehicle to let another vehicle come to meet together.

This compass is sensitive enough to detect the Earth magnetic field. It can point out eight directions, that is, North, North-East, East, South-East, South, South-West, West and North-West. When all the Pin 3 of 1490 compass are connected to a Light Emitting -Diode (LED) respectively and turn the compass with clockwise, the LED will be turned on sequentially. The sequence will be North, North-East, East, South-East, South, South-West, West and North-West. The LED is turned on when the output of Pin 3 is low. People need to use a normal compass to decide if they want to be North or South by following the sequence mentioned above. People cannot read the accurate angle from the 1490 digital compass, but they can get the direction. For the multi-robots, it is needed to adjust all the robots with the same “one-LED lit direction” to get the relative direction. In UCSFRs, the function of 1490 digital compass is enough.

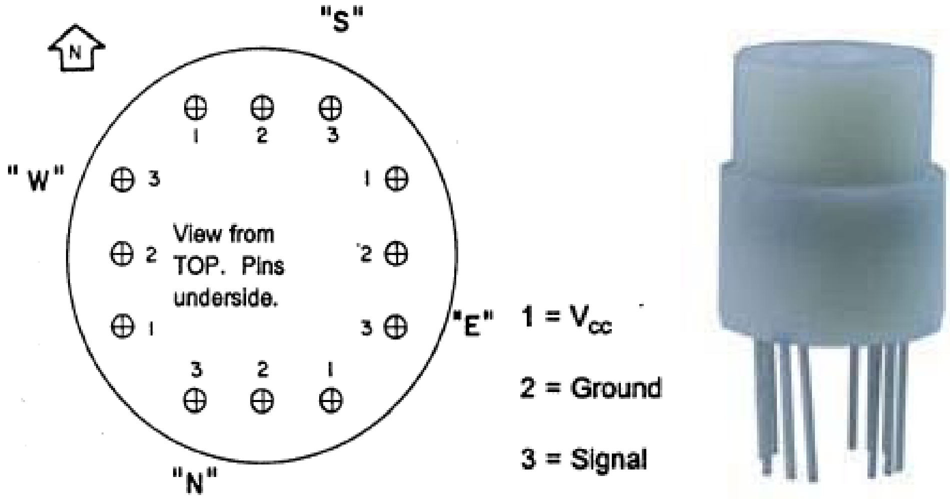


Figure 15. Leads of 1490 digital compass [28].

4) *Distance-Measuring Sensor*

There are two different range-finder sensors on UCSFRs. One is ultrasonic sensor and the other one is infrared sensor. The following are the details of their descriptions.

4.1) *Range-Finder 1: PING Ultrasonic Sensor*

For ultrasonic detector, PING Ultrasonic Distance Sensors manufactured by Parallax are adopted. PING sensors work by transmitting an ultrasonic sensor to detect the distance. PING transmits an output pulse and waits for an echo pulse back. People need to calculate the traveling time of ultrasonic sensor to know the distance between the sensor and obstacles. PING sensor is a three pings (one Vdd, one Vss and one Signal) and we just need to use one I/O pin of microcontroller [29]. PING can detect 2 cm to 3 m. Because PING use ultrasonic to detect the distance, air temperature will be a factor to influence the accuracy. People need to follow the formula: Vair = 331.5 + (0.6 * Tair) where Vair and Tair mean velocity in air and the temperature of the air separately. Unit is meter per second.

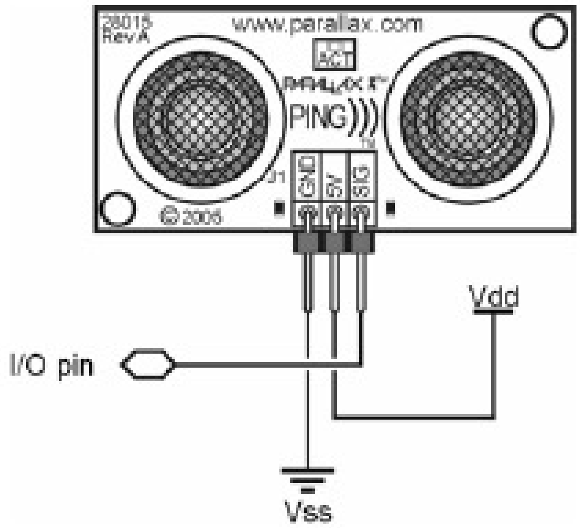


Figure 16. Outline of PING ultrasonic sensor [29].

4.2) *Range-Finder 2: Sharp Infrared Sensor*

Sharp GP-2D-12 IR sensors are adopted in this research. The range of the detection for GP-2D-12 is from 10 cm to 80 cm. Sharp IR sensors use infrared to detect objects and they are analog sensors. Figure 17 is the output and distance characteristic of GP-2D-12 IR sensor.

On the other hand, the signal of the output of GP-2D-12 will be a voltage. Sharp IR sensor is a very popular distance detector. It can be used to detect any object except glasses. Because there are 8 A/D (Analog to Digital) channels in the PIC 16F877, it can convert the signal from the analog to the digital. The Analog to Digital Converter (ADC) value can be recorded and linearize the value.

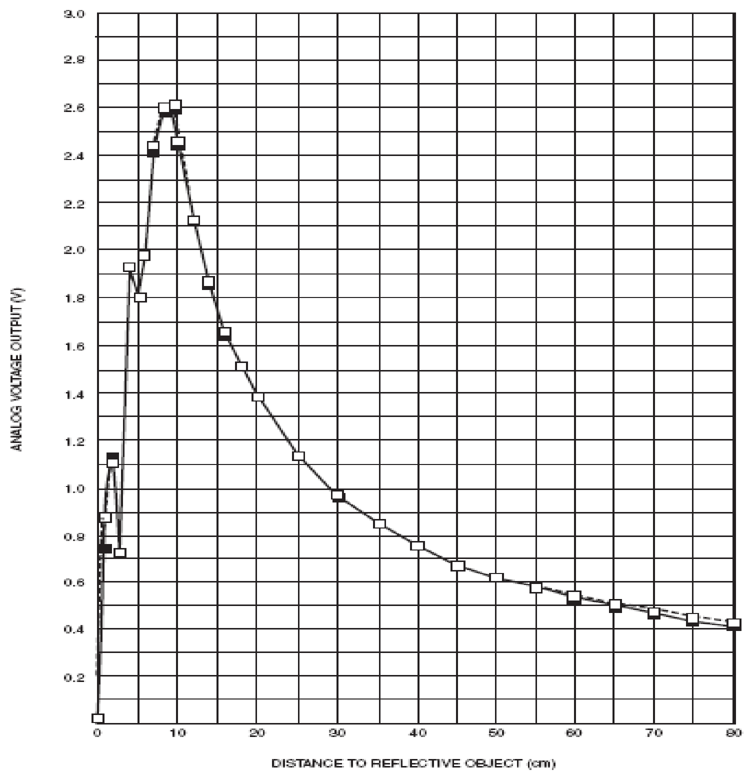


Figure 17. GP-2D-12 output and distance characteristic [30].

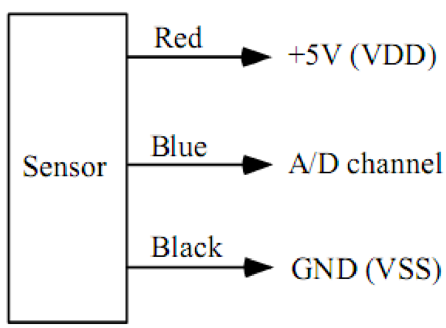


Figure 18. IR distance sensor (GP2D12) connections[30].

Figure 19 is the ADC value and the linearization of one of IR sensors mounted on DV. The downside of ADC value is that the ADC value is not a fixed value and it needs to linearize. Therefore, the distance will not be so accurate. The ADC value at the Figure 19 is a mean.

Dist5	Volt5 (ADC_Value)
80	4
70	5
60	10
50	22
40	45
30	71
20	114
10	217

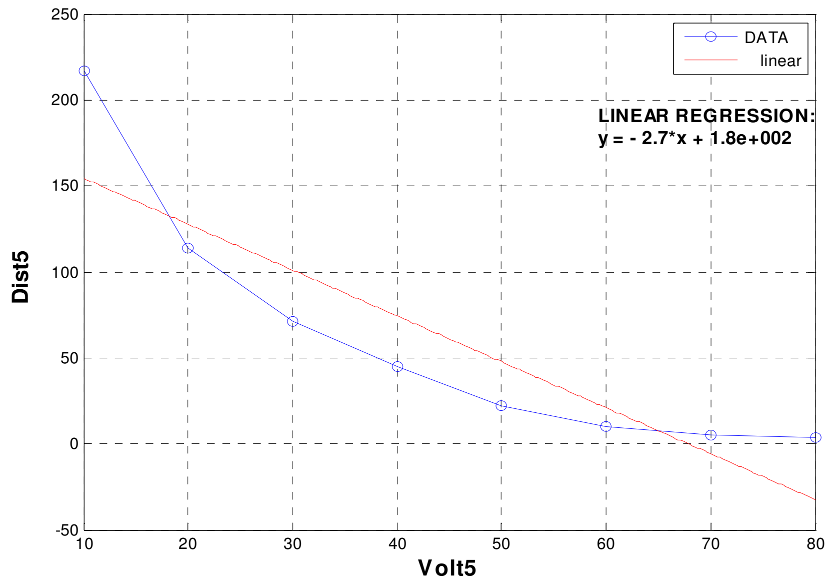


Figure 19. ADC_Value and the linearization of IR sensor for Daughter Vehicles.

4.3) *Mother Vehicle*

Six PING ultrasonic sensors are used. These ultrasonic sensors are used to measure the distance and detect the obstacles. Four ultrasonic sensors including the two ultrasonic sensors in front of MV measure the distance as Figure 20. Two ultrasonic sensors are used to detect the ground to decide if the vehicle is on the stairs or on the ground. On MV, the ultrasonic sensors were chosen to substitute the Sharp IR sensors. The reason is that the value of ultrasonic sensors is much accurate than the one of IR sensor after A/D converting. If the object is over the range of detection, ultrasonic sensor will show the maximum value. However, if the range of detection of IR sensor is over the maximum detectable range, the value will be a random value.

4.4) *Daughter Vehicle*

There are five infrared sensors and one ultrasonic sensor on each DV. The five IR sensors are used for obstacle avoidance. One ultrasonic is used to be a kind of trigger and there will be more details in Chapter V.

5) *Flame Detector*

UVtron flame detectors and UVtron driving circuits from Hamamatsu Inc. are applied to detect the flame in this research. The theory to detect flame is basic on the ultraviolet. If there is fire, it will radiate ultraviolet light. This detector uses this feature of fire to detect flame. There is also ultraviolet light in the sunlight or cosmic ray outdoors but it is all right for the sunlight to penetrate through the window and come to inside. The reason is that the noise can be cancelled in the driving circuit [31]. The UVtron flame detector is sensitive enough to detect a flame within 25 mm length and the distance for this size flame is far away up to 5 m [32]. However, there is a downside on this flame detector. This flame detector can detect the flame, but it can not tell the size and the distance of the fire. Therefore, the temperature is adopted to work with the flame detector together in this research to make up the drawback.

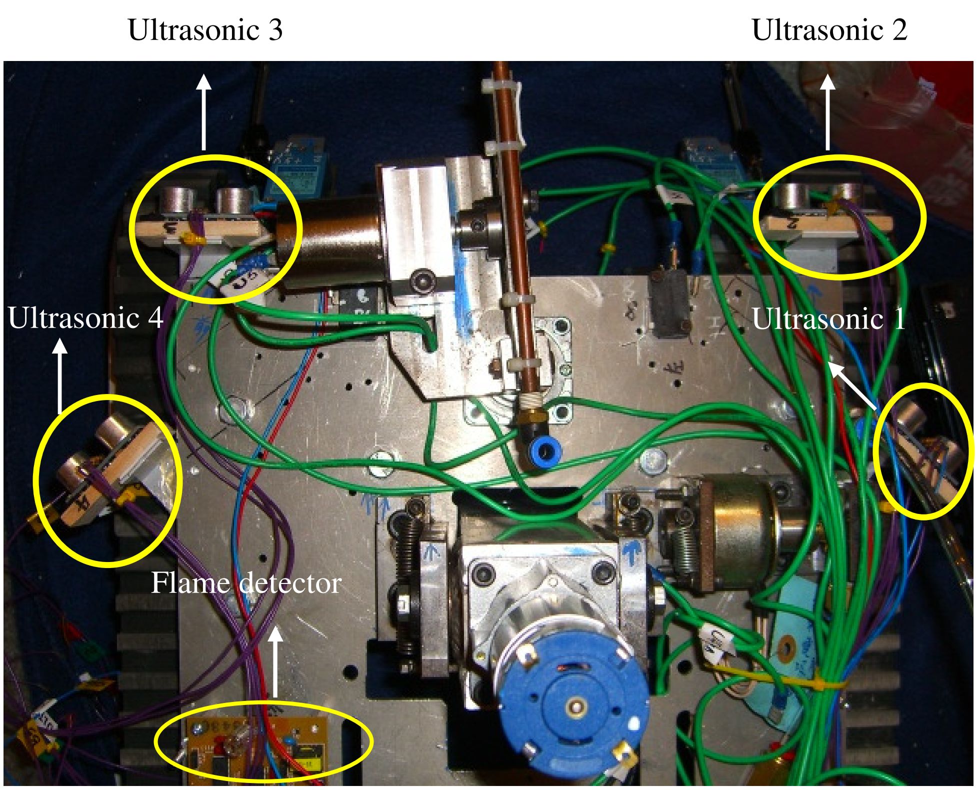


Figure 20. The location of ultrasonic sensors.

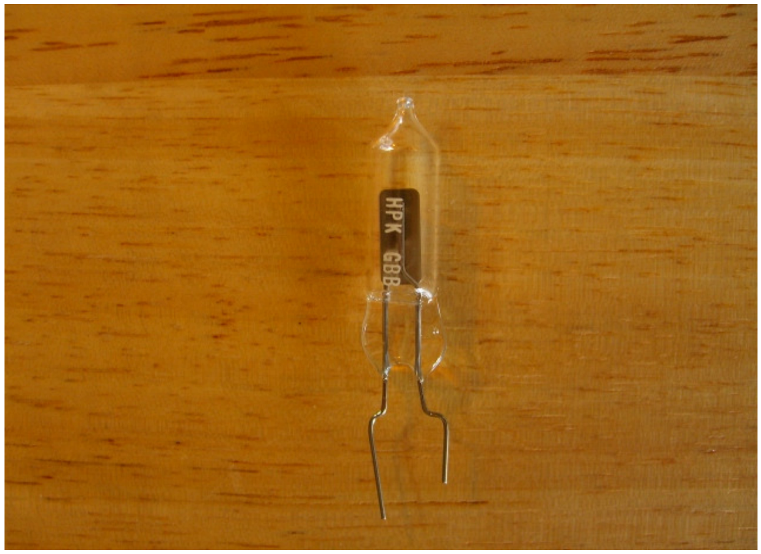


Figure 21. UVtron flame detector.

6) *Temperature Sensor*

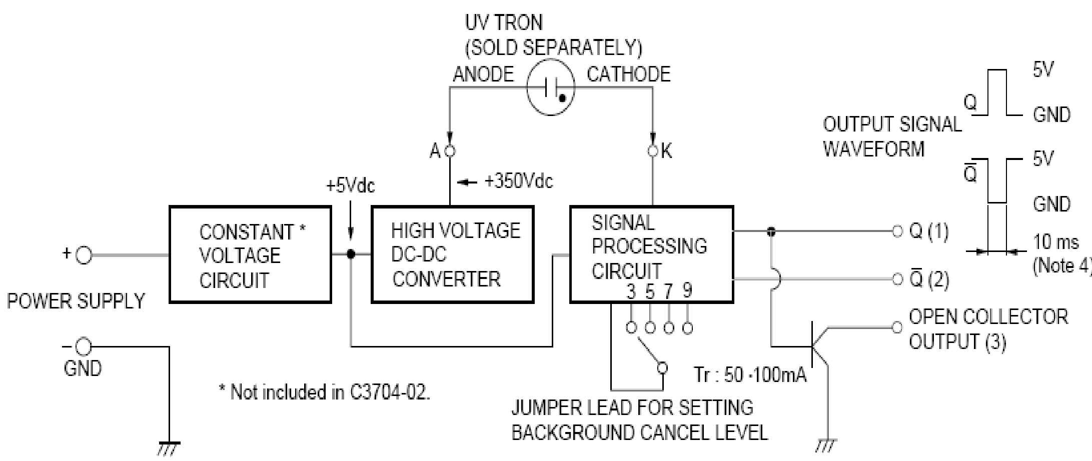


Figure 22. Circuit diagram of UVtron driving circuit [32].

A temperature sensor, DS1620 [33], is used on each vehicle in this research. The purpose of DS1620 is to detect the change of the temperature. This temperature will be used together with the flame detector. Since the flame detector cannot tell the size of the fire and the distance between the fire and UCSFRs, DS160 temperature sensor is adopted to solve the problem. The measure temperature is from −55 °C to +125 °C.

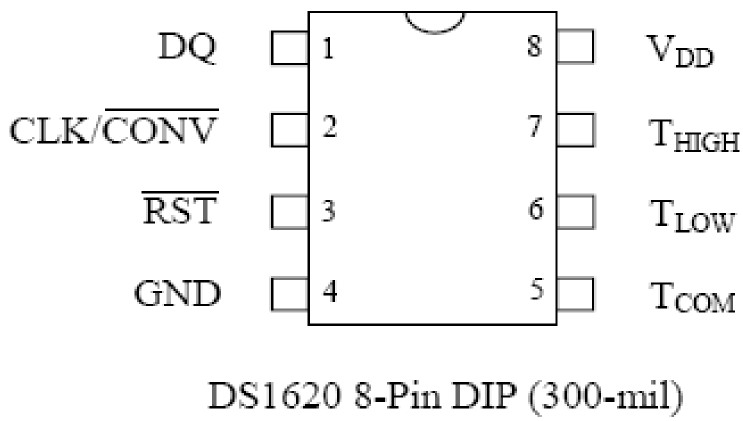
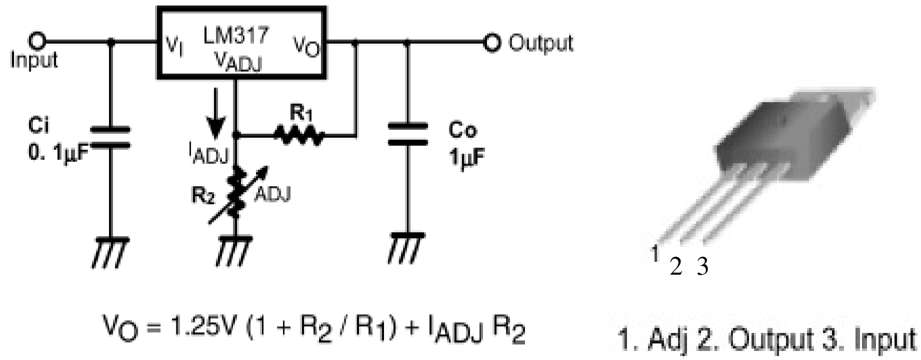


Figure 23. Pin assignment of DS1620 [33].

7) *Voltage Regulator*

There are two types of voltage regulators. One is 7805 [34] and the other is LM317 [35]. On MV, it is a LM317 voltage regulator. On each DV, there is an extra 7805 voltage regulator except one 7805 from the 2840 development board.

For the DVs, the purpose of 7805 is to offer a stable positive voltage, 5 V, which will be used on the compass, operational amplifier, ultrasonic sensor, and gear box. The LM317 is an adjustable voltage regulator. People can decide its output voltage by changing the resistors. LM317 is used to change the voltage from 12–V to 6–V to be the power of relays.



(a) (b)

Figure 24. (a) Typical application of LM 317 [35] and (b) Photograph of LM317 [35].

8) *Operational Amplifier*

LM324 quad operational Amplifiers are used on each vehicle [36]. They can amplify the small signal. Therefore, it is used to amplify the signal of the flame detector. The amplified signal can be input into microcontrollers. People can change the amplification by changing the resistors. There are so many operational amplifiers; however, LM 324 is the best choice for this research. The reason is that LM 324 owns a specific feature, one power supply, which is not so common for other amplifiers. On the most amplifiers, dual supplies are needed. People usually need dual power supply, one positive and one negative, to operate the operational amplifiers. LM 324 does not need the dual supplies, and it just needs one positive and one ground. This feature is very convenient for this research. That is the main reason that LM 324 is adopted on this research.

9) *Timer*

One timer is used to control the back door of MV. The timer is set and will decide how long the back door should be open.

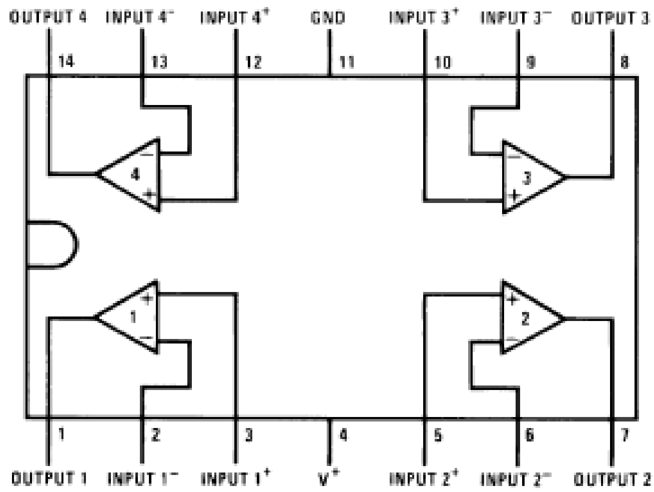
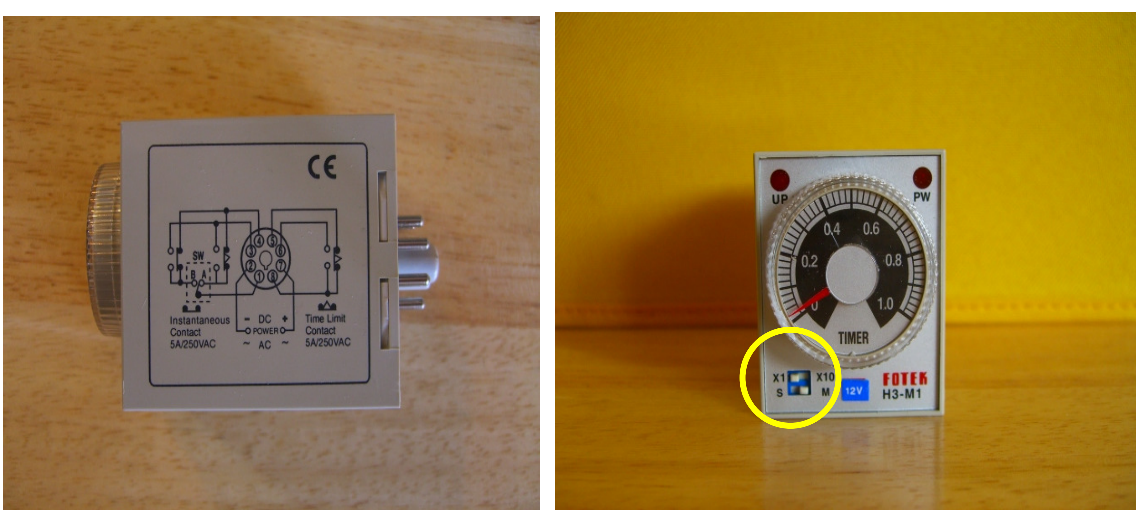


Figure 25. Internal block diagram of LM 324 [36].



(a) (b)

Figure 26. (a) Side view of the timer and (b) top view of the timer.

CHAPTER V
DESIGN AND STRUCTURE

MV has two important functions: to extinguish fire and to carry DVs to the different floors. To fulfill these functions, MV needs powerful DC motors to carry a fire extinguisher and DVs. Besides, MV needs a strong body structure to climb stairs. At the same time, we need to consider the weight of MV. It should not be too heavy, and therefore aluminum was chosen to be the main structure of the body in this research. DVs play an important role. They are assistants of MV. The main purpose of DVs is to find out the fire. When DVs find out the flame, they need to send signals to MV. MV will tell the source of the signals and move forward to the right direction to meet with the DVs which send the fire signals.

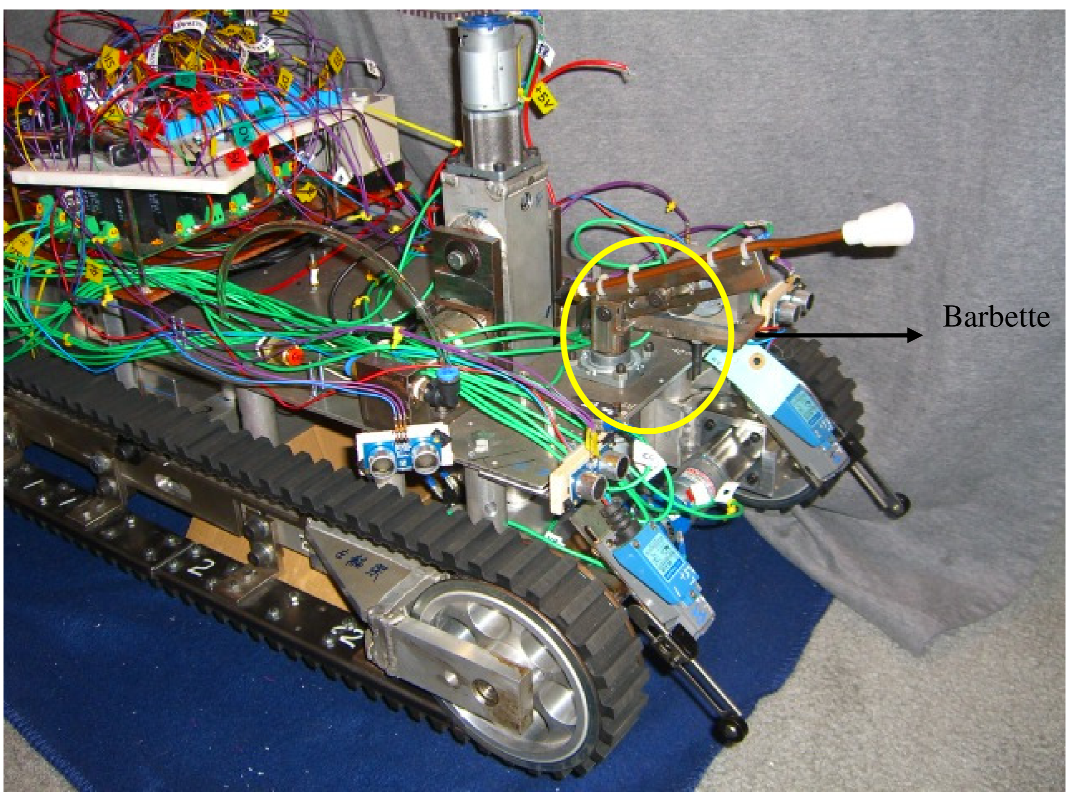


Figure 27. Mother Vehicle.

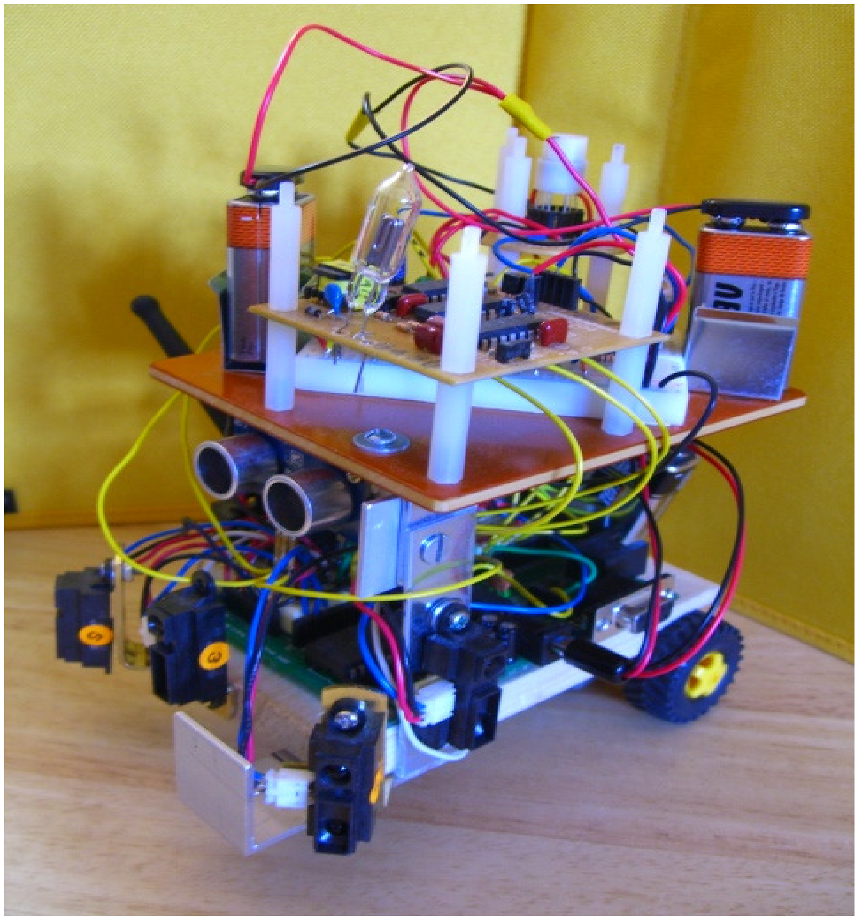


Figure 28. One of the Daughter Vehicles.

A. Mother Vehicle

1) *Overview*

The MV plays a key role in this research. On the back area of the MV, multi-decks-structure is adopted. The circuit boards of MV are located on the different levels as Figure 29. The dimension of the MVs is 85 × 43 × 45 cm. The tail of MV and the micro-switch are not included into the length of MV. The core system of MV is a PIC -16F877 microcontroller with a 2840 development board. The feature of MV in this research is that many relays are used to substitute the motor driver and to meet the same function which motor driver did. There are many different sensors on MV such as one flame detector, one flame detector driver circuit board, six ultrasonic sensors, one temperature sensor, thirty LM series relays, eleven RY series relays, two Reed relay, two

LM 317 adjustable voltage regulator, one 7805 voltage regulator, one operation amplifier, one timer, and one solenoid valve. The power sources of MV are from one 12–V battery and four 9–V batteries. The 12–V battery offers the power to all the relays and DC motors. Two 9–V batteries offer the power for the microcontroller and 2840 development board. The power of the other two 9–V batteries was mainly offered to the temperature sensor, operation amplifier, one flame detector, and the ultrasonic sensors.

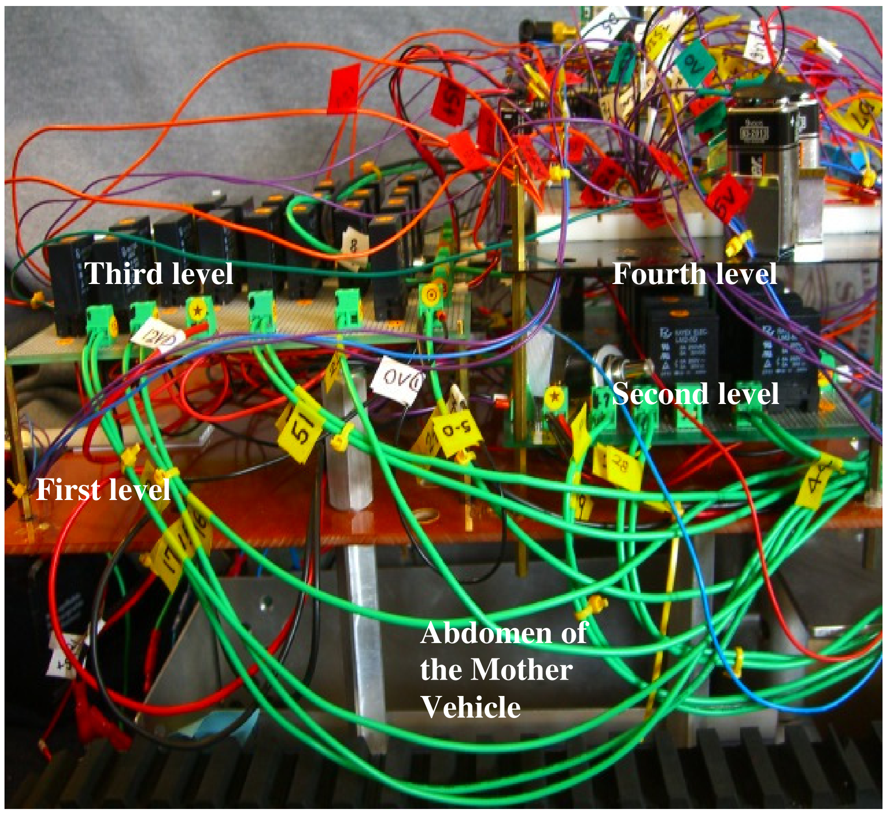


Figure 29. Multi-deck structure of the Mother Vehicle.

2) *Structure and Design*

The frame of MV is aluminum. The chassis of MV is similar to the tank as Figure 30. On MV, tracks are used instead of wheels. On the tracks of the tank, the idler wheels are used to help the tracks in the right position; however, in this research, rails are used instead of idler wheels as Figure 31. On the structure of body, it is not needed to make so many holes on the body of MV to set up the idler wheels.

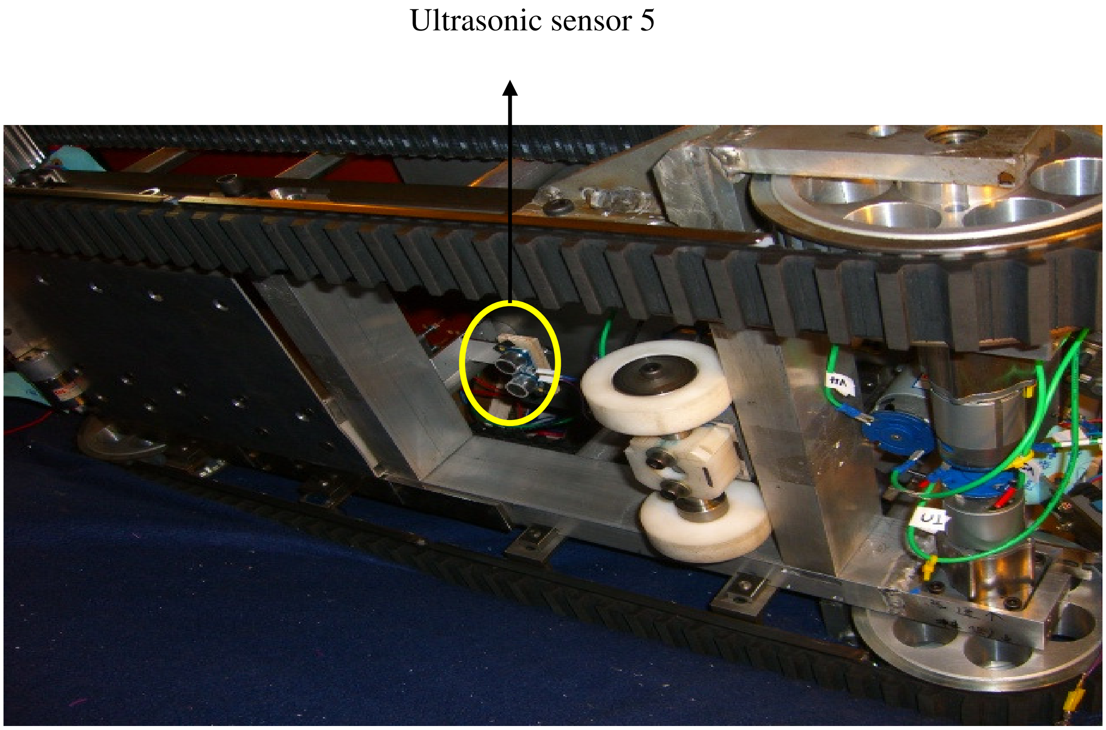


Figure 30. Chassis of the Mother Vehicle.

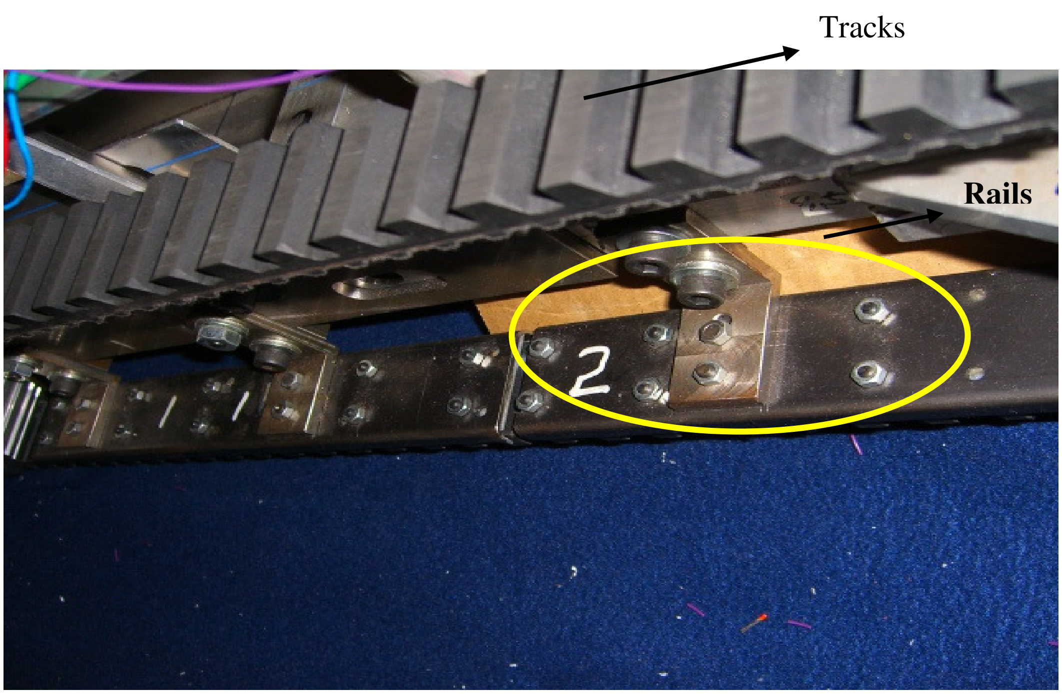


Figure 31. Rails are used instead of the idler wheels.

In this research, the capability of stairs-climbing is one of the important designs. To achieve this purpose, the ball screw is used. The length of ball screw decides the traverse robustness.

As shown in Figure 32, there are two wheels at the end of the ball screw. The purpose of the wheels is to help MV move easily when MV climbs stairs up. When the ball screw props the body of MV over the height of one stair, the tracks of the MV will move on. At this moment, the ball screw does not draw back yet, and therefore it is necessary to mount wheels at the end of the ball screw.

On Figure 32, there are two micro switches on the appearance of the end of the ball screw. These two micro switches decide the stop-time of the ball screw. When the ball screw comes out and touches the second micro switch, the second micro switch will make the ball screw stop. When the ball screw draws back and touches the first micro switch, the first micro switch will make the ball screw stop as well.

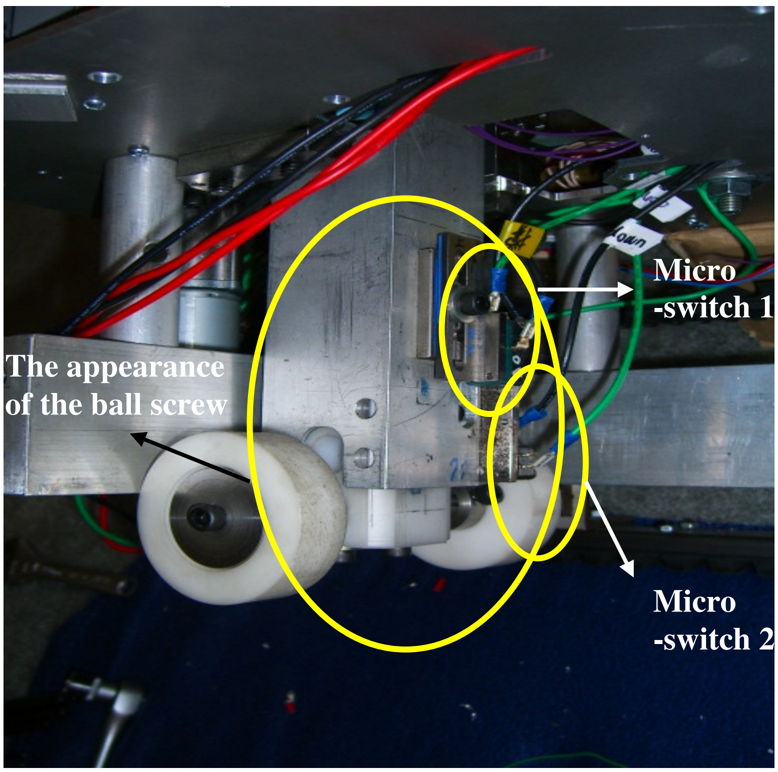


Figure 32. Two wheels at the end of the ball screw help the MV to climb stairs more easily.

One solenoid valve is used to control the output of the extinguisher. When MV finds the flame, it will send a signal to the solenoid valve and open the valve. As shown in Figure 33, there is a spring on the solenoid valve. The purpose of this spring is to help the solenoid valve close the valve.

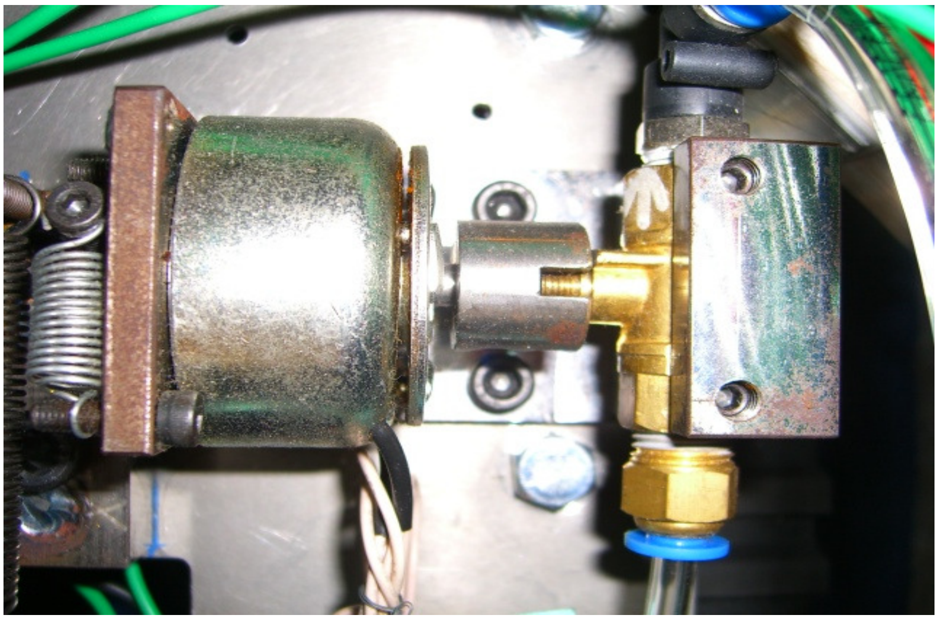
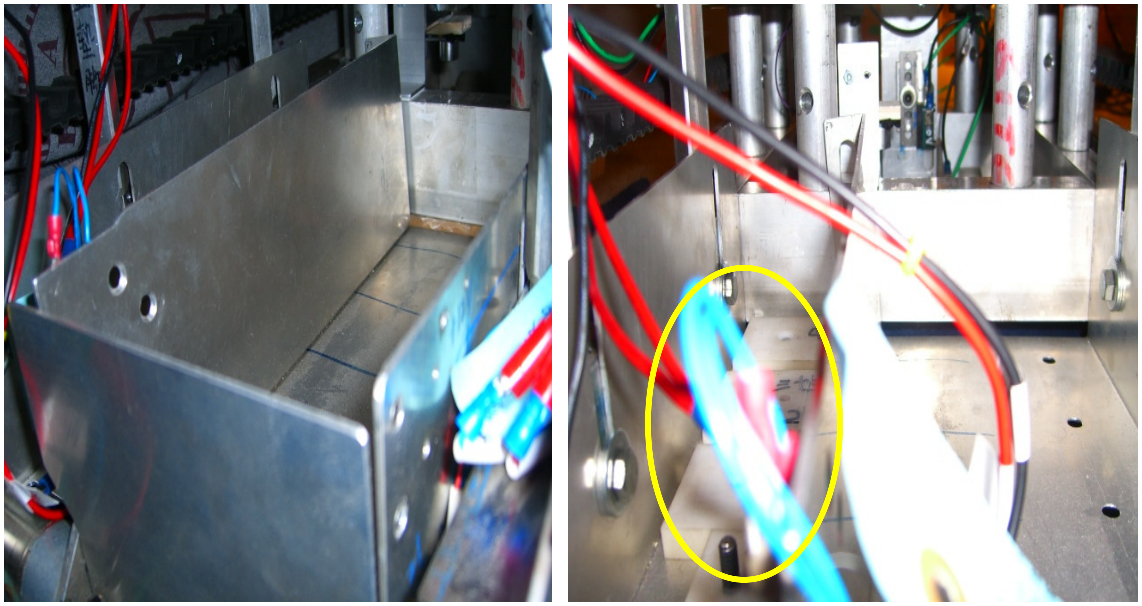


Figure 33. The solenoid valve is used to control the valve of the extinguisher.

As shown in Figure 34, an "Abdomen-space" of MV is designed under the first deck and located in the rear area to put the two DVs. As shown in Figure 34 (b), there is another space to place a 12–V battery behind the abdomen.

On MV, there are six ultrasonic sensors. Among these ultrasonic sensors, there are two of them very important. They are ultrasonic sensor 5 and ultrasonic sensor 6. The ultrasonic sensor 5 is located in the middle of MV and toward the ground as Figure 30. The ultrasonic sensor 6 is located in the rear area as Figure 35. The ultrasonic sensor 5 and the ultrasonic sensor 6 are used to tell the position of MV, and decide the action of the back door in MV. If the position of MV is on the stairs, the ultrasonic sensor five and the ultrasonic sensor 6 will not allow the back door of MV to be opened.

As shown in Figure 36, there are two micro-switches located in the front of the body of the MV. These two are important parts for the capability of stairs-climbing



(a) (b)

Figure 34. (a) Abdomen can accommodate two Daughter Vehicles. (b) The 12–V battery is located behind the abdomen.

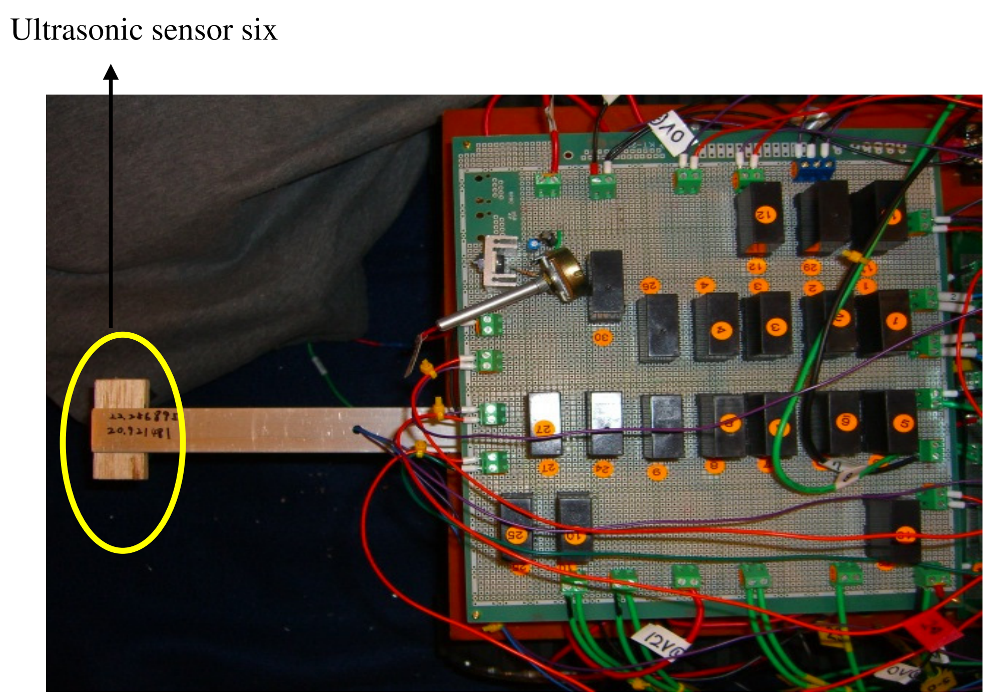


Figure 35. Ultrasonic sensor 6 is located in the rear area of the Mother Vehicle.

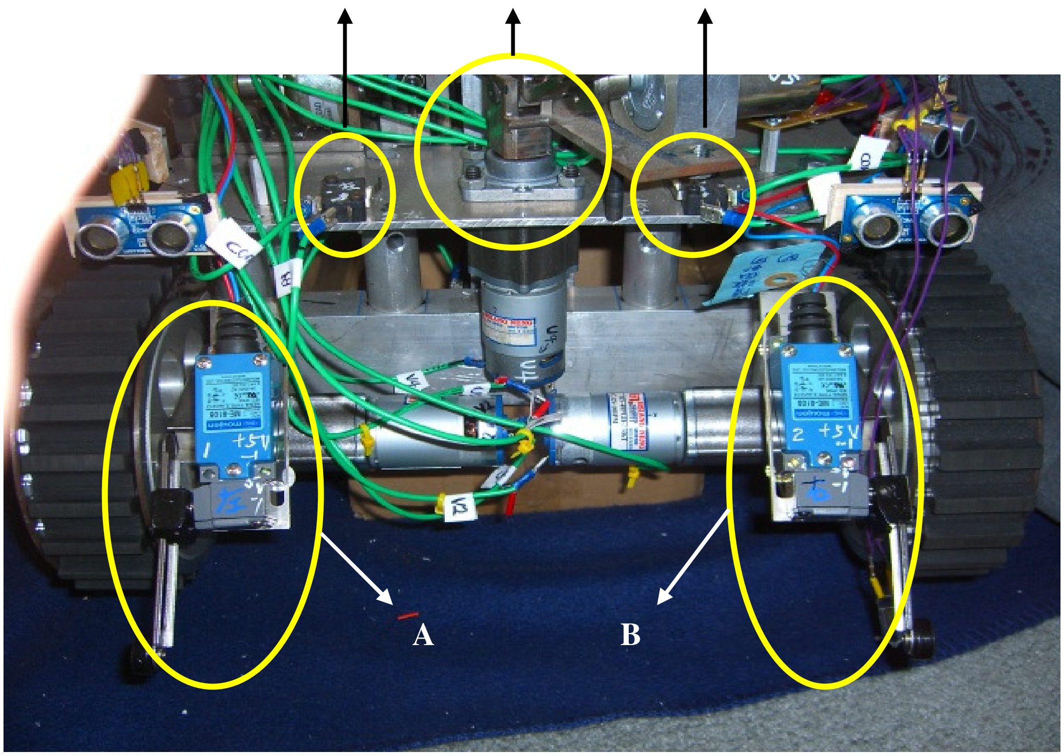


Figure 36. Two micro-switches (A and B) decide the timing to climb stairs.

for MV. When the micro-switch touches the stairs, it will trigger the relay and then drive the motor of the ball screw.

For the purpose of stairs climbing, there is a special design on MV as Figure 37. There is a "T" shape hole behind the ball screw. The hole allows the ball screw to swing when MV climbs up the stairs. In general, when MV climbs up the stairs, the micro-switch will touch the stairs twice in the first and second stair. The time between MV traversing over the first stair and the micro-switch touching the second stair is not long enough so the ball screw does not draw back yet. Under this situation, the ball screw will hit the first stair so the "T shape hole" is necessary to allow the ball screw to swing as Figure 40. When MV climbs up the stairs, there are two springs as Figure 40 to help the ball screw to return to the original position.

If needed, the body of MV can be extended. One inner tube and one outer tube are used together as shown in Figure 38. Inside the inner tube, there are threads of a screw.

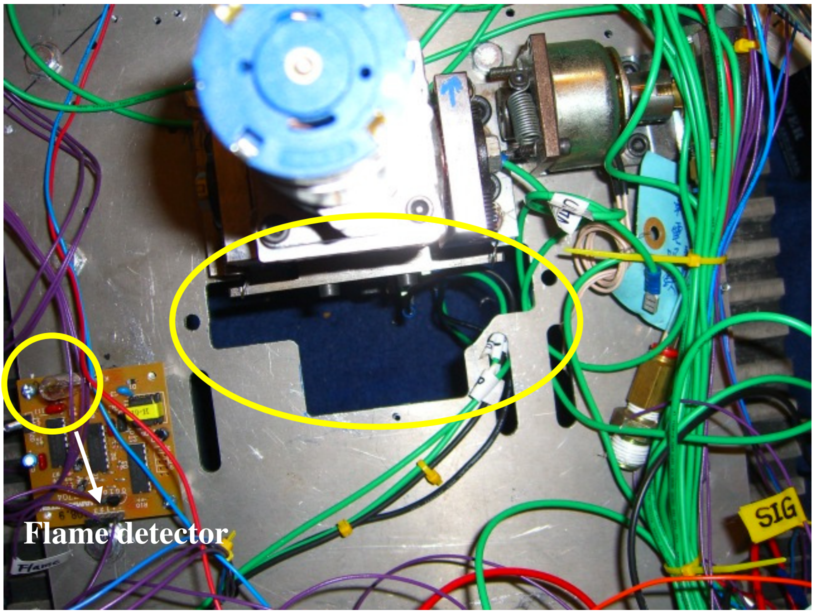


Figure 37. “T” shape hole allow ball screw to swing.

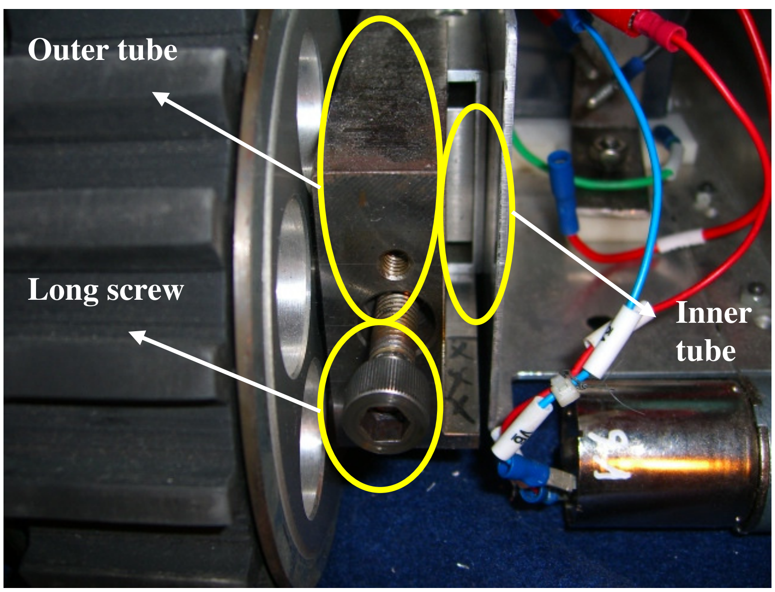


Figure 38. Structure of the extended length of MV.

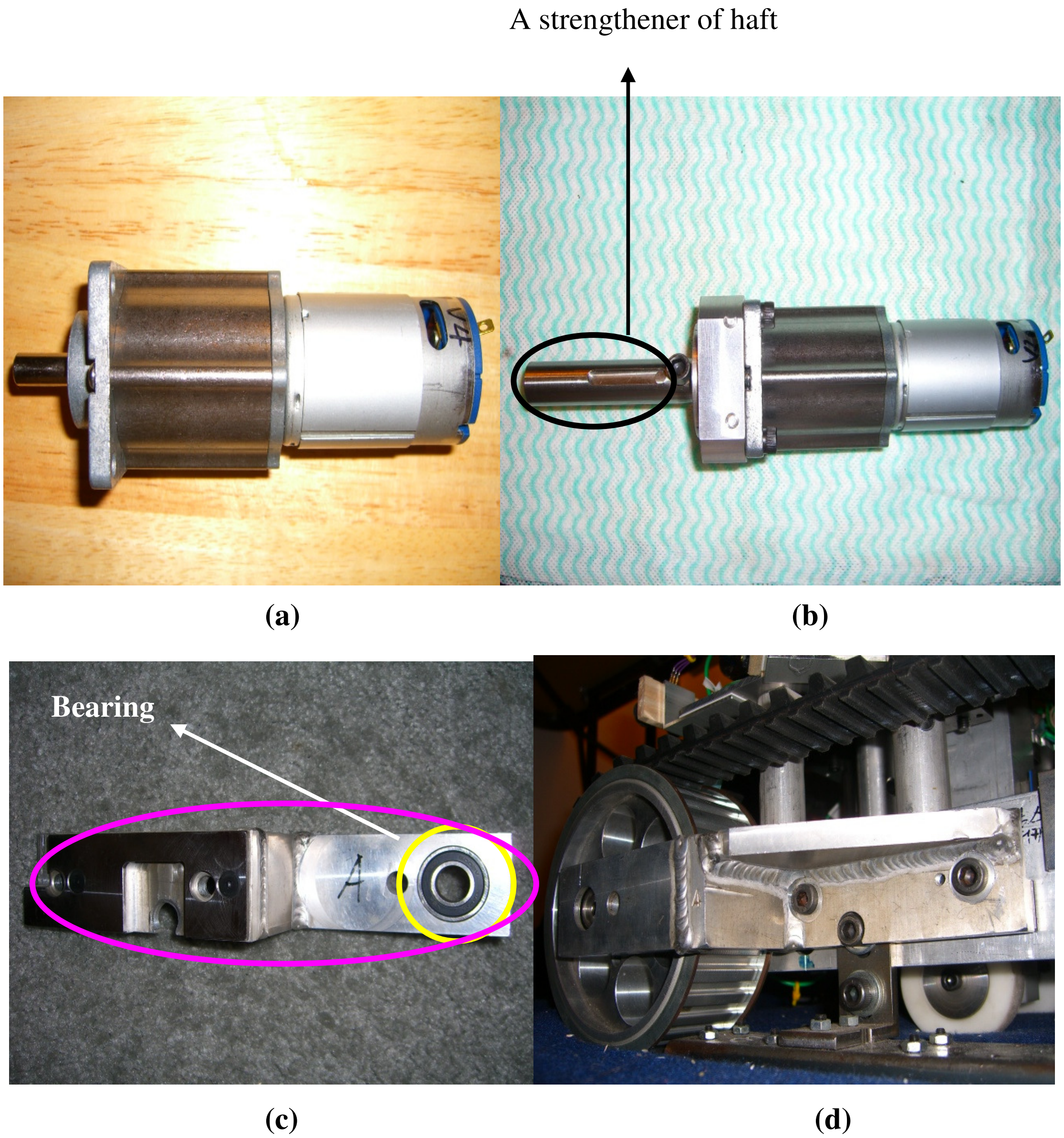


Figure 39. (a) The driver of the wheels with an original shaft. (b) The strengthener of a shaft. (c) The strengthener of the wheels. (d) Side view of the strengthener of wheels.

If the body of MV needs to be extended, it can be done by rotating the long screw shown in Figure 38.

The shaft of the DC motor is short and thin (Figure 39 (a)) so that it can not drive a wheel with a track. For this reason, a strengthener is needed for the shaft of the motor.

The strengthener makes the shaft of the motor become a thicker and stronger one. Because the original shaft of the motor becomes bigger and thicker, another strengthener is needed to help the “new shaft” of the motor in right position.

3) *Circuit Design*

As shown in Figures 42–46, there are some circuit designs. The Figure 41 is the definitions of the symbol used on Figure 42–46. For Figures 42 and 43, it is about the two micro-switches between the DC motors and the ball screw. The purpose of the circuit (Figure 41) which is the most complicated one among these three circuits is to substitute the commercial DC motor driver. For Figure 45, it is about the back door of MV. The Pin_X means the PIN number on the microcontroller. The numbers on the Figure 42 are the same as Figure 43. For example, R3 on Figure 42 is the same as number 3 on Figure 43.

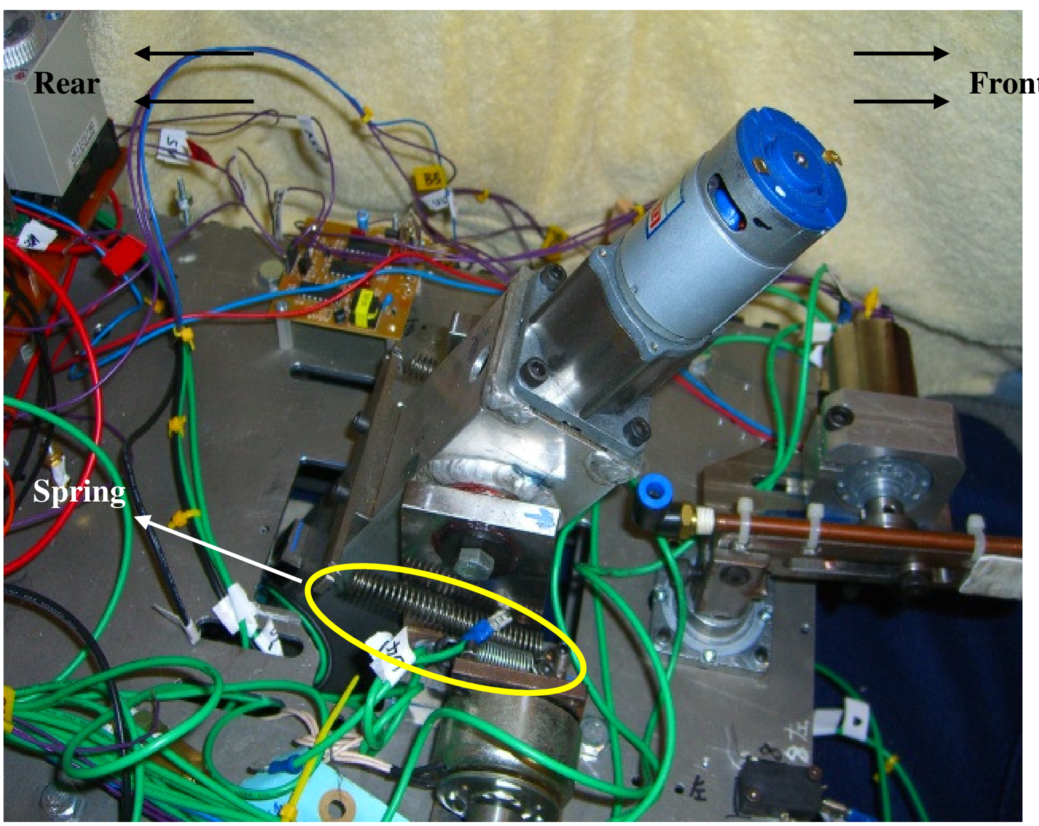


Figure 40. Ball screw is inclining.

B. Daughter Vehicles

1) *Overview*

Because of the limited space of the "abdomen" of MV, the design of DVs applies the double-deck structure. The advantage of the double-deck structure is that each DV does not need to occupy the large space. The dimension of DV is $16 \times 11.5 \times 18$ cm. The core system of the DVs is a PIC 16F877 microcontroller with a 2840 development board. On the DVs, there are many different types of sensors such as one L298N motor driver, one LM 324 operation amplifier, one 7805 voltage regulator, five IR sensors, one flame detector driver circuit board, one ultrasonic sensor, one digital compass, one temperature sensor and one flame detector sensor. Four 9–V batteries are the power source for each DV. Two 9–V batteries offer the power to 2840 development board including one microcontroller, one L298N, one Bluetooth communication module, and five IR sensors. Two 9–V batteries offer the power to the driver system and other sensor systems including one twin motor gear box, one ultrasonic sensor, one digital compass, one flame detector sensor, one LM 324 operation amplifier, and one temperature sensor.

2) *Structure and Design*

As shown in Figure 47, the chassis of the DVs applies the three-wheels-structure including one ball caster and two wheels. A twin motor gear box is adopted to control the two wheels. A motor controller such as L298N can be used to control this type of

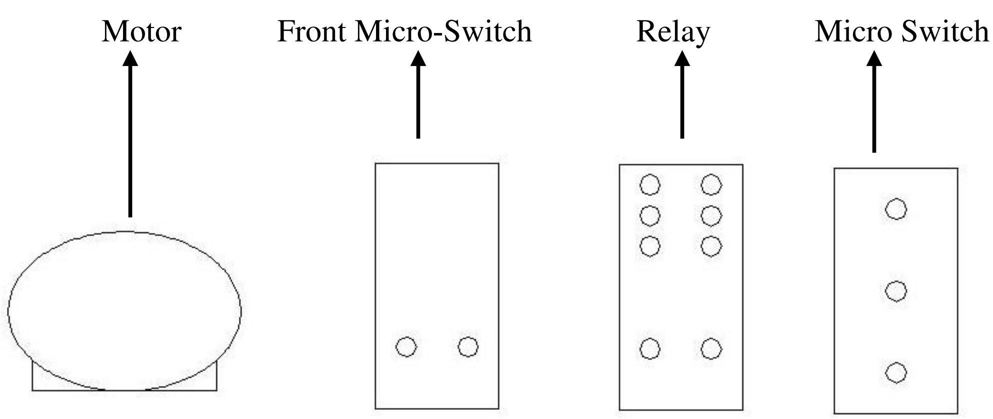


Figure 41. Definition of the symbol.

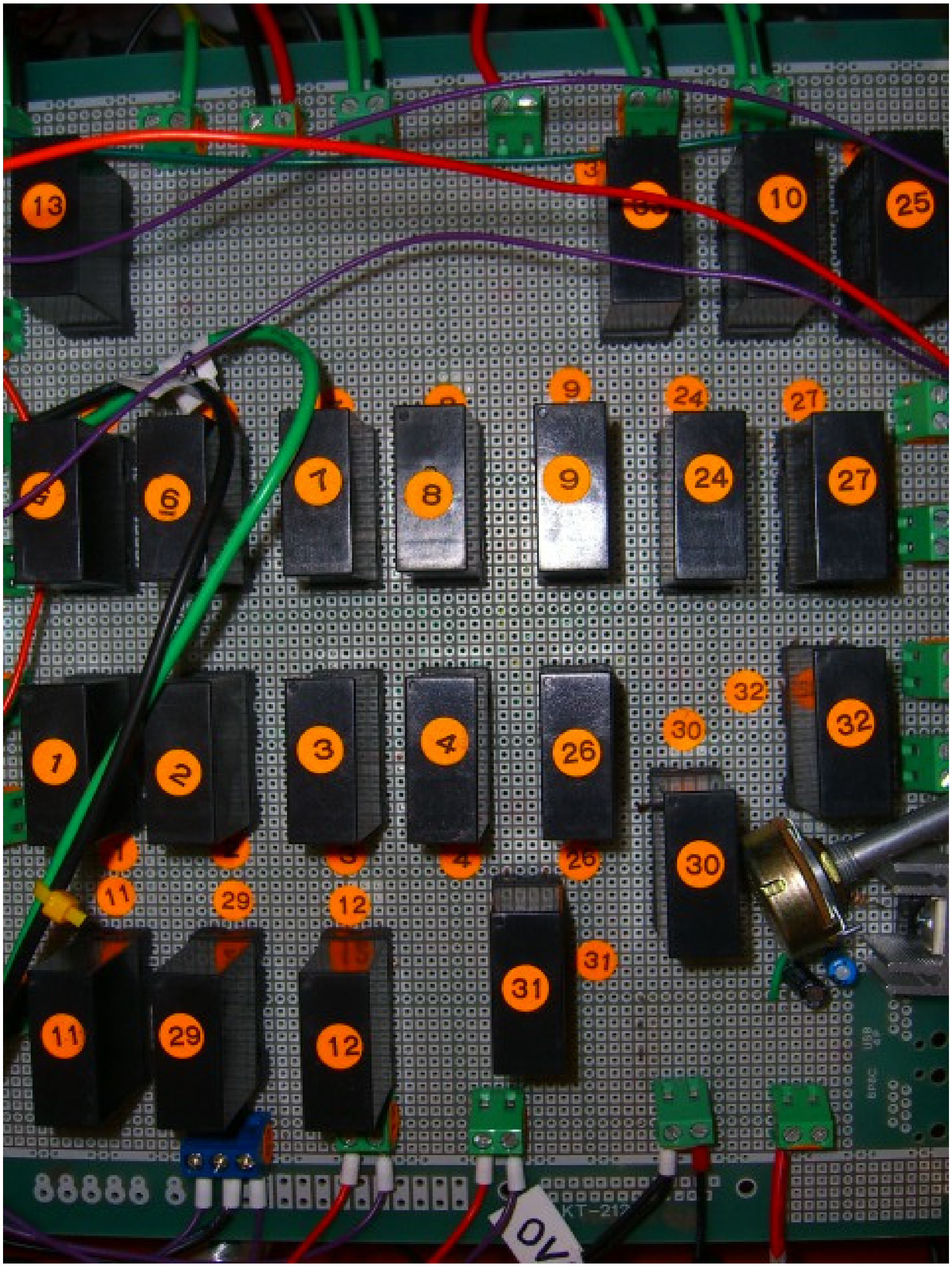


Figure 42. Relays of the ball screw and the driver motors on the Mother
Vehicle.

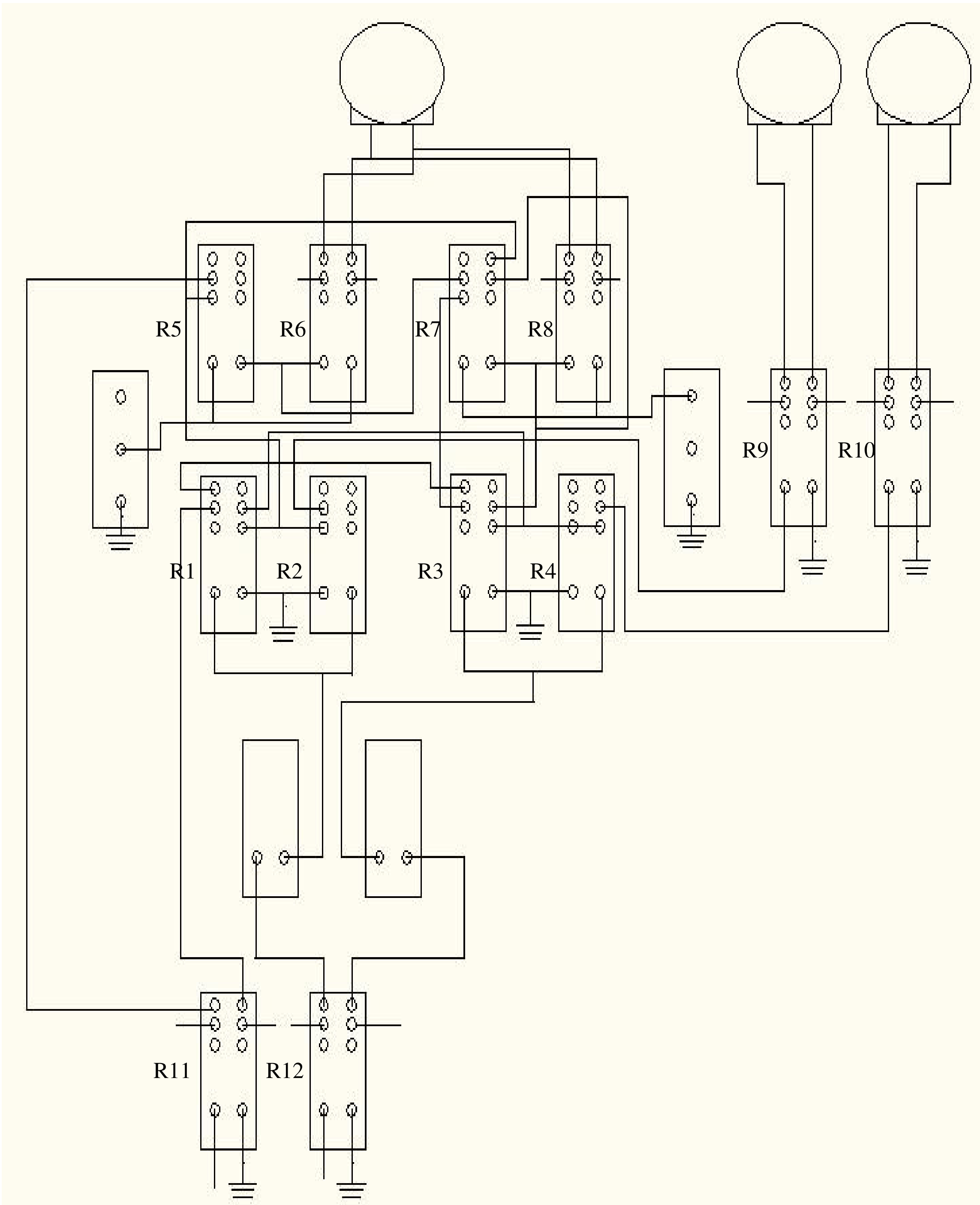


Figure 43. Circuit of the ball screw and the driver motors on the Mother Vehicle.

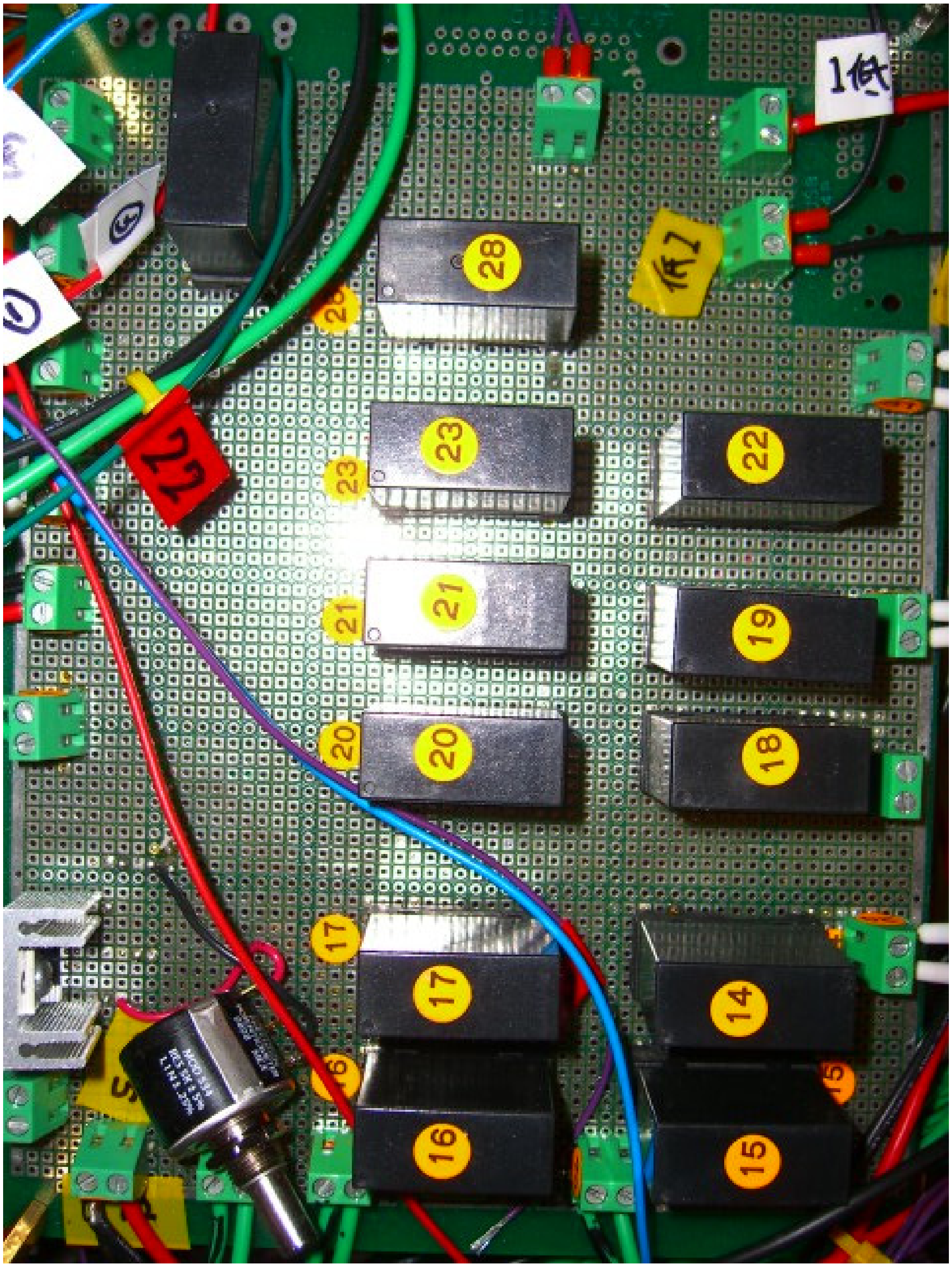


Figure 44. Relays of the back door of the Mother Vehicle.

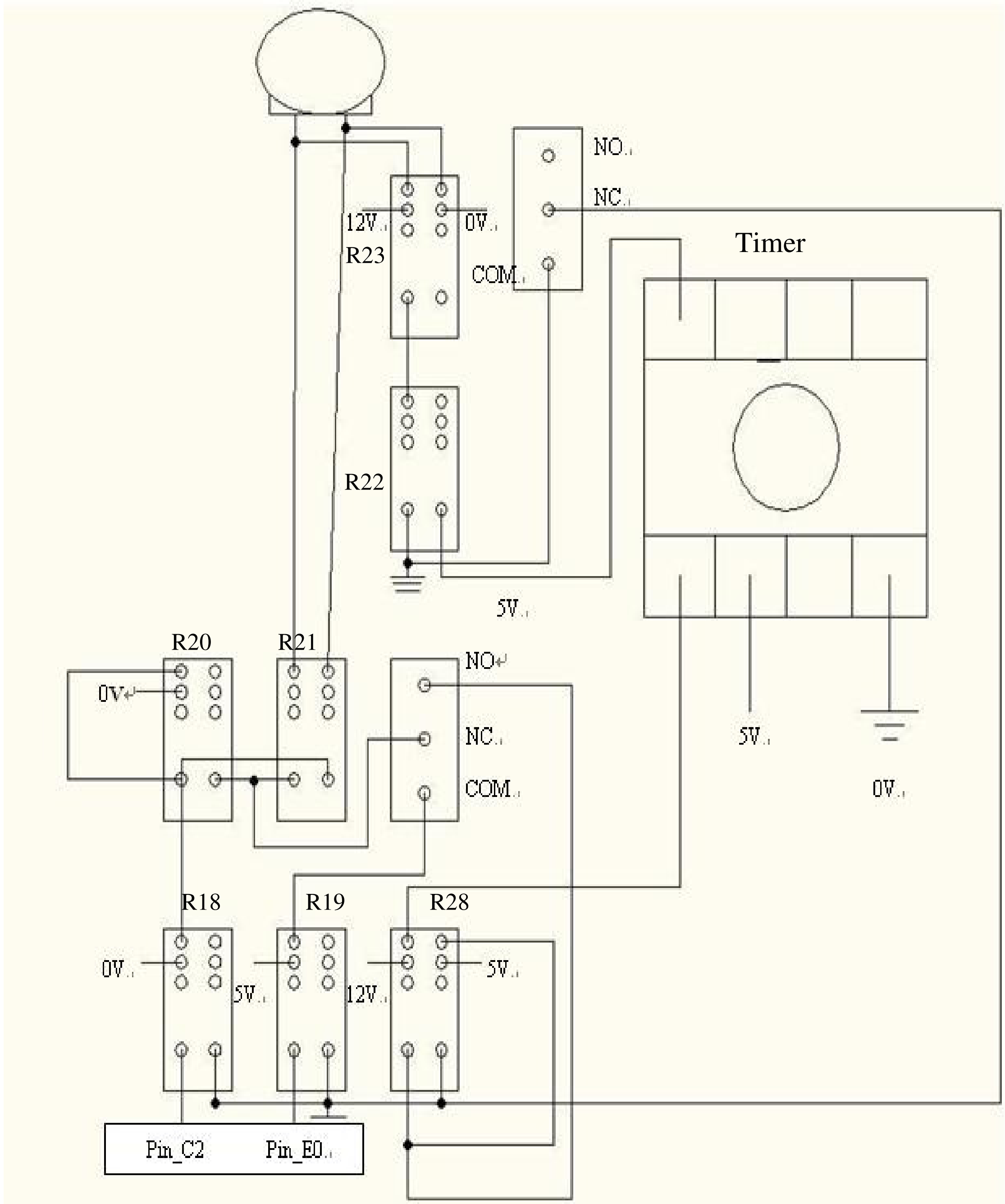


Figure 45. Circuit of the back door of the Mother Vehicle.

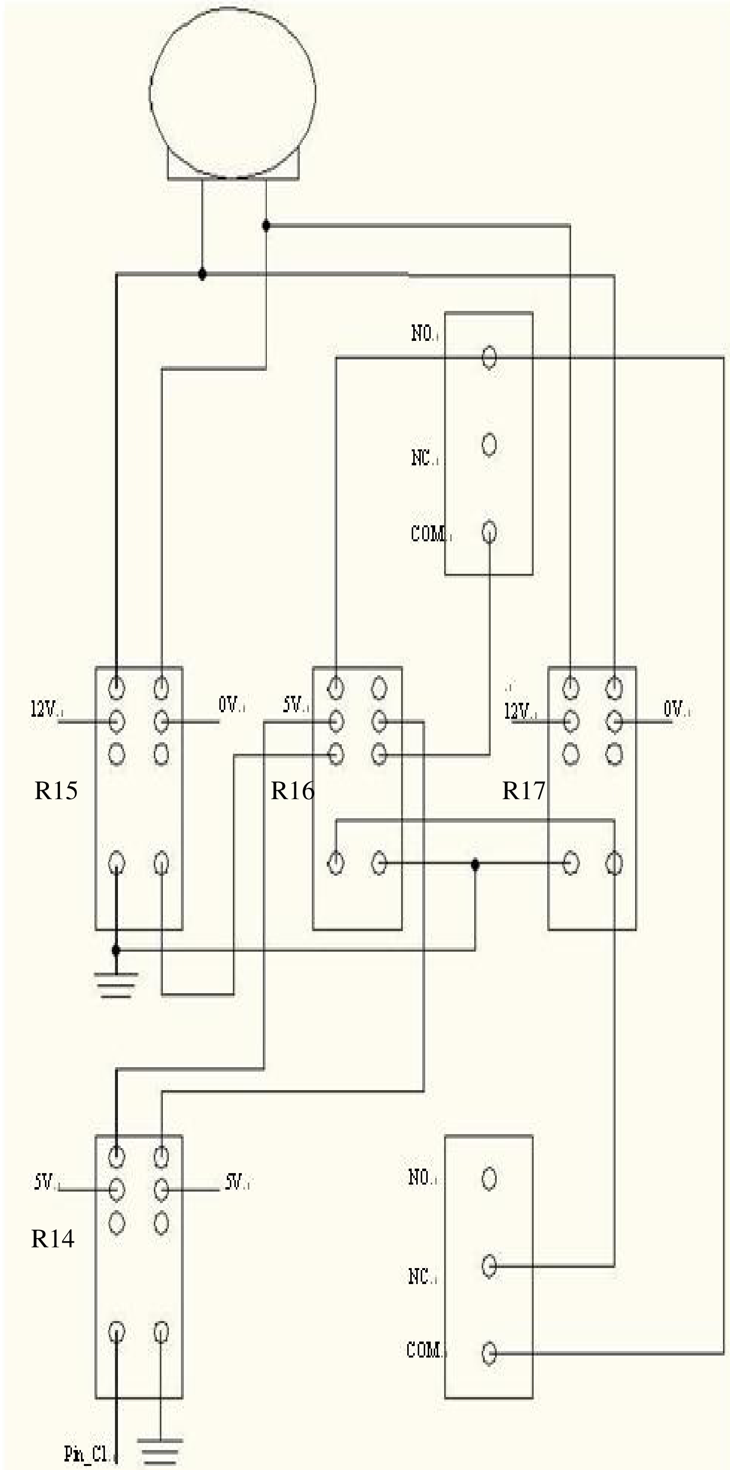


Figure 46. Control circuit of the barbette.

the twin motor gear box easily. The direction and the speed of the motor can be decided by L298N as Figure 48.

As shown in Figure 49, there are five IR sensors located on the first deck. IR sensors are put in the five different positions and toward five directions. The reason to put IR sensors on the first deck is for the purpose of detection. IR sensors are used to detect the obstacles. The lower altitude of IR sensors can detect smaller obstacles. Therefore these IR sensors can help DV prevent collision.

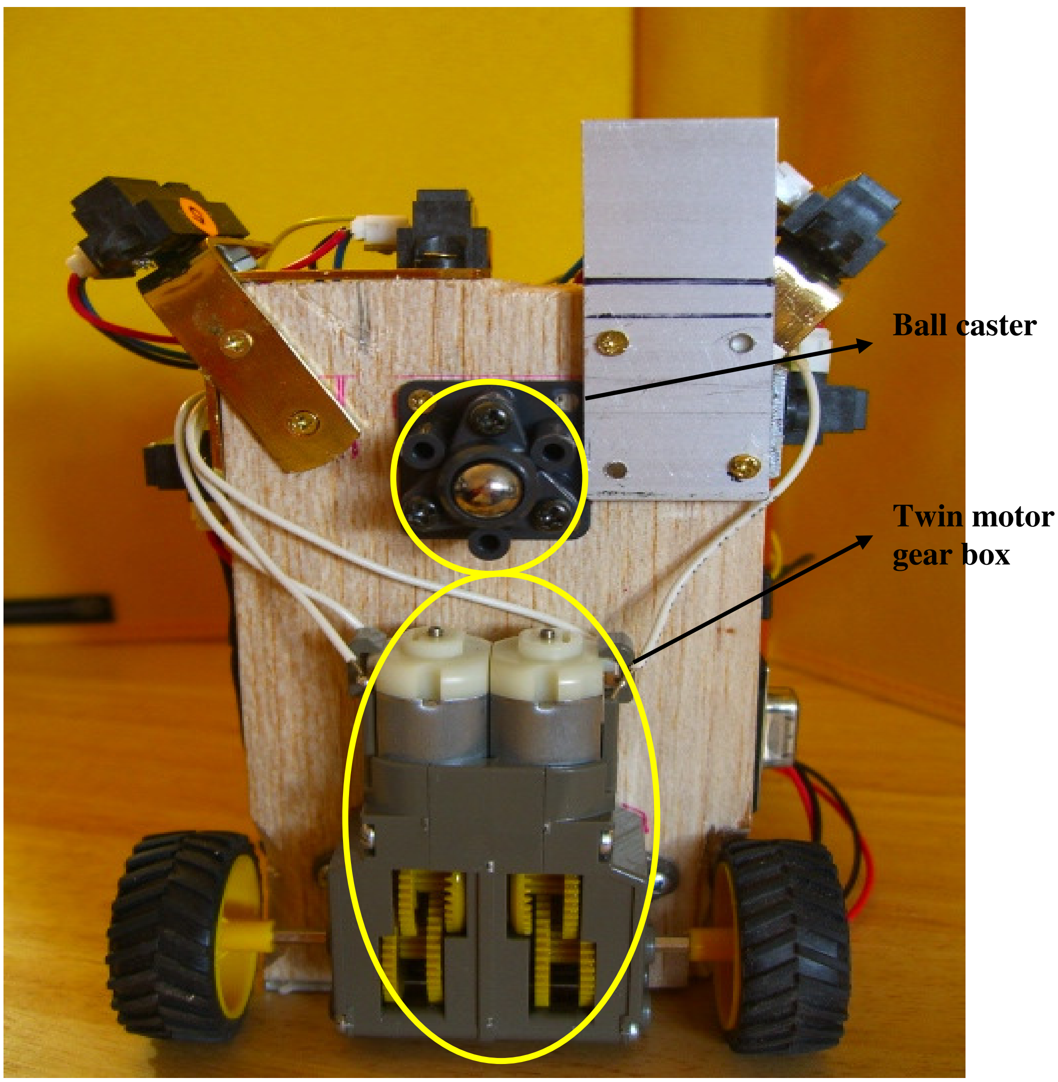


Figure 47. Bottom view of the Daughter Vehicle.

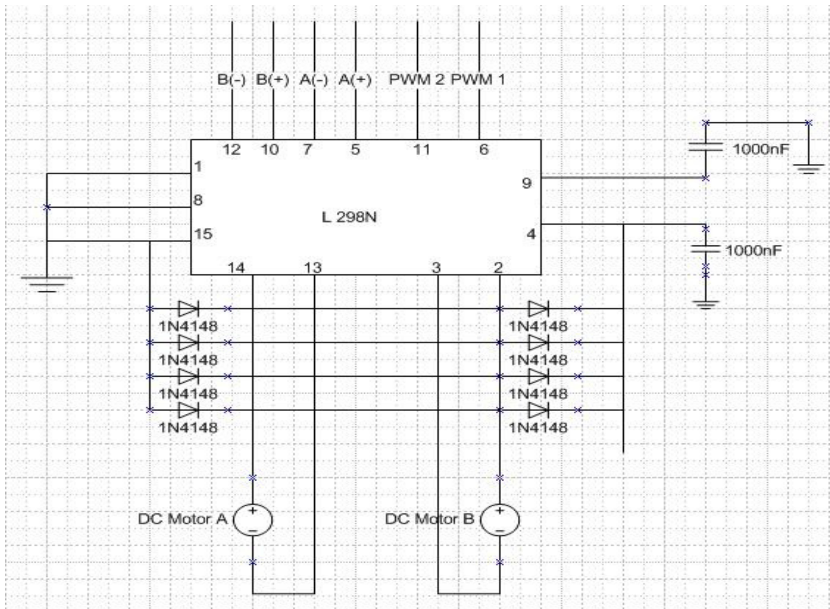


Figure 48. L298N bi-direction drive circuit for the DC motor of the Daughter Vehicles.

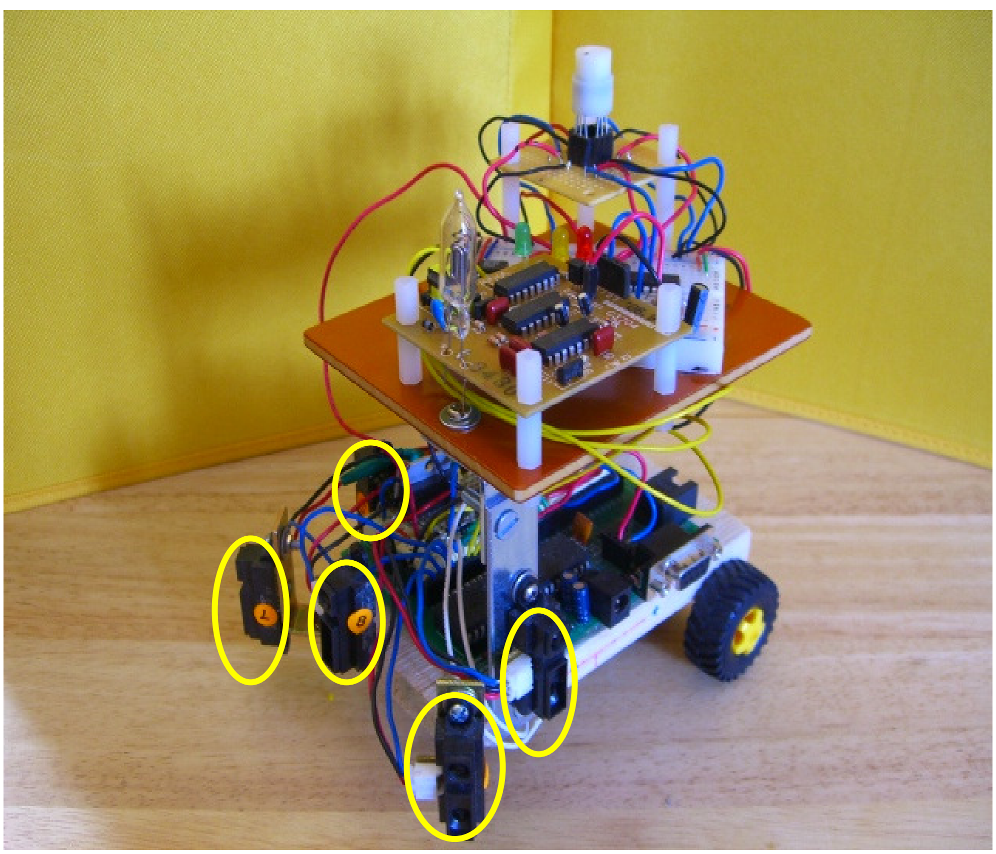


Figure 49. Five IR sensors are applied to detect the obstacles.

As shown in Figure 50, one ultrasonic sensor is used. The main purpose of the ultrasonic sensor is to trigger the system of the DVs. In the beginning, DVs are located in the inside of MV. PING ultrasonic sensor is used to detect the back door of MV. When MV needs help, she will open the back door to let DVs out. DVs' power is always on. DVs wait for the signal from the ultrasonic sensor to run out of MV and implement the tasks. The location of the ultrasonic sensor is between the first deck and the second deck, and is higher than the IR sensors. There are two reasons for the arrangement of the ultrasonic sensor. The first reason is that the ultrasonic sensor utilizes the echo of sound to detect obstacles. Therefore, it cannot be located too close to the ground or other objects. The second reason is that the height of the back door of MV is low so it cannot be put on the second deck.

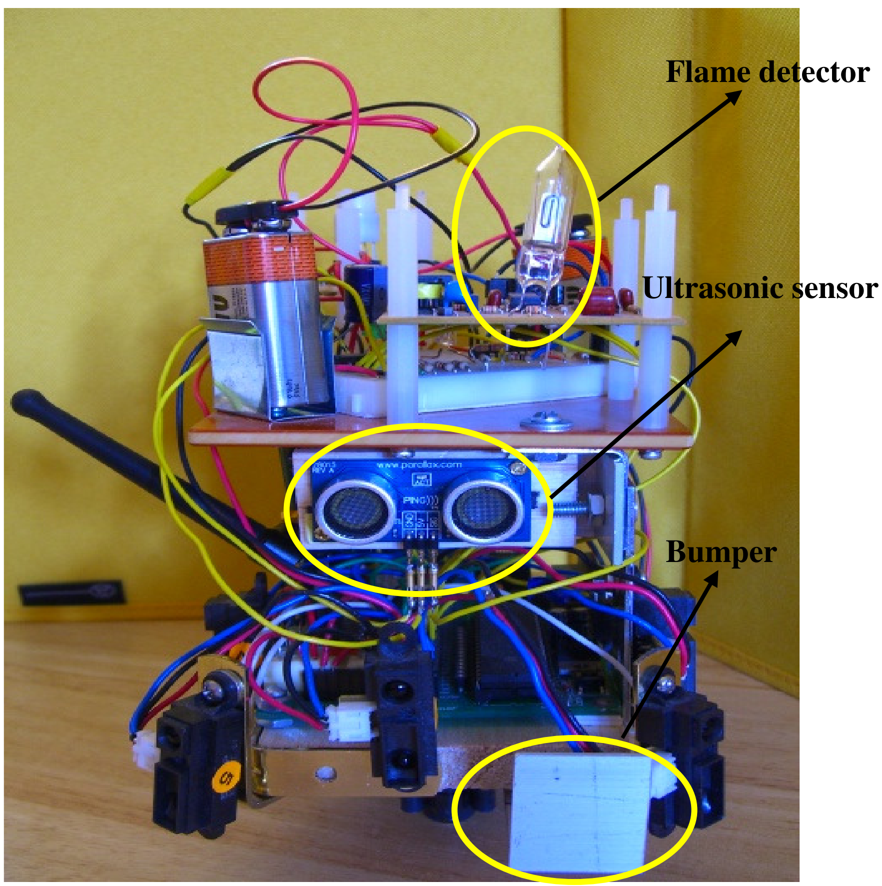


Figure 50. Front view of Daughter Vehicle.

As shown in Figure 50, one flame detector is adopted on each DV. The flame detector is put on the second deck and located in front of the bread board. The flame detector needs a good view to detect fire. That is the reason the flame detector is placed on the second deck and in the front of other items.

As shown in Figure 51, there is a bumper on each DV. The bumper can protect the wire. Because of the limited space for the abdomen of MV, these two DVs will be very close in there. When MV climbs up the stairs, the DVs will collide with each other. The wire of the IR sensor could be damaged under this situation. Therefore, it is necessary to use a bumper to protect the wire of IR sensor. The bumper can also guarantee the distance between the two DVs. When the two DVs are placed in the inside of the abdomen of MV, they can be very close. The detectable range of the ultrasonic sensor is from 2 cm to 3 m. The bumper is used to get the assured distance to put the ultrasonic sensor in the detectable range.

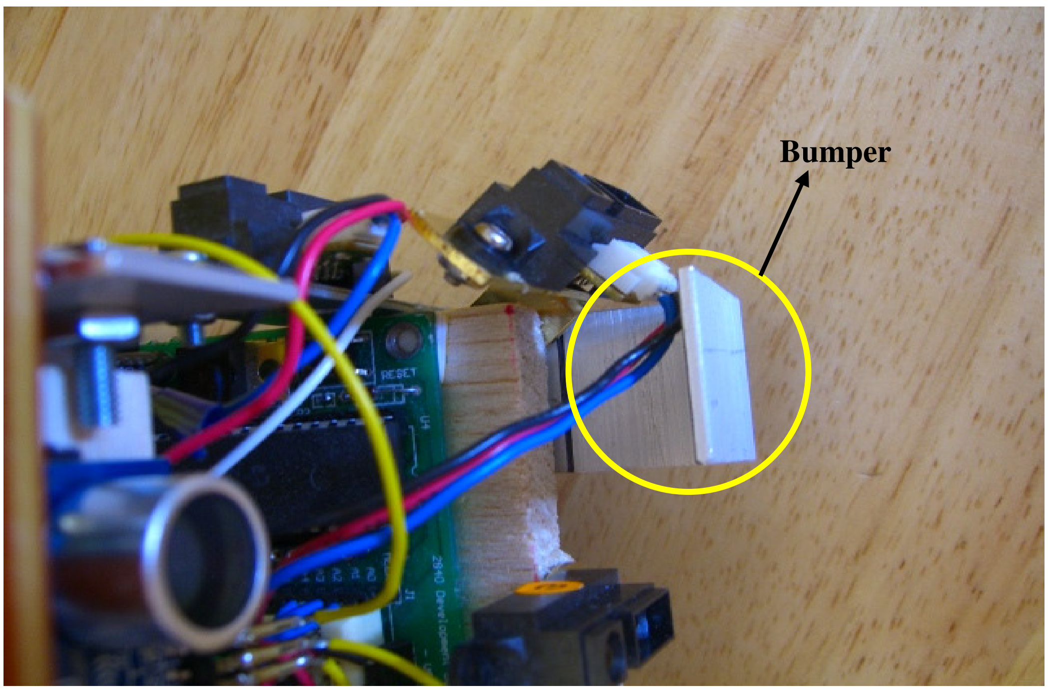


Figure 51. Wire is protected by the bumper.

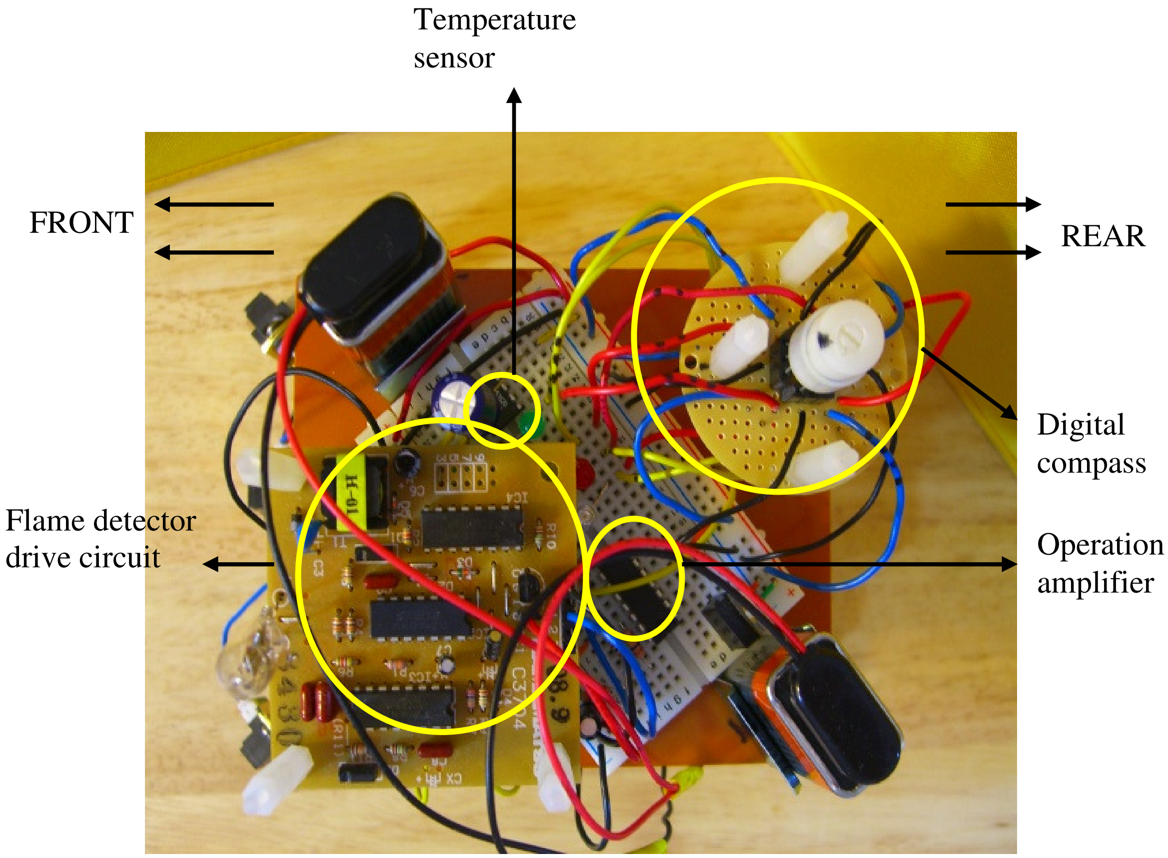


Figure 52. Top view of a DV.

As shown in Figure 52, the digital compass is put on the second deck and located on the rear area. The compass needs to detect the magnetic field of the Earth. The position of the compass is not considered very much. However, the compass cannot be put near the iron or any magnetic object. If the compass is put on the first deck, it will be too close to the motors. The magnet inside the motors will influence the accuracy of the digital compass.

As shown in Figure 52, there are an operation amplifier and one temperature sensor on the bread board. The bread board is put on the second deck and located on the diagonal line of the second deck. The purpose of the bread board on the diagonal line is to create more space to mount a flame-detector drive circuit, a compass, and two batteries.

CHAPTER VI
OPERATION AND TESTING

A. Assumptions

As a cooperative multi-robot system, the UCSFRs will find out flame and extinguish fire. MV will climb up the stairs and let the DVs out. The DV will go in the opposite directions to search fire. In this research, the following assumptions are made regarding the testing environment:

- The hallway has only two directions.
- MV will start by climbing up the stairs.
- DVs will go in the opposite directions.
- After DVs are out, MV will stay to wait until it gets the temperature signal from one of DVs.
- UCSFRs cannot climb the stairs like those shown in Figure 53.
- UCSFRs only work inside a building.

B. Operation

These UCSFRs are autonomous robots. Bluetooth communication modules between UCSFERs and a laptop are used to turn the system on and run the program only. These tests are performed to verify the functionality of the UCSFRs.

In the first test, a flame detector, a temperature sensors and MV work together. If there is fire in the vicinity (5 m), the flame detector will output a "high (5 V)" signal to the microcontroller of MV. When MV receives this signal, she will check the temperature status. The distance between MV and fire is determined by temperature.

For the testing purpose in this research, if temperature is 30°C, it is considered that MV is closes to fire enough to operate a fire extinguisher to extinguish fire. If the

Figure 53. It is hollow between two stairs. Because MV used micro-switch to do the mechanical interaction between MV and stairs, this type of stairs can not be climbed by MV. The reason is that micro-switches can not touch the wall of stairs since they are mounted in front of MV. The micro-switches help MV to decide when ball screw should come out.

temperature is always below 30°C, MV will keep moving until the temperature increase beyond 30°C.

For the second test, Bluetooth, a flame detector, a temperature sensor, one timer, IR sensors, and ultrasonic sensors are tested and used. In the first sub-test, MV will find fire first and look for the high temperature. In this test, MV will not find the fire but she got an abnormal high temperature (30°C). Under this condition about no fire but high temperature, it is considered that there is fire in somewhere of this floor but MV do not see the fire yet. At this moment, the MV will need help from DVs. Under this high -temperature but no-fire condition, MV keeps recording the high-temperature, but the flame detector does not output a "high" signal. MV will open the back door to let both DVs out to help her. DVs start their task when they get signal from ultrasonic 5^{th} sensor. The ultrasonic sensors are set if they detect the distance is greater than 5 cm, they will trigger DVs. That is the reason for DVs' motion. When the back door of MV is opened, DVs will come out and DV1 will be followed by DV2. When DVs come out, they will try to detect fire. When one DV find fire, it will stop there and wait for wireless connection with MV. If DVs are out, MV will keep receiving the temperature data from DVs. In this research, if DVs find the fire, they will send 99 to MV. MV will consider the large number as high temperature value.

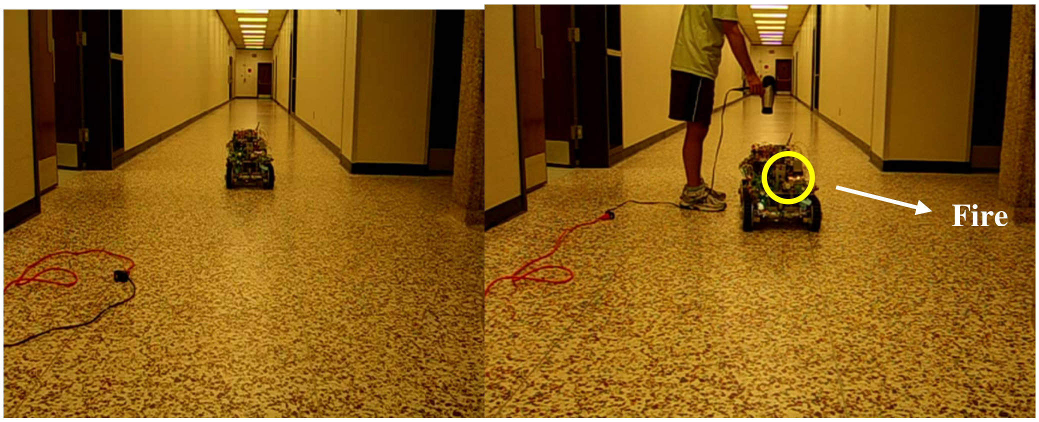
In the third test, the main purpose is to test the capability of MV to climb the stairs. In this test, two micro-switches, ultrasonic sensor 5, ultrasonic sensor 6 and ball screw will be used. When the micro-switches of MV touch the stairs, MV will stop moving and the ball screw will be triggered. The ball crew will come out until two micro-switches stop touching the stair. The ball screw is designed to allow swinging. The purpose of this design is to let MV move forward easily. When MV climbs up the first stair, the micro-switch might be touching the second stair again. At that moment, the ball screw may not draw back yet, so there is a "T" shape (Figures 37 and 40) allowing the swinging of ball screw. At the same time, if micro-switches touch the second stair, it means MV needs another help to climb the stair. If ball screw does not draw back, but the micro-switches are triggered again, the ball screw will draw back all the way until it touches the micro-switch 1 as Figure 32. After the ball touches micro-switch 1, ball screw will stop drawing back and come out again to help MV climb up to the second stair. The following subsection will introduce all operation step by step.

1) *Mother Vehicle Find Fire and Stop Moving*

In this test, the position of MV is located on the first floor as Figure 54 (a). In this operation, it is assumed that MV finds the fire and it tries to approach fire. The temperature sensor is used to set the distance between MV and fire. In this part, if the temperature is higher than 30°C, it is considered that MV is very close to the fire and then MV needs to stop. In order to test this operation, a candle is placed in front of the flame detector (Figure 54 (b)) to assume that fire is found by MV and then a heat gun is used to heat the temperature sensor up. When the temperature is over 30°C, MV stops moving.

2) *Communication Test between MV and DVs*

In the second operation, the cooperation and communication ability between MV and DVs are tested. In the beginning, MV is moving in the hallway like the first



(a) **(b)**

Figure 54. Mother Vehicle find fire and stop test. (a) MV stays in the hallway. (b) MV finds and approaches.

operation, but there is one difference which is no fire in front of the flame detector and the temperature heat up first. This step is used to assume that the environment is in the high temperature, but MV does not find the fire. Under this situation, MV will let DVs out to help her to find out the flame. In this operation, 30°C is considered an abnormal high-temperature environment. DVs are put in the abdomen of MV and stand by. At that time, the power of DVs is on, but DVs will wait for the signals from their ultrasonic sensors. When the back door is open, the ultrasonic sensors will know and send signals to DVs. DV 1 will come out when the door is open. When MV's temperature is over 30°C, she stops and opens the back door as shown in Figure 55. When DVs come out from the abdomen of MV, DVs are designed to go in opposite directions and one DV will be put a mask to make sure that the flame detector will not detect the fire as in Figure 55 (d). When one DV finds fire, it will stop there and wait for MV. When the wireless connection is established, MV sends an "ask-signal" to ask the DV to send data. MV will connect these two DVs one by one and compare the values sent by DVs. MV will head forward to the DV which sent fire signals. If there is no fire, MV will

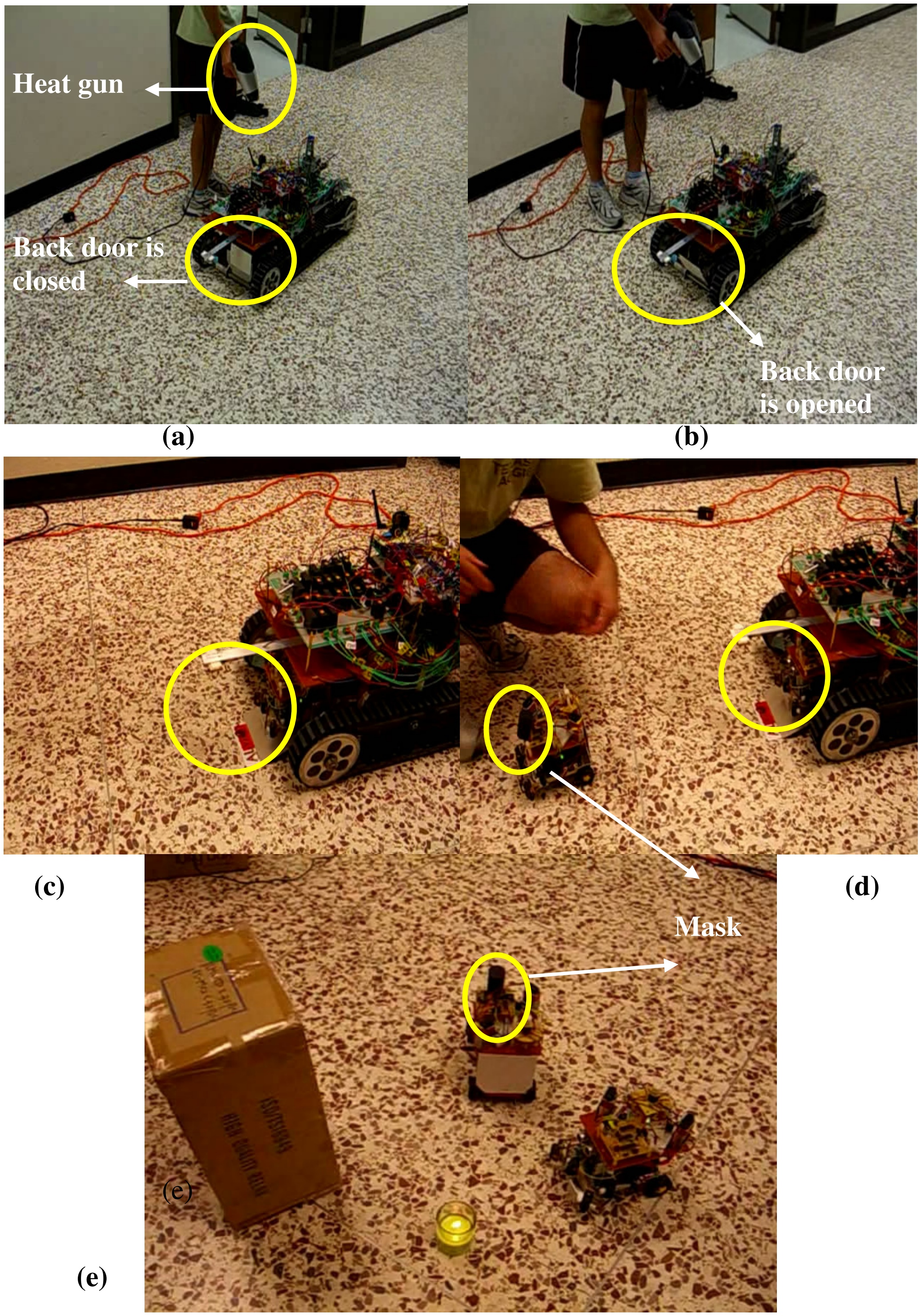


Figure 55. (a) A heat gun is used to heat up the temperature sensor and the back door is closed. (b) The temperature on MV is over 29 so the back door is opened. (c) DV 1 is coming out. (d) DV 2 is coming out and one mask is placed on DV 1. (e) A candle is placed in front of a DV.

compare the temperatures from DVs.

If MV is on the stairs and receives an abnormal-temperature signal, the back door will not open. There are two conditions for MV to open the back door. The first condition is the abnormal-high temperature. The other condition is that MV is not on the stairs. As mentioned in the previous chapter, two ultrasonic sensors are used to decide the position of MV. If MV is on the stairs, the back door will not be open until she climbs to another floor.

3) *Stair-Climbing Capability Test*

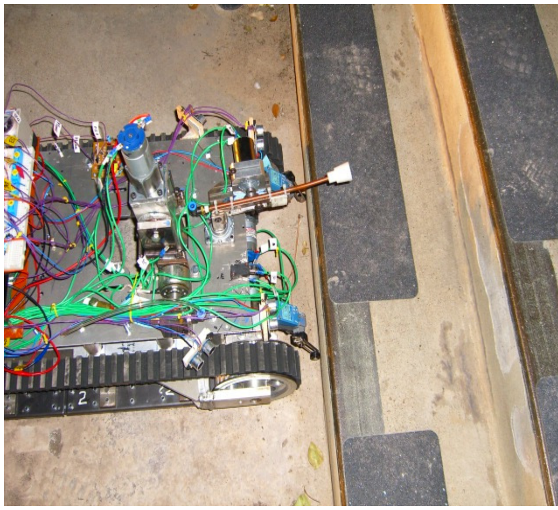
Figure 56 is the sequent photos about MV to climb the stair. On MV, there are two types of relays. One is the LM Series and the other one is the RY Series. The LM Series relay can deal with 5 A and 30 V DC. For the RY Series, it can deal with 1 A and 24 V DC. Because the output high of the microcontroller cannot offer enough current to trigger the LM Series, The output high of the microcontroller is used to trigger the RY Series first and then the RY Series to trigger the LM Series. The flowchart shown in Figure 55 illustrates the overall operation of MV and DVs.

4) *Circuit Operation*

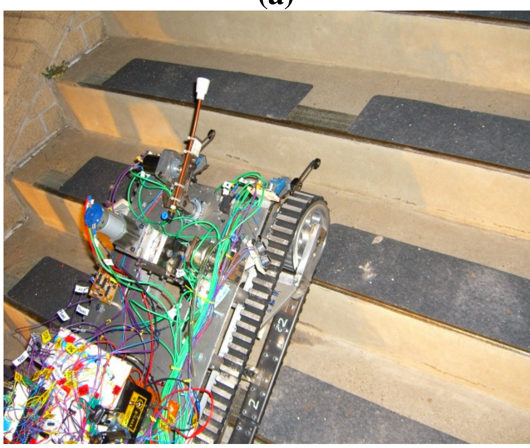
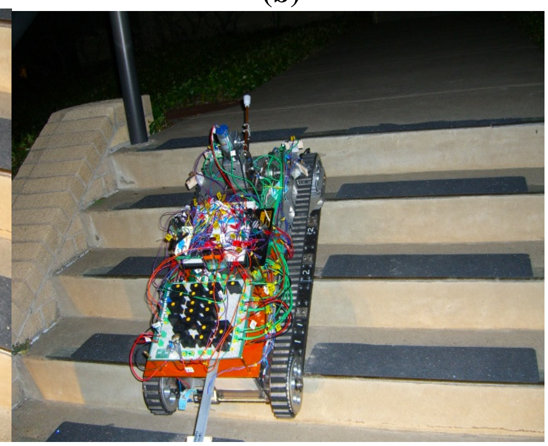
The circuit operation explains how the circuit works. The circuit is mentioned in Chapter V (3). The following Table 8 points out the function of each pin on the microcontroller.

4.1) *Circuit between Forward and Ball Screw*

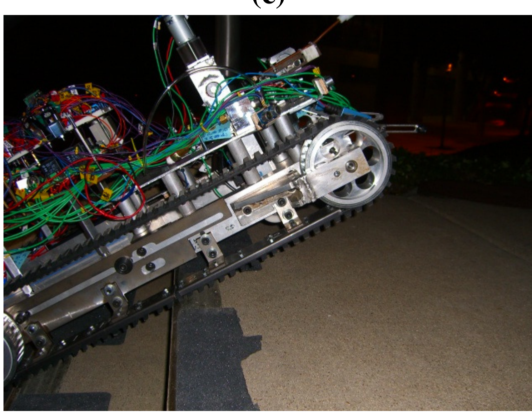
When UCSFRs want to move forward, users need to output high signals to PIN_D0 and PIN_D1. These signals will trigger R11 and R12. The Normal Open points in R11 and R12 will become close and then the current will go through R5. If the current go through R5, the current will trigger R9 and R10. If R9 and R10 is triggered, MV will move forward. When MV moves forward and micro-switches are touched, R1-R4 will be triggered. If R1 to R4 are triggered, R5 to R8 are also triggered. Under this status, R9 and R10 stop triggering so MV stops moving forward. At the same time, ball screw




(a) **(b)**

(c) **(d)**




(e) **(f)**

Figure 56. (a) Micro-switches touch the stairs. (b) Ball screw is coming out. (c) MV climbs over the first stair and the micro-switch touch the wall of the second stair. (d)~(e) MV is on the stairs and climbing up. (f) MV is on the second floor.

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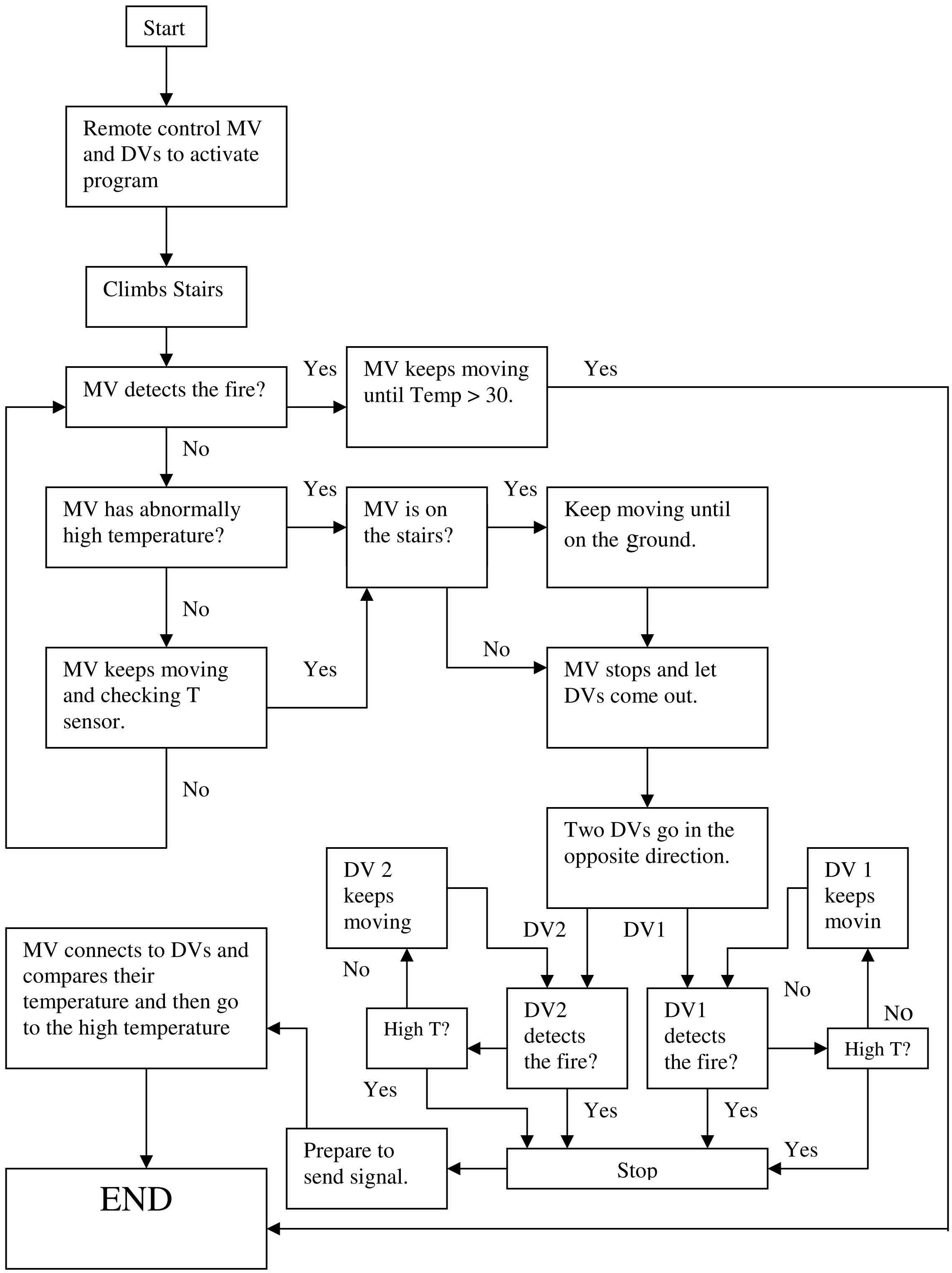

Figure 57. Flowchart of the operation of MV and DVs.

Table 8 PINs' number on the microcontroller and device number.

PIN on Microcontroller	Connective Device Number
A0	r1*-R27
A1	B-relay**
A2	r2-R25
B0	T-sensor***
B1	T-sensor
B2	T-sensor
B4	Ultrasonic 6
B5	Ultrasonic 5
B6	Ultrasonic 1
C0	r3-R13
C1	r4-R14
C2	r5-R18
C3	R30
C4	Ultrasonic 2
C6	Bluetooth
C7	Bluetooth
D0	r7-R11
D1	r8-R12
D2	r9-R26
D3	r10-R24
D4	r11-R29
D5	Flame detector
D6	Ultrasonic 4
D7	Ultrasonic 3
E0	r12-R19

*: Small relays shown in Figure 58.
**: Small relay controls the power of Bluetooth.
***: Temperature sensor.

comes out. If the micro-switches are released, R1 to R8 will not be triggered. Therefore, the ball screw will draw back.

4.2) *Circuit between MV and Back Door*

When MV receives an abnormal high-temperature and does not find the fire, it will open the back door to let DVs out. Figure 43 shows the circuit about the back door. When MV wants to let DVs out, she output "high" signals to PIN_C2 and PIN_E0. At this moment, R18 and R19 are triggered so R20 and R21 are triggered as well. If R21 is triggered, the current will go through R21 from COM to NO and then the motor of the back door will rotate. The motor of the back door will not stop until it touches the micro switch 1 as shown in Figure 59. If the back door touches the micro switch 1, the timer will be triggered. Timer is pre-set up. When it is triggered, the time will count down. When the time is up, the back door will close. If the motor of the back door touches the micro switch 2 as shown in Figure 60, the motor will stop.

4.3) *The Circuit of the Barbette*

As shown in Figure 46 and Table 8, if PIN_C1 receives a "high", relay R14 will be triggered. If R14 is triggered, the current will go to R5 via R6. If the current goes to R5, R5 will be triggered. The motor of the barbette will rotate clockwise until it touches the micro-switch 1 shown in Figure 36. After touching the micro-switch 1, it will rotate counterclockwise until it touches the micro-switch 2 shown in Figure 36. The barbette will keep rotating like this until the output of PIN_C1 is low.

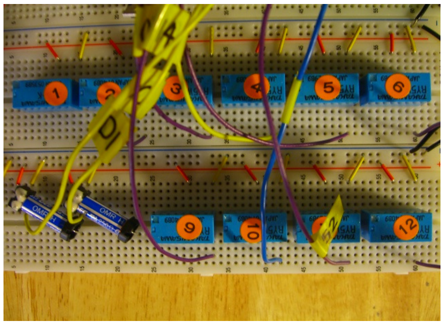

Figure 58. Small relays control big relays.

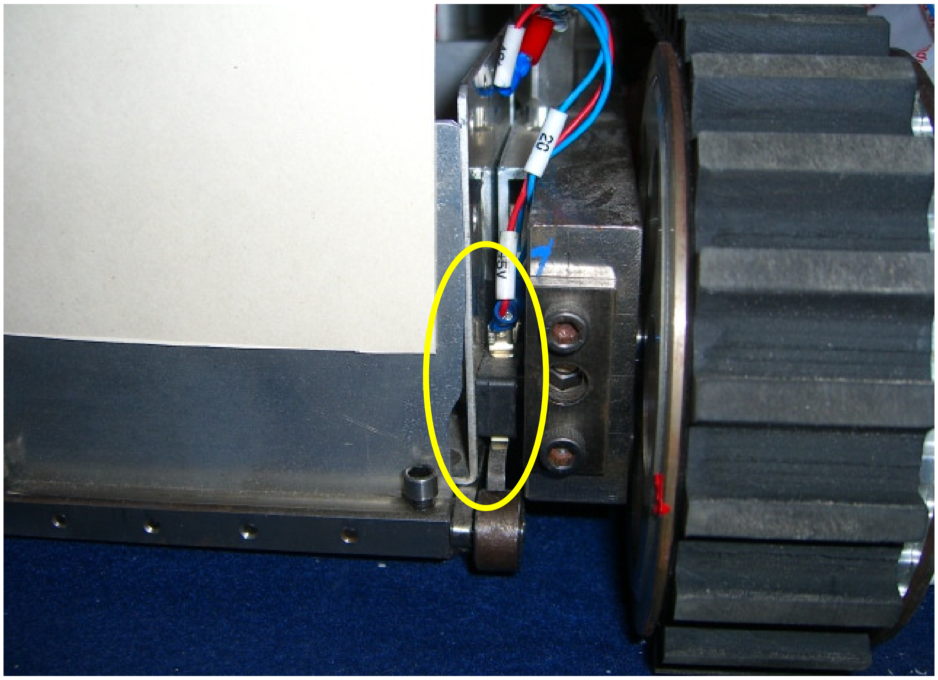

Figure 59. Micro switch 1 of the back door.

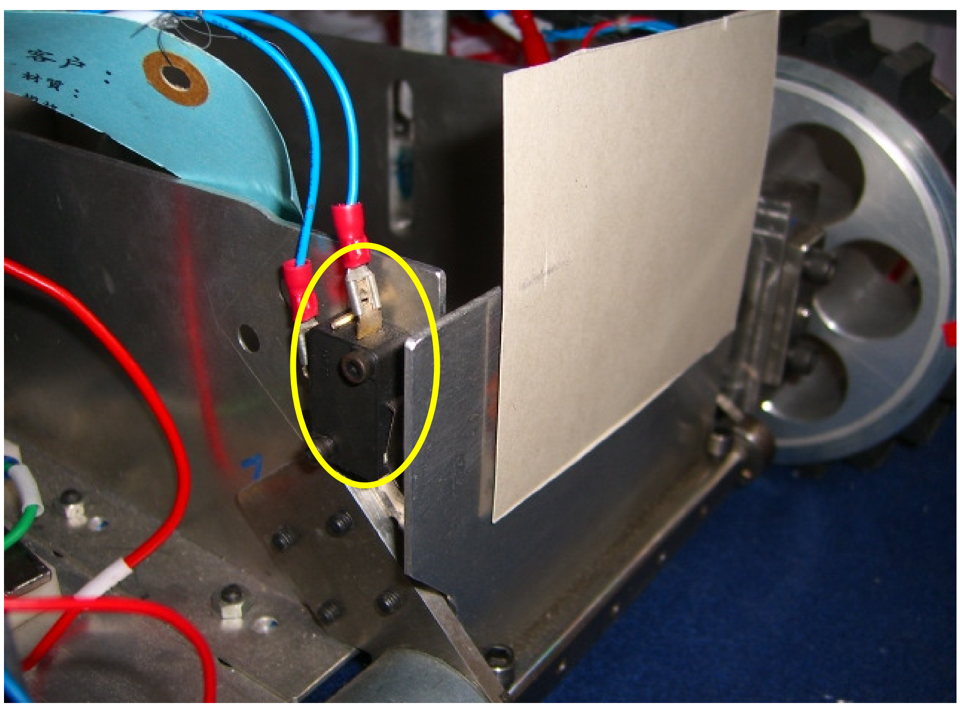

Figure 60. Micro switch 2 of the back door.

CHAPTER VII
CONCLUSIONS

A. Conclusions

The UCSFRs have been successful to achieve their objectives such as the capability of stair-climbing, autonomous cooperative fire-seeking, and fire-fighting. MV possesses the capability of autonomous detecting and extinguishing fire inside a building. DVs own the capability of detecting fire and sending the signal to MV. The capability of UCSFRs is not only finding fire but also approaching the fire enough to extinguish it. So far, this capability has not been found on other fire-fighting robots developed by other researchers. There is a significant advantage of the UCSFRs, that is, they can be semi-autonomous or autonomous. If UCSFRs are in the semi-autonomous mode, they will be remotely operable over Bluetooth by human beings. If they are in the autonomous mode, users just need to trigger them over Bluetooth. There is no need to adopt many devices to operate and control UCSFRs. That means that users only require one Bluetooth, a laptop, and the Hyper Terminal built in Windows XP to control UCSFRs is under the semi-autonomous mode. The main reason to use Bluetooth is its high data rate, cost, and portability compared with other wireless communication modules. All sensors on UCSFRs are not permanently mounted. This feature allows that all sensors can be replaced easily for expansion or specific missions.

Another unique feature for UCSFRs is their methods to detect stairs. A feedback of mechanism is employed on UCSFRs to achieve the capability of stair-climbing. When micro-switches touch the stairs, the ball screw comes out. If micro-switches are released, the ball screw draws back. Mechanical detection with micro-switches substitutes electronic sensors. It will decrease the chance of missing stairs and errors from the sensors

Another unique feature compared with other fire-fighting robots is that UCSFRs are a three dimension (3-D) fire-fighting robot. Other fire-fighting robots are 2-D. The difference is that UCSFRs can work from one floor to another one, but 2-D robots can only work on the same floor.

B. Suggested Future Work

There are some points we can improve. For the motors, it can be changed from 12–V DC motors to the 24–V DC motors. The 24–V motors can offer more torque. Low speed DC motors (10 rpm) are employed in this research. In the future, it may need to change the speed of the motors. In this research, ultrasonic sensors were not used to obstacle-avoidance. The ultrasonic sensors work very well and accurately. The only downside in this research is that they cannot use at the same time. Under these assumptions of the operation, it is not necessary to use so many ultrasonic sensors. They are easily interfered by the motors. When the motors start or change the direction, they usually cannot work normally. The temperature and the ultrasonic sensors need independent power source.

REFERENCES

[1] U.S. Fire Administration *Fire-Related Firefighter Injuries Report in 2004* , Report February 2008.

[2] U.S. Fire Administration. Statistics on fire accidents, http://www.usfa.dhs.gov (accessed on 02/15/2009).

[3] Lockheed Martin Incorporation. The data of AUV, http://www.lockheedmartin.com/ (accessed on 04/15/2009).

[4] Air Force Technology. The data of predator, http://www.airforce-technology.com/ (accessed on 06/01/2009).

[5] Naval Technology. The information of AUV, http://www.naval-technology.com/ (accessed on 05/30/2009).

[6] NASA Jet Propulsion Lab. The information of Spirit/Opportunity, http://marsrovers.jpl.nasa.gov/ (accessed on 08/15/2009).

[7] B. K. Muirhead, "Mars Rover, Past and Future," in *Proc. of IEEE Aerospace Conference,* 2004, vol. 1, pp. 128–134.

[8] N. Sharkey, "Cassandra or False Prophet of Doom: AI Robots and War" *IEEE Intelligent Systems,* vol. 23, no. 4, pp.14–17, July/August 2008.

[9] Talon Family. The information of UAV, http://www.foster-miller.com/index.asp (accessed on 02/15/2009).

[10] iRobot. The information of iRobot, Inc. http://www.irobot.com/ (accessed on 02/15/2009).

[11] Chian Di Enterprise Co. The structure of ball screw, http://www.cdc.com.tw/ (accessed on 04/10/2010).

[12] R. A. Lindemann, D. B. Bickler, B. D. Harrington, G. M. Ortiz, and C. J. Voorhees, "Mars Exploration Rover Mobility Development," *IEEE Robotics and Magazine,* vol. 13, no. 2, pp. 19–26, June 2006.

[13] J. B. Webb and W. W. Walter, “Exploration of a Hybrid Locomotion Robot,” in *Proc. of ASME International Mechanical Engineering Congress and Exposition* pp. 1-11, 2007.

[14] W. Wang, Z. Du and L. Sun, “Dynamic Load Effect on Tracked Robot Obstacle Performance,” in *Proceedings of International Conferenc*e, pp.1-6 May 2007.

[15] N. Baker, “Bluetooth Strengths and Weaknesses for Industrial Applications,” *IEE Computing & Control Engineering,* vol. 16, no. 2, pp. 20–25, April/May 2005.

[16] Bluetooth Inc., The information of Bluetooth. http://www.bluetooth.com (accessed on 05/10/2009).

[17] ZigBee Alliance. The information of ZigBee, http://www.ZigBee.org/ (accessed on 05/10/2009).

[18] C. Evans-Pughe, “BZZZZ,” *IEE Review*, vol. 49, pp.28–31, March 2003.

[19] Z. Pei, Z. Deng, Bo. Y, and X. Cheng, “Application-Oriented Wireless Sensor Network Communication Protocols and Hardware Platforms: A Survey,” in *Proc. of IEEE International Conference on Industrial Technology,* pp. 1-6, 2008.

[20] C. H. Hsieh, B. Q. Nguyen, Z. Jin, D. Marthaler, A. L. Bertozzi, D. J. Tung, and R. M. Murray, “Experimental Validation of an Algorithm for Cooperative Boundary Tracking,” in *Proc. of American Control Conference,* pp.1078-1083, 2005.

[21] J. Pugh, X. Raemy, C. Favre, R. Falconi and A. Martinoli, “A Fast Onboard Relative Positioning Module for Multirobot Systems,” *IEEE/ASME Transactions on Mechatronics*, vol. 14, no. 2, pp. 151-162, , April 2009.

[22] F. Rivard, J. Bisson, F. Michaud and D. Letourneau, “Ultrasonic Relative Positioning for Multi-Robot System,” in *Proc. of IEEE International Conference on Robotics and Automation,* pp. 323- 328, May 2008.

[23] A7 Engineering Inc. “eb-501 serial guild,” 2007. http://www.a7eng.com/index.htm (accessed on 01/10/2009).

[24] Microchip “PIC 16F87X datasheet”. http://www.microchip.com 2001. (accessed on 02/10/2009).

[25] Basicmicro "2840 development board datasheet". http://www.basicmicro.com/ 2002. (accessed on 02/10/2009).

[26] PIC MCU C Compiler Reference Manual, 2003, CCS Inc. http://www.ccsinfo.com/ (accessed on 02/10/2009).

[27] Rayex. The pin information of relays, http://www.relay-rayex.com/ (accessed on 01/10/2010).

[28] Robson. The data sheet of 1490 digital compass, http://www.robsonco.com/ (accessed on 02/10/2010).

[29] PING Ultrasonic Sensor datasheet. Vol.15 02/18/2008. http://www.parallax.com/ (accessed on 03/10/2009).

[30] Sharp GP2D120 datasheet 2006. http://document.sharpsma.com/ (accessed on 03/10/2009).

[31] HAMAMATSU UVtron driving circuit C3704 series. http://jp.hamamatsu.com/ (accessed on 02/10/2009).

[32] HAMAMATSU Flame Sensor, 2008. http://jp.hamamatsu.com/ (accessed on 02/10/2009).

[33] MAXIM DS1620 Temperature Sensor datasheet. http://datasheets.maxim-ic.com/ (accessed on 01/10/2009).

[34] Fairchild LM7805 Voltage Regulator datasheet, 2006. http://www.fairchildsemi.com/ (accessed on 02/10/2009).

[35] Fairchild LM317 Adjustable Regulator datasheet, 2005. http://www.fairchildsemi.com/ (accessed on 11/10/2008).

[36] National Semiconductor "LM324 Quad Operational Amplifier." http://www.national.com/analog, 2000 (accessed on 11/10/2008).

APPENDIX A

```
//************************Code for MV*******************************//

//Definition : when the temp > 30 and PIN_D5 !=0, it means that we find the fire and
//           we very close fire.  If temp>33, it means that there is a abnormal temperature

//So far, I try to use this one on Mother Vehicle.

#include <16F877.h>
#device ADC=10
#use delay(clock=10000000)
#use rs232(baud=9600, xmit=PIN_C6, rcv=PIN_C7, ERRORS)
#include<stdio.h>
#include <math.h>  // for temperature sensor

#define DQ PIN_B0               //for temperature sensor
#define CLK PIN_B1               //for temperature sensor
#define RST PIN_B2               //for temperature sensor

//#define MARGIN 2

unsigned char GetByte(void);      //for temperature sensor
void PutByte(unsigned char d);   //for temperature sensor
void Ultrasonic(void);

int16 overflow_count;
#int_timer1
void timer1_isr()
```

```
{
overflow_count++;
}
int16 time1, time2,time3,time4,time5,time6;
unsigned char Temp,TempDVA, TempDVB, TempDVAACK, TempDVBACK;  //
        Temp is the T-sensor on MV.
unsigned char sign_bit;
char TempDV1fake1, TempDV2fake2;
float distance1,distance2,distance3,distance4, distance5, distance6;

void main()
{
setup_timer_1(T1_INTERNAL|T1_DIV_BY_8);
enable_interrupts(INT_TIMER1);

enable_interrupts(global);

//while(1)
//{
       delay_ms(3000);
       output_high(PIN_D0); //go forward ;
       output_high(PIN_D1); // go forward ;
       output_high(PIN_C0); //Start Fire Gun
       output_high(PIN_C1); //Start barbette

       delay_ms(5000);  // initial ans settle down everything

start1:
```

```
	output_low(RST);	//for temperature sensor
			output_high(RST);	//for temperature sensor
			PutByte(0xEE);		//for temperature sensor
			output_low(RST);	//for temperature sensor
			delay_ms(500);		//for temperature sensor
			output_high(RST);	//for temperature sensor
			PutByte(0xAA);		//for temperature sensor
			Temp=GetByte();		//for temperature sensor
			sign_bit = GetByte();	//for temperature sensor
			output_low(RST);	//for temperature sensor
			Temp >>= 1;		//for temperature sensor

	//printf("Temperature now is in start1 %d\n\r",Temp);
	delay_ms(700);
	Ultrasonic();
	delay_ms(700);
if (Temp>29 && input(PIN_D5)) //
{
//printf("Now Temperature is %d get in first if including PIN_A2 \n\r ", Temp);

output_low(PIN_D0);  //stop Mother Vehicle
output_low(PIN_D1);  //stop Mother Vehicle
delay_ms(1000);      //This delay is due to inertia of DC motor
output_low(PIN_C0);  //Stop Fire Gun
delay_ms(2000);      //this delay is due to inertia of DC motor
output_low(PIN_C1);  //Stop the barbette
//printf("Open the extinguish\n\r");
//** Open extinguish **//
}
```

```
else if(Temp>29)   // this condition means abnormal temperature so it let DVs out.
{
start2:
//printf("Now Temp > 33, now is in start 2 elseif Temperature is  is %d\n\r ", Temp);
      if(distance6<22&&distance6>18&&distance5>11&&distance5<14) //Another
       condition to make sure that
         {                                                 //we on the ground to let DVs out//.

         delay_ms(3000);
         output_low(PIN_D0);   // Stop Forward ;
         output_low(PIN_D1);   // Stop Forward ;
         output_low(PIN_C0);   // Stop Fire Gun;
         output_low(PIN_C1);   // Stop the barbette;

         delay_ms(1000);
         //printf("Open Back Door\n\r");
         output_high(PIN_E0);  //.
         output_high(PIN_C2);  /
         delay_ms(500);
         output_low(PIN_C2);
         // goto Other_Action;  //.
//**now DV1 and DV2 go out **//
         delay_ms(1500);     //
connect_again:
         output_low(PIN_C5);
         delay_ms(1000);
         output_high(PIN_C5);
         delay_ms(2500);
         puts("con 00:0C:84:00:8C:21");//
```

```
delay_ms(5000);                     /
if(kbhit())
{
TempDVAACK=getc();
//printf("TempDV1ACK is %d\n\r", TempDV1ACK);
}
delay_ms(1500);
putc(1);
delay_ms(100);
putc(1);
//delay_ms(1000);
//if(kbhit())
//{
  TempDVA=getc();       //
  //printf("TempDV1 is %d\n\r", TempDV1);
 //}
  delay_ms(1500);
  output_low(PIN_C5); //
  delay_ms(1000);
  output_high(PIN_C5);
  delay_ms(2500);
  puts("con 00:0C:84:00:8C:3E");/
  delay_ms(5000);
  //if(kbhit())
  //{
 // TempDV2ACK=getc();
  //printf("TempDV2ACK is %d\n\r", TempDV2ACK);
  //}
  //delay_ms(1500);
```

```
    putc(1);
    delay_ms(300);
    putc(1);
    //delay_ms(1000);

    //if(kbhit())
    //{
    TempDVB=getc();     //
   // printf("TempDV2 is %d\n\r", TempDV2);
    //}
    delay_ms(1500);
    output_low(PIN_C5);
  if (TempDVA>23 && TempDVA<120 || TempDVB>23 && TempDVB<120)   //
this temperature need to check again
  {
     delay_ms(100);
     if (TempDVA>TempDVB)  //DV1 is higher than DV2
     {
        output_high(PIN_D3);   /
        output_high(PIN_D4);   /
        delay_ms(16000);       //
        output_low(PIN_D3);    //stop turn_right ;
        output_low(PIN_D4);    //Stop turn_right ;

        delay_ms(1500);        //for relay, it needs time to release.
        output_high(PIN_D0);   //  go_straight();
        output_high(PIN_D1);   //  go_straight();
        output_high(PIN_C0);
        output_high(PIN_C1);
```

```
DV1_Detect:
            if ( Temp>29&& input(PIN_D5))  /
               {
               output_low(PIN_D0);   //stop();
               output_low(PIN_D1);
               delay_ms(1000);      /
               output_low(PIN_C0);  //Stop Fire Gun
               delay_ms(2000);      /
               output_low(PIN_C1);  //Stop the barbette
               //*****Open extinguish*****//
               }
            else
               {
               goto DV1_Detect;
               }
          }
          else if(TempDVB>TempDVA)
          {
            output_high(PIN_A2);   //turn_left();
            output_high(PIN_C3);   //turn_left();
            delay_ms(16000);
            output_low(PIN_A2);    //stop turn_left;
            output_low(PIN_C3);    //Stop turn_left;

            delay_ms(1500);        //for relay, it needs time to release.
            output_high(PIN_D0);   //  go_straight();
            output_high(PIN_D1);   //  go_straight();
            output_high(PIN_C0);
            output_high(PIN_C1);
```

```
DV2_Detect:

        if( Temp>29 && input(PIN_D5)) //maybe PIN_D5 is needed to change to
    "input(PIN_D5)!=0"
        {
          output_low(PIN_D0);   //stop();
          output_low(PIN_D1);   //stop();
          delay_ms(1000);      //This delay is due to inertia of DC motor
          output_low(PIN_C0);  //Stop Fire Gun
          delay_ms(2000);      //this delay is due to inertia of DC motor
          output_low(PIN_C1);  //Stop the barbette
          //*****Open extinguish*****//
        }
        else
        {
          goto DV2_Detect;
        }
      }
      else
      {
       goto connect_again;
      }
    }
    else
    {
    goto connect_again;
    }
```

```
        }
        else
        {
        goto start2;
        }
}
else
{
//printf("This is Else in the first IF\n\r");
//printf("Now is in start 1 else Temperature is  is %d\n\r ", Temp);
//printf("Now Ultrasonic1 distance 1 is %f\n\r", distance1);
//printf("Now Ultrasonic2 distance 2 is %f\n\r", distance2);
//printf("Now Ultrasonic5 distance 5 is %f\n\r", distance5);
//printf("Now Ultrasonic6 distance 6 is %f\n\r", distance6);

delay_ms(1000);
goto start1;
}



//}    // for if()
//}    // while()
}    //void main()

void Ultrasonic(void)
{
//***** Ultrasonic 1 *****//

delay_ms(100);
```

```
output_high(PIN_B6);
delay_us(5);
output_low(PIN_B6);
while(!input(PIN_B6))
set_timer1(0);
overflow_count=0;
while(input(PIN_B6))
disable_interrupts(global);
time1=get_timer1();
time1=time1+(overflow_count*65535);
delay_ms(10);
time1 /=2;
distance1=34776.4*time1;
distance1 *=0.0000032;
//printf("Ultrasonic 1 %f\n\r", distance1);
delay_ms(1000);

//***** Ultrasonic 2 *****//

enable_interrupts(global);
delay_ms(100);
output_high(PIN_C4);
delay_us(5);
output_low(PIN_C4);
while(!input(PIN_C4))
set_timer1(0);
overflow_count=0;
while(input(PIN_C4))
disable_interrupts(global);
```

```
time2=get_timer1();
time2=time2+(overflow_count*65535);
delay_ms(10);
time2 /=2;
distance2=34776.4*time2;
distance2 *=0.0000032;
//printf("Ultrasonic 2 %f\n\r", distance2);
delay_ms(1000);
//***** Ultrasonic 3 *****//
enable_interrupts(global);
delay_ms(100);
output_high(PIN_D7);
delay_us(5);
output_low(PIN_D7);
while(!input(PIN_D7))
set_timer1(0);
overflow_count=0;

while(input(PIN_D7))
disable_interrupts(global);

time3=get_timer1();
time3=time3+(overflow_count*65535);
delay_ms(10);
time3 /=2;
distance3=34776.4*time3;
distance3 *=0.0000032;
//printf("Ultrasonic 3 %f\n\r",distance3);
delay_ms(100);
```

```
//***** Ultrasonic 4 *****//
enable_interrupts(global);
delay_ms(100);
output_high(PIN_D6);
delay_us(5);
output_low(PIN_D6);
while(!input(PIN_D6))
set_timer1(0);
overflow_count=0;

while(input(PIN_D6))
disable_interrupts(global);
time4=get_timer1();
time4=time4+(overflow_count*65535);
delay_ms(10);
time4 /=2;
distance4=34776.4*time4;
distance4 *=0.0000032;
//printf("Ultrasonic 4 %f\n\r",distance4);
delay_ms(100);



//***** Ultrasonic 5 *****//

enable_interrupts(global);
delay_ms(500);
output_high(PIN_B5);
```

```
delay_us(5);
output_low(PIN_B5);
while(!input(PIN_B5))
set_timer1(0);
overflow_count=0;
while(input(PIN_B5))
disable_interrupts(global);
time5=get_timer1();
time5=time5+(overflow_count*65535);
delay_ms(100);
time5 /=2;
distance5=34776.4*time5;
distance5 *=0.0000032;
                    //this is the same as above
//***** Ultrasonic 6 *****//
enable_interrupts(global);
delay_ms(500);
output_high(PIN_B4);
delay_us(5);
output_low(PIN_B4);
while(!input(PIN_B4))
set_timer1(0);
overflow_count=0;
while(input(PIN_B4))
disable_interrupts(global);
time6=get_timer1();
time6=time6+(overflow_count*65535);
delay_ms(100);
time6 /=2;
```

```
distance6=34776.4*time6;
distance6 *=0.0000032;
 //printf("Ultrasonic 6 %f centimeters\n\r",distance6);
}

unsigned char GetByte(void)
{
int i, data, D;
D=0;
for(i=0;i<=7;i++)
{
output_low(PIN_B1);
output_high(PIN_B1);
data = input(PIN_B0);
D=D+data*pow(2,i);
}
return D;
}
void PutByte(unsigned char d)
{
int i;
for (i=0;i<=7;i++)
{
if(d%2==1)
output_high(PIN_B0);
else
output_low(PIN_B0);
output_high(PIN_B1);
output_low(PIN_B1);
```

```
d>>=1;
}
}
//****************************Daughter Vehicle**********************//

//this is for DV1.  I use r to mean DV1.
//I do not test this in the DV yet
//I need to check the motor and IRs position
//check the goto function work.

#include <16F877.h>
#device ADC=10
#use delay(clock=10000000)
#use rs232(baud=9600, xmit=PIN_C6, rcv=PIN_C7, ERRORS)
#include<stdio.h>
#include <math.h>  // for temperature sensor
#define DQ PIN_B0               //for temperature sensor
#define CLK PIN_B1               //for temperature sensor
#define RST PIN_B2               //for temperature sensor

unsigned char Temp;
unsigned char sign_bit;

unsigned char GetByte(void);      //for temperature sensor
void PutByte(unsigned char d);   //for temperature sensor
void stop(void);
void gostraight(void);
void turnleft(void);
void turnright(void);
```

```
void back(void);
void PWMRL(void);
void PWMLR(void);
int IR1Dist1(void);
int IR2Dist2(void);
int IR3Dist3(void);
int IR4Dist4(void);
int IR5Dist5(void);

float PingUltrasonic(void);

long DistSensor1, DistSensor2, DistSensor3,DistSensor4,DistSensor5;
int Dist1, Dist2,Dist3,Dist4,Dist5;
float Ultradist,Ultra;
int IR1, IR2, IR3, IR4, IR5;
int16 time;

int16 overflow_count;
#int_timer1
void timer1_isr()
{
overflow_count++;
}
#INT_RDA
RS232C_Receive_Interrupt()
{
    char a;
    int b;
//    printf("RS232 receive interrupt\n\r");
```

```
    a=getc();
    delay_ms(500);
    if(input(PIN_D5))
    {
     while(1)
     {
     stop();
     delay_ms(300);

     putc(66);
     }
    }
    else
    {
     delay_ms(600);
     putc(Temp);
     //delay_ms(1000);
     //putc(Temp);
     //printf("Give Temp %d\n\r",Temp);
     //delay_ms(500);
     //printf("Give Temp %d\n\r",Temp);
     delay_ms(500);
    }
}
void main()
{
while(1)
{
   setup_timer_1(T1_INTERNAL|T1_DIV_BY_8);
```

```
   enable_interrupts(INT_TIMER1);
   enable_interrupts(INT_RDA);
   enable_interrupts(global);
      setup_adc_ports( ALL_ANALOG );
      setup_adc(ADC_CLOCK_INTERNAL);
   delay_ms(2000);
setup_timer_1(T1_INTERNAL|T1_DIV_BY_8);
enable_interrupts(INT_TIMER1);
enable_interrupts(global);
//while(1)
//{
start:
      output_low(RST);        //for temperature sensor
                  output_high(RST);       //for temperature sensor
                  PutByte(0xEE);          //for temperature sensor
                  output_low(RST);        //for temperature sensor
                  delay_ms(500);          //for temperature sensor
                  output_high(RST);       //for temperature sensor
                  PutByte(0xAA);          //for temperature sensor
                  Temp=GetByte();         //for temperature sensor
                  sign_bit = GetByte();   //for temperature sensor
                  output_low(RST);        //for temperature sensor
                  Temp >>= 1;             //for temperature sensor
delay_ms(500);
output_high(PIN_B4);
delay_us(5);
output_low(PIN_B4);
while(!input(PIN_B4))
set_timer1(0);
```

```
overflow_count=0;
while(input(PIN_B4))
disable_interrupts(INT_TIMER1);
time=get_timer1();
time=time+(overflow_count*65535);
delay_ms(100);
time /=2;
Ultradist=34776.4*time;
Ultradist *=0.0000032;
//printf("%f centimeters\n\r",Ultradist);
delay_ms(500);
//start:
        //Ultradist=PingUltrasonic();
if (Ultradist>=5)
{
        delay_ms(3000);
        gostraight();
        delay_ms(10000);
        stop();
        delay_ms(1000);
        //turnleft();
        turnright();
        delay_ms(4000);
        stop();
        delay_ms(1000);
        gostraight();

        IR1=IR1Dist1();
        IR2=IR2Dist2();
```

```
        IR3=IR3Dist3();
        IR4=IR4Dist4();
        IR5=IR5Dist5();
        delay_ms(10);

Detect:
        if (input(PIN_D5))
          {
            stop();
            goto finish;
          }
        else
          {
            if(Ultradist>50&&IR1>20&&IR2>20)
            {
                gostraight();

                if(input(PIN_D5))
                {

                    stop();
                    goto finish;

                }
                else
                {
                    if(IR5>IR4+5)
                    {
                    PWMRL();
```

```
            }
            else if(IR4>IR5+2)
            {
            PWMLR();
            }
            else if(Ultradist<20&&IR5<15&&IR4<15)
            {
             stop();
             goto finish;
            }
            else
            {
            goto Detect;
            }
        }

    }
    else if(Ultradist>30&&IR1>IR2+5)
    {
        turnleft();
        delay_ms(1000);
        stop();
        gostraight();
        if(input(PIN_D5))
        {
        stop();
        goto finish;
        }
        else
```

```
      {
         if(IR5>IR4+2)
         {
         PWMRL();
         }
         else if(IR4>IR5+2)
         {
         PWMLR();
         }
         else if(Ultradist<25&&IR3<15&&IR4<15)
         {
         stop();
         goto finish;
         }
         else
         {
         goto Detect;
         }
      }
}
else if(Ultradist>30&&IR2>IR1+5)
{
   turnright();
   delay_ms(1000);
   stop();
   gostraight();
     if(input(PIN_D5))
     {
        stop();
```

```
        goto finish;
      }
      else
      {

        if(IR5>IR4+5)
        {
        PWMRL();
        }
        else if(IR4>IR5+5)
        {
        PWMLR();
        }
        else if(Ultradist<25&&IR5<15&&IR4<15)
        {
        stop();
        goto finish;
        }
        else
        {
        goto Detect;
        }

      }
}
else
{
stop();
goto finish;
```

```
      }

   }
}
else
{
//printf("%f centimeter. Thie is else \n\r",Ultradist);
//printf("%d temperature, this is else \n\r", Temp);
goto start;
}
finish:
    stop();
    delay_ms(60000);
    stop();
    delay_ms(60000);
}
}


void stop(void)
{
setup_ccp1(CCP_PWM);
setup_ccp2(CCP_PWM);
setup_timer_2(T2_DIV_BY_4, 255, 1);
set_pwm1_duty(0);
set_pwm2_duty(0);
delay_ms(10);
output_low(PIN_C0); // motor B in sensor 1
output_low(PIN_C5);// motor B in sensor 1
```

```
output_low(PIN_C4);
output_low(PIN_C3);
}

void gostraight(void)
{
setup_ccp1(CCP_PWM);
setup_ccp2(CCP_PWM);
setup_timer_2(T2_DIV_BY_16, 255, 1);
set_pwm1_duty(520);
set_pwm2_duty(520);
delay_ms(10);
output_low(PIN_C0);
output_high(PIN_C5);
delay_ms(10);
output_low(PIN_C4); // for motor A at sensor 2
output_high(PIN_C3); // for motor A at sensor 2
delay_ms(1000);
}


void turnright(void)
{
setup_ccp1(CCP_PWM);
setup_ccp2(CCP_PWM);
setup_timer_2(T2_DIV_BY_4, 255, 1);
set_pwm1_duty(520);
set_pwm2_duty(520);
delay_ms(10);
```

```
output_low(PIN_C0);
output_high(PIN_C5);
delay_ms(10);
output_high(PIN_C4);
output_low(PIN_C3);
//delay_ms(4000); // In here, we decide how long to stop this.
              // We can change the delay time to decide it.
//stop();
}

void turnleft(void)
{
setup_ccp1(CCP_PWM);
setup_ccp2(CCP_PWM);
setup_timer_2(T2_DIV_BY_4, 255, 1);
set_pwm1_duty(520);
set_pwm2_duty(520);
delay_ms(10);
output_high(PIN_C0);
output_low(PIN_C5);
delay_ms(10);
output_low(PIN_C4); //sensor 2
output_high(PIN_C3);  //sensor 2
//delay_ms(4000);
//stop();
}

void back(void)
{
```

```
setup_ccp1(CCP_PWM);
setup_ccp2(CCP_PWM);
setup_timer_2(T2_DIV_BY_4, 255, 1);
set_pwm1_duty(520);
set_pwm2_duty(520);
delay_ms(10);
output_high(PIN_C0); // motor B in sensor 1
output_low(PIN_C5);// motor B in sensor 1
delay_ms(10);
output_high(PIN_C4);
output_low(PIN_C3);
//delay_ms(1000);
}

void PWMRL(void)
{
set_pwm1_duty(520);
set_pwm2_duty(420);
}


void PWMLR(void)
{
set_pwm1_duty(420);
set_pwm2_duty(520);
}

int IR4Dist4(void)
{
```

```
set_adc_channel(0);  // IR 4
delay_ms(10);
DistSensor4 = read_adc();
Dist4=66.4796-(0.3818*DistSensor4);
//printf("Sensor 4 %d\n\r", Dist4);
return Dist4;
}

int IR3Dist3(void)
{
set_adc_channel(1);  // IR 3
delay_ms(10);
DistSensor3 = read_adc();
Dist3=67.3228-(0.3441*DistSensor3);
//printf("Sensor 3 %d\n\r", Dist3);
return Dist3;
}

int IR5Dist5(void)
{
set_adc_channel(2);  // IR 5
delay_ms(10);
DistSensor5 = read_adc();
Dist5=67.8569-(0.3747*DistSensor5);
//printf("Sensor 5 %d\n\r", Dist5);
return Dist5;
}

int IR2Dist2(void)
```

```
{
set_adc_channel(5);  // IR 2
delay_ms(10);
DistSensor2 = read_adc();
Dist2=(69.0601-(0.3455*DistSensor2));
//printf("Sensor 2 %d\n\r", Dist2);
return Dist2;
}


int IR1Dist1(void)
{
set_adc_channel(6); //IR 1
delay_ms(10);
DistSensor1 = read_adc();
Dist1=(68.2471-(0.3212*DistSensor1));
//printf("Sensor 1: %d\n\r",Dist1);
return Dist1;

}

float PingUltrasonic(void)

{
delay_ms(500);
output_high(PIN_B4);
delay_us(5);
output_low(PIN_B4);
```

```
while(!input(PIN_B4))
set_timer1(0);
overflow_count=0;
while(input(PIN_B4))
disable_interrupts(global);
time=get_timer1();
time=time+(overflow_count*65535);
delay_ms(100);
time /=2;
Ultradist=34776.4*time;
Ultradist *=0.0000032;   //this is from 10M hz clock div (4*8)
delay_ms(300);
return Ultra;
}
unsigned char GetByte(void)
{
int i, data, D;
D=0;
for(i=0;i<=7;i++)
{
output_low(PIN_B1);
output_high(PIN_B1);
data = input(PIN_B0);
D=D+data*pow(2,i);
}
return D;
}
void PutByte(unsigned char d)
{
```

```
int i;
for (i=0;i<=7;i++)
{
if(d%2==1)
output_high(PIN_B0);
else
output_low(PIN_B0);
output_high(PIN_B1);
output_low(PIN_B1);
```

VITA

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