Introduction

The goal of junior design class is to use the knowledge from our previous classes to build a completely autonomous robot. This robot is to be able to navigate a small maze, which contains rooms of a predetermined size. In this maze, the purpose of the robot is to first find a candle, which is located in one of the rooms and then extinguish it. This robot is to be built to possibly compete in one of two competitions. The first of these is the Trinity Home Fire-Fighting Robot Competition at Trinity College in Connecticut. The Electrical Engineering Department holds the second of these contests here at New Mexico Tech.

For the purpose of both the competition and for the class itself there are rules and guidelines for our robots. We were provided with most of the materials to build the robot. This included the motors and other important components. The rest of the materials for the robot are the responsibility of the individual groups in class out of a $100 budget that the groups are allotted.

We decided to set up the project into different systems that could be tied together as a whole. These systems include the mechanical design, hardware electronics design and software design. In this paper we will explain how we designed these systems and each of the subsystems that are part of the entire project. The first part of the paper goes over the background information about the project itself and then the design and implementation of our project is explained.

The Requirements

The robot project is to meet the requirements of the Trinity College Fire Fighting Home Robot Contest or other mobile robot project approved by our instructors. There is also a fire-fighting robot contest held by the Electrical Engineering Department the day of the final presentation for the class. Entering either one of these competitions is completely optional.

The Trinity College Fire Fighting Home Robot Contest is an annual event that is held at Trinity College in Hartford, Connecticut. This contest is known to be the largest, public, true Robotics competition held in the U.S. that is open to entrants of any age, ability or experience from anywhere in the world. The objective of this competition is to build a computer-controlled robot that can navigate a model of a home floor plan. The robot then needs to find a fire represented by a candle and then extinguish it. This model floor plan is included below as figure one.

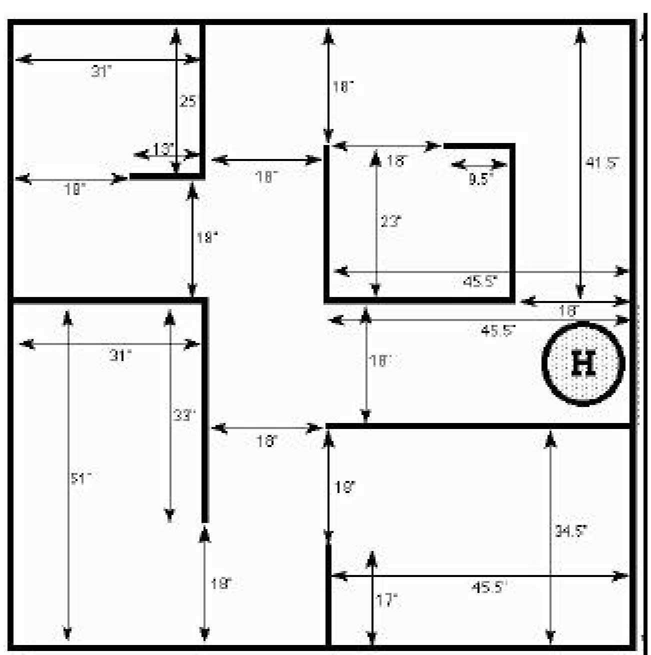

Figure 1: The Maze

Once the robot is turned on it must be self-controlled, it cannot have any human intervention. The robot is allowed to touch the walls of the model floor plan but it isn't supposed to damage or mark the walls. If the robot does touch a wall, there is a penalty. The robot also cannot use any destructive or dangerous method to put out the fire. The candle is also not to be knocked down by the robot. The robot also must fit into the dimensions of 12.5" by 12.5" by 12.5" and will be carefully measured. There are no restrictions on the weight of the robot or the materials used to build the robot.

The candle represents a small house fire and is between six and eight inches high. This candle is placed randomly in the rooms of the maze. There are no restrictions on the sensors used on the robot as long as they do not violate any other rules. No modifications of the maze can be made to aid the robot. These include reflectors, other sensors or beacons placed on the walls or floor of the maze. The maximum time the robot has to find the fire is six minutes. After finding the fire and putting it out, the robot has three minutes to return to the point where it started in the maze. The starting point in the maze is called the "Home Circle". On figure one, it is the shaded circle with an H in the middle.

These are the requirements for the robot that we are to follow. After these requirements are understood, it is time to start on the actual design. For the first three weeks of the class our professors, Dr. Bruder and Dr. Wedeward lectured the class on basic design principles that could be applied to the robot. Also during this time, basic parts were passed out to the individual groups to get started. These parts included two electric motors to propel and to steer the robot. Also included were chips called H bridges that are used to supply the motors with a constant voltage supply that they require to run.

The class was also supplied with metal plates to build the robot with. Another part that was supplied are called distance sensors. The next part of the paper is about the distance sensors, what they do and how we used them.

Component Placement / Mechanical Assembly

There were many aspects to consider when designing a placement configuration for components on the robot. Because of the large number of components and lack of space, our team decided to use a second platform. Mounted roughly 4.5” above the lower platform, it gave added room for more components plus it was just about the right height for the fire sensors to be on level with the flame of the candle (which is from 6-8” in height). Both plates were made of 1/8” thick aluminum, 10” in diameter, allowing another 2 inches for components to extend out from the plates, which proved helpful when mounting the fan. All components were mounted with bolts, nuts, and lockwashers where needed. The only exception were the distance sensors, which were mounted with velcro to allow for adjustment. Each circuit board was mounted using 2 standoffs in opposite corners, varying in length for each board, with insulating nylon washers. The result was a solid, robust product which was very strong and stable.

Lower Plate

The large components took priority in the placement of the robot. The motors, battery, and HC12 took first concerns. In a successful attempt to block EMI, the high-power components (12V), specifically the h-bridge circuit board and battery, were mounted on the bottom of the lower plate, along with the motors. The rest of the underside of the lower plate was home to the main fuse, rear caster wheel, and white line sensor (which fit snug through a hole in the plate) mounted slightly off center-front. This mounting position was chosen to allow slightly more time for the robot to turn into a room before detecting a white line. The motors were mounted in the center of the plate with the axles pointing outward in opposite directions, creating the differential drive setup. Custom aluminum brackets were constructed to rigidly hold the motors. The rear caster was mounted on the edge of the plate along the perpendicular axis of the motors. A special cage made of sheet metal was constructed to house the battery, which also doubled as EMI protection. To add balance, the heavy lead acid battery was mounted toward the rear of the robot, so as to move the center of gravity closer to the rear caster wheel. This left room for the h-bridge board in front of the motors, along with the main fuse. Appendix D shows the layout of the underside of the bottom plate.

For our wheels, it was decided that the 1-1/2" wheels that were given out by the EE dept. were too small in diameter and caused rubbing of the motor gearhead casing on the ground. We wanted to keep the diameter of the wheels as small as possible to allow better control from the PWM. Our choice was 1-5/8" R/C plane wheels, which we picked up at a hobby shop. These wheels gave us just enough clearance to run while keeping the better control characteristics from the PWM. The hubs were drilled out to ¼" on a lathe, and snugly mounted on the axles of the motors. The rear supporting caster wheel was a simple plastic wheel design found at any hardware store. It gave about 1 ½" of clearance, which turned out to be just the right height to match our motors.

The topside of the lower plate was chosen to mount the HC12. This location provided easy wiring access to any component on the top or bottom plate. It was mounted toward the rear of the robot, leaving room for the 3 distance sensors, which were placed facing the front, approximately 45 degrees apart. Due to the sensors' output curve, each was mounted 4cm back from the edge of the plate. Another component on the top of the lower plate was the power supply board, which fitted nicely between the center distance sensor and the HC12. The final component was the main and H-bridge control switch, which were mounted on an aluminum bracket next to the left distance sensor. Appendix D shows the topside of the lower platform.

Upper plate

The upper plate on the robot allowed much more space to mount components. The underside of the plate was home to the frequency to voltage converter circuit board. It was mounted toward the back of the plate to make room for both the Hamamatsu UV sensor, and the narrow-band fire sensor. The narrow-band sensor was mounted directly in the center-front of the plate with the Hamamatsu next to it. Also on the narrow-band circuit board was the circuitry for the fire suppression system, consisting of mainly the opto-isolated relay. The final component on the underside was the white-line sensor circuitry, which took up very little room and was mounted in between the Hamamatsu and frequency to voltage boards. Appendix D shows the underside layout of the top plate.

The final place to mount components was the top of the robot. It was logical to place the fire suppression device (simple high rpm dc motor and prop) at the front and center so as to extinguish the candle. The motor was mounted on a simple l-bracket constructed of aluminum. Lock-washers were used to prevent loosening of the mounting bolts due to vibration of the motor. The propeller (approximately 5” in diameter) extended out in front of the plate by about ½” (using some of the extra 2” allowed), which allowed the blades of the propeller to extend below the upper plate, thus keeping the height of the robot under 12”.

The last circuit to be mounted was the tone decoder, which fit nicely on a 2” square board. It was mounted on the top plate for easy access to the microphone by the operator. The final location was next to the fan motor bracket.

The final component on the top plate was a simple aluminum handle to allow for easy portability and those long sleepless nights of carrying the robot from the computer terminal to the maze and back again. It was mounted behind the fan motor with about 3” of clearance on either side to allow plenty of room for the operator’s hand. Appendix D shows the placement of components on the top of the upper plate.

The top and bottom plates were linked with 4 all-thread bolts approximately 10” in length. Both plates were held in place with nuts and lock-washers to prevent movement. The continuous thread design of the bolts allowed for height adjustment of either plate. The final distance between the plates turned out to be 5”, which positioned the narrow-band fire sensor 7” from the ground (average height of the candle flame). The 5” of space also allowed easy access to components on the interior of either plate.

Wiring & Connectors

Wiring of the robot proved to be very tedious as an attempt was made to simplify and streamline the wiring process. For sensitive data lines such as the IR distance sensors, shielded cable was used to lessen EMI. In most cases, each set of power & ground wires to their respective boards were twisted to reduce EMI effects. The power and ground were color-coded orange and purple, respectively. Also in most cases, polarized locking connectors were utilized for protection of components and proper operation of the robot. Where locking connectors weren’t used, simple grouped pin-header connectors were implemented.

Hardware

The hardware on the robot is made up of several subsystems. The subsystems include power distribution, sensors, drive electronics, and fire suppression. The power distribution subsystem consists of the chassis wiring and the power distribution board. The chassis wiring provides the connections to the battery and the main power lines that go to the power distribution board. The power distribution board is a simple board that provides the 12-volt and regulated 5-volt supplies that power the sensors and drive electronics. The sensor subsystem of the robot comprises the bulk of the robot's electronics. The reason for this is because the robot must take in a lot of information from the outside world in order to perform its tasks. To do this the robot needs to know how fast its wheels are turning, how far it is from the walls of the maze, if it has crossed a white line, if there is a fire in a room, and where the fire is located. The robot needs sophisticated sensors to perform these tasks. The most fundamental hardware subsystem is the drive electronics. The drive electronics consist of a motor controller board that allows the microcontroller to control the speed and direction of the high powered motors that drive the robot. The final subsystem to be dealt with is the fire suppression system, which consists of a relay that is activated by the microcontroller and some sort of electrically actuated method of putting out the flame.

Power Distribution Subsystem

The power distribution subsystem begins with the 12-volt 3.5 amp-hour lead acid battery. The battery is in turn connected to a fuse and a main power switch and a ground bus before going to the power distribution board. The power distribution board is a fairly simple board with a ground bus, 12-volt bus, and a regulated 5-volt bus. The LM-7805

National Semiconductor voltage regulator is used to produce the clean 5-volt power supply needed by most of the electronics in the robot. The 7805 was chosen for several important reasons. The first reason was its simplicity of use. It does not need any external circuitry thus making the design for the power distribution board extremely simple. A second reason the 7805 was picked was because of its 90db ripple rejection ratio. This makes the regulator able to produce a good clean 5-volts even if it is given a noisy input. This characteristic is good for use in the robot because the drive electronics can introduce noise into the power system. As extra insurance against problems occurring from voltage level dropping when the motors are turned on a diode was placed in series with 12 volt with a capacitor in parallel placed between 12-volts and ground. When the voltage is at normal level current flows through the diode and the capacitor is charged to the supply voltage. When the drive motors are turned on they draw large amounts of current and the voltage level may drop because of the inability of the battery to supply a large surge current. When this occurs the diode maintains the capacitor voltage by blocking the motors from drawing current from the capacitor. A good supply voltage is thus maintained for the voltage regulator. The electronics in the robot that use 12-volts do not need a clean supply voltage so the 12-volt supply can be unregulated.

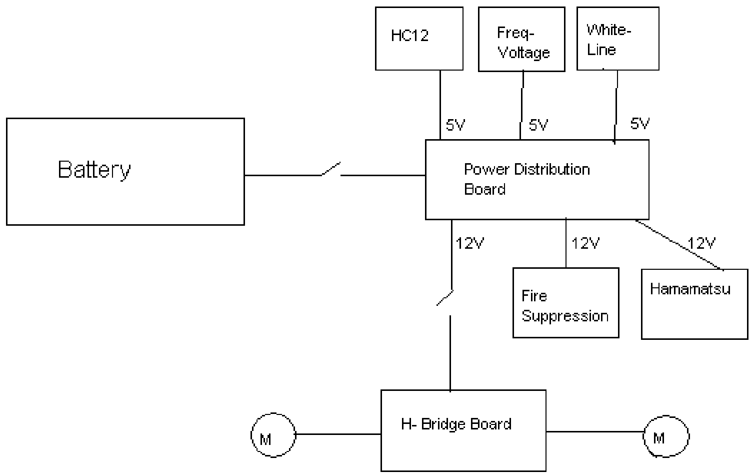

Figure 2: Power Distribution

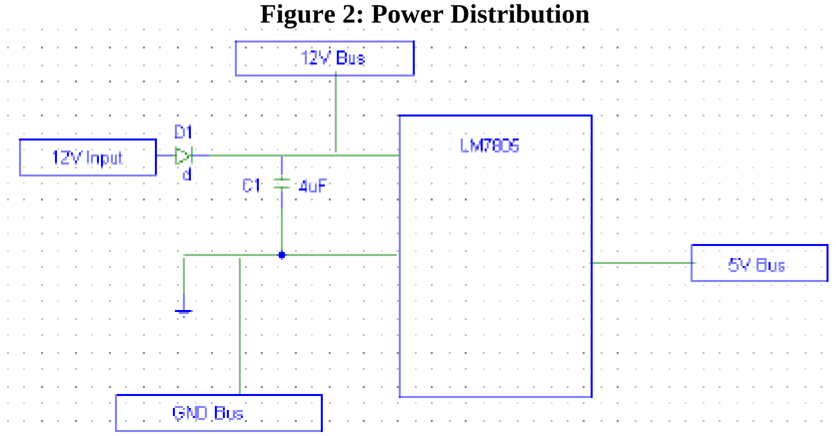

Figure 3: Power Distribution Schematics

Distance Sensors

One of the rules of the fire-fighting robot competition is that the robot be computer controlled. The robot also has to navigate a maze that represents a model of a home floor plan, complete with walls and rooms. To navigate this maze, the robot has to be able to know what its surroundings are. This doesn't mean that the robot has to know where its exact location in the maze is. The robot does have to be aware of the walls in the maze and be able to follow a wall to make its way around the maze. This idea is known as wall following.

Wall following is the first decision to make for the robot. Should the robot follow the wall of the maze on the right or on the left? We decided to have the robot follow the left wall, because of the layout of the maze. Three of the rooms are easily navigated by following the left wall. This is after starting in the home circle facing directly left, leaving only one room that becomes tricky. If right wall following was used only one of the rooms would be easily navigated, leaving three rooms that would be difficult to navigate. Left wall following, what it means and how to do it, is controlled completely by software and is discussed in greater detail in the navigation software section.

The next part of the project was the decision on what to use on the robot so that the robot can find the wall. The different ways to identify an object can be put into two different groups. The first group finds an object using part of the device to come in contact with this object. The second group uses near infrared light reflected off an object to determine its position relative to the object.

The first type of sensor is called a force sensor. An example of this sensor is called a microswitch. These are small switches that can be attached to a bumper on a robot. The switch gives out a signal when it bumps into something to help the robot to determine its position. Another type of force sensor is called a bend sensor. A bend sensor is a device that looks like a ruler. A bend sensor outputs a varying resistance based on how far it is bent. This value changes by a factor of about 3 to 5 from straight to maximum bend. Another name for a bend sensor is a force-sensing resistor. The only difference is that the force-sensing resistor can be different lengths. The final force sensor is called a rubbery ruler. This device looks like a bend sensor with a tail coming out. A rubbery ruler can accurately measure changes in its own length as it bends.

The second type of sensors are known as near infrared proximity sensors. The simplest of these detectors work using an emitter and a detector. The emitter emits near infrared light that bounces off of an object to the detector. The output from one of these sensors is a varying voltage based on the position from the object. This type of sensor comes in a box-like structure with the emitter and the detector each pointed inwards toward each other at a slope. This type of sensor is also insensitive to both the color and the texture of the surface that it is facing.

After learning about the options for distance sensors, we chose to use the near infrared proximity sensors. The output of these sensors is convenient and the sensors themselves are easy to use. Since they use near infrared light they can’t be damaged as easily since there are no parts touching the wall. Also, as part of the class we were provided with three different types of near infrared proximity sensors to choose from. The Sharp Company makes all of these sensors; the GP2D02, GP2D12 and the GP2D120 distance measuring sensors. The last sensor, the GP2D120 is only available in Japan. Each of these sensors has different kinds of outputs, as well as different distance ranges.

Both the GP2D02 and GP2D12 sensors have a distance measuring range between 10 and 80 centimeters. The distance measuring range for the GPD120 sensor is between 4 and 30 centimeters. The distance measuring range is the range of values between the smallest value that the sensor can identify to the largest. For the GP2D02 and GP2D12 sensors, this range starts at 10 centimeters. This is the point where the sensor can start to accurately detect an object. The sensor will accurately detect objects up to 80 centimeters away. The GP2D20 sensor’s range is smaller but it can detect items as close as 4 centimeters and up to 30 centimeters away.

Both the GP2D12 and GP2D120 sensors feature a linear voltage output. This means that as the distance that the sensor is detecting changes, a different voltage is seen at the output. For these sensors the voltage is higher at the closer range and the voltage shrinks as the distance becomes farther. The GP2D02 sensor has an eight bit serial output. The output from this sensor is a number from 1 to 255 with the closer distances as a higher number that shrinks as the object is farther away. Using a computer, this type of output is easy to understand. The other two sensor outputs are also easy to interpret because their output can be connected into an analog to digital converter to give a computer values that it can understand.

All three of these sensors have good points. In the end, the decision came down to usable range. Based on the size of the maze it made more sense to use the GP2D120 sensors. Using the Motorola HC12 Microcontroller as the computer, it was easy to decipher this sensor’s output because the HC12 has built in analog to digital converter channels. We decided to use three sensors total, one at the center and one at each side of the robot. The way that the sensors are used in their positions is discussed in more detail in the Navigational Software section of this report.

Wheel Speed Sensors

In order for the robot to navigate the maze in a controlled manner, the robot needs to know the speed at which it is turn its wheels. This is for two reasons the robot needs to be able have a set speed at which it navigates the maze, and the robot needs to be able to make course corrections as it navigates by first knowing its wheel speeds and then adjusting them accordingly. The wheel speed sensors provide feedback needed to implement speed control and course correction in software. The easiest way to tell how fast the wheel is turning is to place an encoder on the output shaft of the motor. The encoder in this case is a slotted disk placed between an LED and phototransistor pair. As the disk rotates it alternately blocks and passes light. If one looks at the output of the phototransistor, it looks like a square wave whose frequency varies with the speed of the motor. In case of the motors for our robot, the encoders are built into the motor. Instead of the encoders being on the output shaft of the motor, the encoder is on the main shaft of the motor before the gearbox.

Given the out put signal from the encoders, there are several options for calculating the motor speed. The three main choices were using frequency to voltage converters, implementing a counter in Altera, and using the input capture on the HC12. The solution that was chosen was to use the frequency to voltage converters. The frequency to voltage converter takes an input signal within a frequency range determined by external component selection and outputs a voltage proportional to the frequency its input. The A/D converters on the HC12 then take in the voltage produced by the frequency to voltage converters.

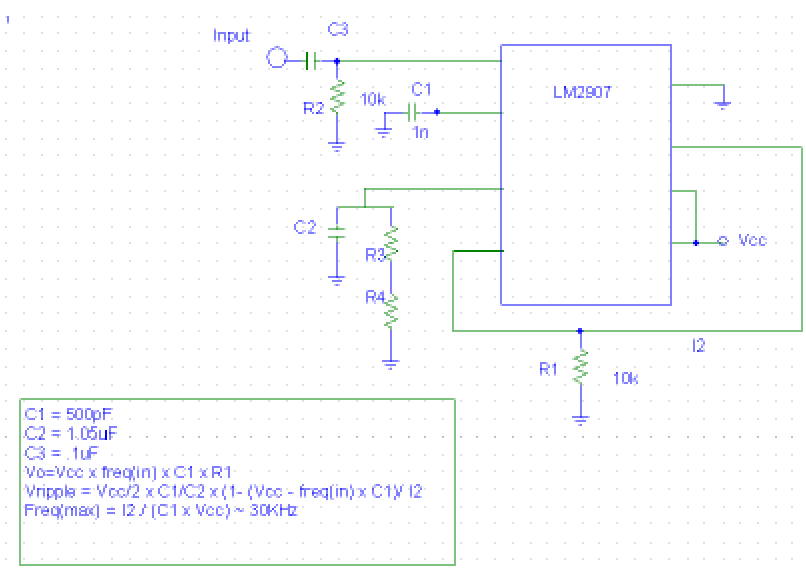

Figure 4: Frequency to Voltage Converter

The frequency to voltage converters were built to have a maximum frequency of around 30Khz. At the maximum frequency the voltage output was about x-volts. Overall the LM-2907 proved to be very linear and worked well.

The White Line Sensor

Another important sensor for the fire-fighting robot is the white line sensor. A white line is painted across the front of room, where the doorway would be in a real house. This white line is there for the robot to know that it is located at the front of a room. The rest of the floor in the maze is painted black. The walls of the maze are painted white. Once the robot knows that it is in a room it can scan the room to check for a fire. This is why there is a need for a white line sensor. It is a sensor that can be placed under the robot that gives out a signal when it is directly underneath a white line. Unlike distance measuring sensors that can just be purchased, the white line sensor was designed and built from electronic components.

The idea behind the white line sensor is to be able to notice a change between the normal black floor and the white paint. If some sort of light is used, it will reflect off of the white paint and it won’t reflect when it is under the black paint. Now, if a device is used to detect this reflected light it will be able to signal the computer when it detects a white line.

To accomplish this idea we used an infrared LED (light emitting diode) as a light source and a PN168 photo transistor as a way to pick up the reflected light. We used an infrared LED because it is very powerful and the PN168 can pick it up very easily. The PN168 phototransistor is a device that allows current to flow when it detects light. This leaves a voltage across the output of the PN168. This voltage can then be used as a signal to the computer.

These two devices work together by pointing both of them down at the ground. There has to be some type of cover over these two devices to block what is called ambient light. Ambient light is any light that could set off the phototransistor by accident. This type of light includes sunlight and the light from overhead lights. The type of cover that we decided to use looks like a straw. The straw covers both the LED and phototransistor and it follows down a little bit past the top of both. This straw prevents any light except the reflected light from the LED triggering the phototransistor.

Both the LED and the phototransistor require a resistance at the output to work correctly. Typically a resistor for an LED should be in the range between 500 and 1000 ohms. From this we chose to use a value in the middle of this range, 820 ohms. The resistor value for the phototransistor was found by experimentation. After trying many different ranges for values we learned that using a very high value resistor seemed to work best. We had our best results for a reliable signal using a 120,000 ohm resistor. A diagram of our white line sensor is pictured below as figure two.

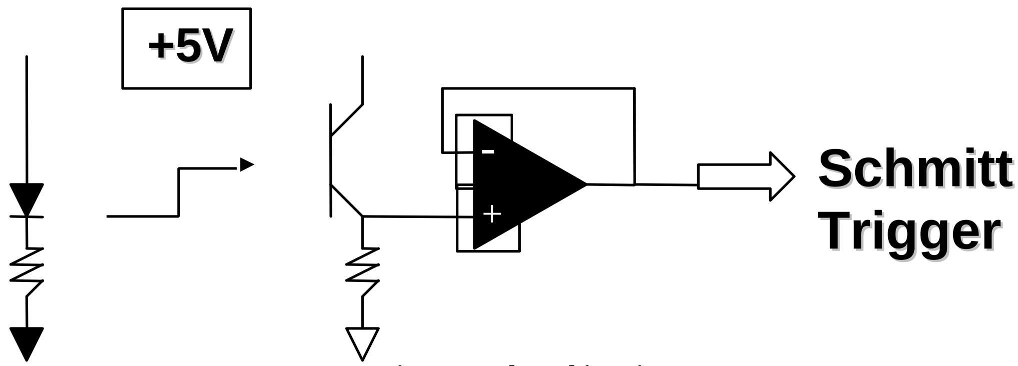

Figure 5: The White Line Sensor

After the resistor values were chosen, the next part was the actual design of the circuit and the amplification of the signal so that it would be strong enough to be sensed. To accomplish this we used an op-amp follower circuit. This worked out very well since we were able to get more current out of the output from the phototransistor to make it stronger.

Now, we needed a solid 0 or 5 volt signal output. This type of output signal will signal as a 1 or zero to our computer. To get this result we attached our signal to a schmitt trigger. A schmitt trigger takes a signal that has a low point and a high point that won't exactly be seen as a 1 or a 0 and adjusts the low point to be a 0 and makes the high point output a 1.

Now that the design for the white line sensor was complete it was time to build a board for it. This was done using Microsim, a program to design boards for circuits. On this board there are the two resistors, the op-amp chip and the schmitt trigger chip. There is also a connection for input voltage, ground and the output from the circuit. There is also a four-pin connection that goes to the LED and the phototransistor.

Flame Sensors

In order for the robot to find the fire in order to put it out, the robot must figure out which room the fire is in. After it has found the room that the fire is in, the robot needs accurately figure our where in the room the fire is so that it can drive up the flame and put it out. To accomplish the task finding the fire, the robot has two flame sensors with differing fields of view. To figure out whether a flame is in a room the robot uses a Hamatsu UV band flame sensor that is very sensitive over its wide field of view. To pinpoint the exact location of the flame, a Honeywell phototransistor in an enclosure to limit its field of view down to 10° is used. Using these flame sensors the robot can check the rooms in the maze by simply going past the doorway. Once the room with the flame is found, the robot uses the narrow field of view sensor to scan the room and pinpoint exactly where in the room the flame is.

Hamatsu Flame Detector

The Hamatsu R2868 flame sensor works in much the same way as a Geiger counter except that it is triggered by UV radiation. The Hamatsu uses a gas filled tube across which a high voltage is applied. Any time UV radiation strikes the tube it discharges and produces a voltage spike. The driving circuit simply provides the voltage source for the tube and counts up the pulses given off by the tube. After every third pulse from the tube the driving circuit outputs a 10ms logic level pulse. The main advantages of the Hamatsu flame sensor over an IR phototransistor are its immunity to interference and its sensitivity.

Honeywell Flame Sensor

The Honeywell flame sensor is simple yet extremely effective. It uses a Honeywell SDP8407 IR NPN phototransistor housed in a field of view limiting enclosure to sense the flame. The phototransistor is both sensitive and reasonably immune to interference from ambient light. These characteristics make it very useful detecting a flame. The only thing that needed to be changed was its field of view, which needed to be reduced from 135° to 10° so that the robot would be able to pinpoint the flame from across the room. For the circuit the collector of the transistor is tied to 5-volts and the emitter is tied to ground through a 100KΩ resistor. The voltage at the emitter is then run to the A/D converter to relay to the HC12 the light intensity as seen by the transistor. For the resistor many values were experimented with until 100 KΩ was found to be a good value that would work in just about any ambient lighting condition. The dimensions of the enclosure were calculated to be a 4mm spacing with a 4.5cm to give a length to spacing ration that would give the desired 10° field of view.

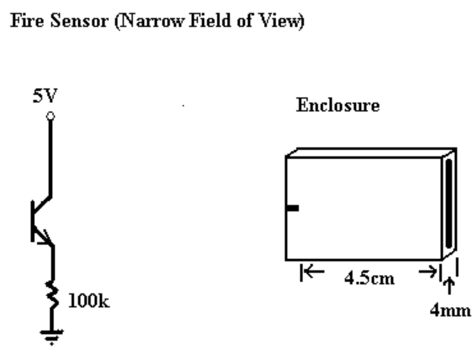

Figure 6: Honeywell Sensor as Narrow View

Drive Electronics Subsystem

The drive electronics are one of the simplest subsystems in the robot because of the single chip solutions that exist for implementing h-bridge control of motors. The two choices that were available were the Alegra dual h-bridge chip and the National Semiconductor single h-bridge chip. The National Semiconductor 18200 parts were chosen because they had been used successfully by many groups in the past and their superior current handing ability. Their only disadvantages were that they only came one to a chip and they each require 2 external bootstrap capacitors. The h-bridges were simple to interface to the HC12 because they accept normal 5-volt PWM from the HC12 and they need a single logic line to control their direction.

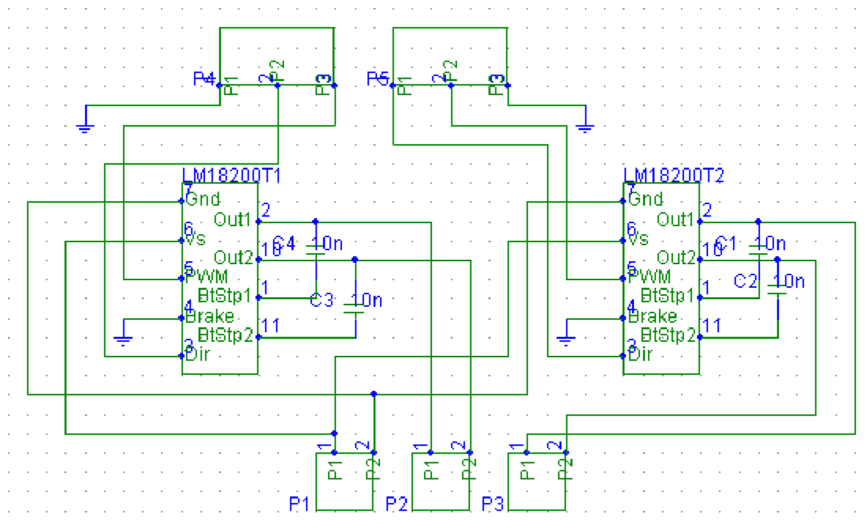

Figure 7: H-Bridges

Tone-Decoder

The Tone-Decoder was used to power up Homer by remote. This was not required by the Trinity College fire-Fighting Home Robot Contest; therefore, the tone decoder was merely an accessory for Homer. The only stipulation is that we have to send a 3.5 kHz sound signal to activate the robot.

For our remote, we used a LM567 tone decoder chip. Unfortunately, none of the group members were familiar with this chip. So, we built and tested the chip by following New Mexico Tech's EE322 Lab 10: PLL tone decoder.

We built the circuit in figure 8. R1 is a resistor in series with a 10K pot that is used to adjust the oscillator center frequency between 2 and 4 kHz. We chose R1 and C1 using equation 1 given in EE322 Lab 10. fo is the center frequency of the tone decoder.

$$fo \approx 1 \div [1.1(R1)(C1)] \qquad \text{equation 1}$$

C2 is a loop low-pass filter and C3 is an output filter. C2 also determines the bandwidth. The LM567's output is active high until it receives an input that falls in the range of its programmed bandwidth. We chose C2 to give us a 10% bandwidth by using equation 2 given in EE322 Lab 10.

BW = 1070 [Vi ÷ fo(C2)]^(½) equation 2

We then interfaced a microphone with the input pin on the tone decoder. Here, we had to capacitively couple the input signal. With this circuit, we were able to power up Homer very well. We chose not to amplify the signal because we felt it worked well without any amplification. However, when we power up Homer, we must initiate the 3.5 kHz signal very close to the microphone.

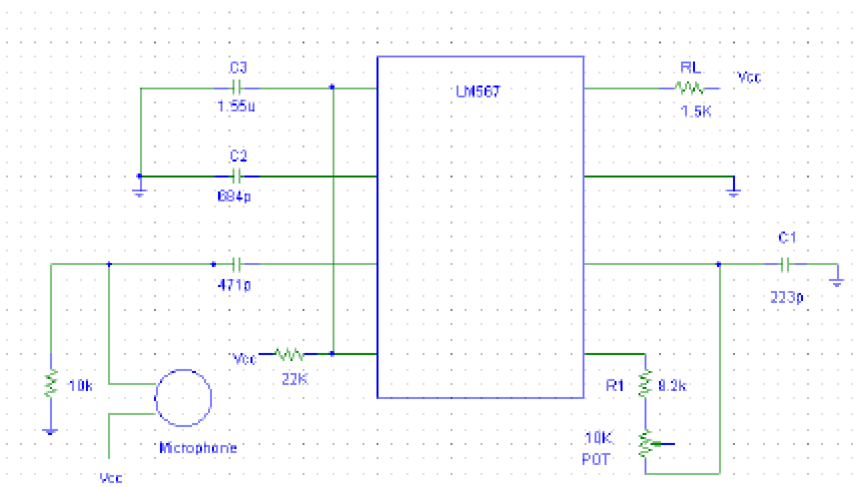

Figure 8: Tone Decoder

Software Design

Navigation Software

After the distance sensors were chosen and the white line sensor was designed, it was time to use them with the other drive components, the motors and the H-bridges (motor drivers), and a computer to make the robot navigate the maze by itself. The computer that we used is called a Microcontroller. We used a Motorola 68HC12 Microcontroller that was used in EE 308, a sophomore Electrical Engineering class. We already had experience with this Microcontroller so we already had a head start in what to do.

The first part of the program was designed for the distance sensors. The purpose of this program is to simply read the values from the sensors and then convert them to a digital number from 0 to 255. This program was written by setting up the HC12's built in A/D converter channels and then assigning values to the outputs of this register. This program works continuously in background mode so the values change all the time.

The motors were run through a feature of the HC12 known as pulse width modulation. Pulse width modulation or PWM is a way of motor speed control by turning on the motor for a certain time, then turning it off, then turning it back on and then off and so on. We used two motors so that we could change a value to either one of them, left or right to turn, spin or go straight. This idea is called differential drive.

Using the program that analyzes the distance from the wall the left and right wheels can be controlled to closely follow the left wall. In the program, if the robot is to close to the left wall, the program slows the right wheel and speeds up the left wheel to veer away from the wall. When the robot is to far from the left wall, the program slows the left wheel and speeds up the right wheel to drive towards the wall. This program was written using a simple equation changing the value of the set speed for each wheel based on its position relative to the left wall. This equation consists uses a constant speed, a constant left distance and the measured distance from the wall. These two equations look like this:

left speed = constant speed – (constant left distance – measured left distance)

right speed = constant speed + (constant left distance – measured left distance)

It is important to know that the higher the value from the distance sensor, the closer it is to the wall. In these two equations, if the measured left distance is less than the constant, desired distance then the robot is too close to the wall and a value is subtracted from the left speed while this same value is added to the right speed. Now, that the robot will drive away from the wall.

The programming for the left wall following can control left turns since the program is always following left. For the right turns, something else had to be written. We decided to navigate right turns by using the center distance sensor. In the program, whenever the value from the center distance sensor passes a set value (this means that the robot is close to hitting a wall) the left wheel spins forward and the right wheel spins backward until the wall is cleared, thus performing a right turn.

The next part of the navigation system is the identification of the white lines that are at the front of each room and in front of each candle. The way that the white line sensor is set up it sends a 1 when it is over a white line and a 0 when it is not. In the program, we have this value from the sensor connected to an interrupt. This is so whenever the HC12 gets a 1 value from the white line sensor it will react immediately. When a white line is seen the main program goes to a function that stops the robot for a moment to check for a fire. If there is no fire, the robot spins on its axis until the room is cleared and it can continue to left wall follow. The way that this program works, the robot can navigate the entire maze without entering a single room.

The way that the program is organized is by the use of functions. The first of these functions sets up the different parts of the HC12 that are needed for the drive system. This includes the pulse width modulation system (for powering the motors), the A/D system (for the distance sensors and to measure the speed of the motors) and the input capture interrupts (for the white line sensor and fire sensor). After the program finishes up with the setup program it then enters a loop that runs at all times throughout the program. In this loop it waits to see a white line. If there is a white line then the loop exits to the scan room function where the HC12 uses the fire sensor to find a fire. If there is no white line seen, this loop exits to the left wall follow function where until the program does see a white line. The last function is the extinguish function. This is the program that has the robot find the fire in a room, go to it and put it out.

In-Room Fire Suppression Program

Once the Hamamatsu UV sensor has detected a flame in the room, the robot enters the in-room fire function. This function consists of the following steps:

- Drive forward into the room.
- Rotate 360° while recording the highest analog value received by the narrow band fire sensor.

- Rotate in the opposite direction until the fire sensor reads a value that is very near the highest value that was previously recorded. The robot should now be facing the candle.
- Drive toward the candle and stop when a white line is seen.
- Turn on the fan and rotate clockwise about 60°, then counter-Clockwise 120°. Turn off the fan.

This program turned out to be very effective while keeping simplicity a factor. Another option we did not have time to try was using a second narrow-band fire sensor with the first in a binocular vision setup. In theory, this setup would have minimized the time necessary to pin-point the candle's location. However, we were satisfied with the method that was implemented.

Our goal was to write the code in a simple to follow straight forward way so that we could easily make changes and be able to follow the code with ease. We felt that by separating the major parts of the code into these functions it would be much easier to follow. Using the equation that we wrote basing the speed on the left distance sensor and using the center distance sensor for right turns we were able to write very efficient code for the successful navigation of every part of the maze.

Budget

Our funds were budget for us by the Electrical Engineering Department at New Mexico Tech. Each Group was allotted $100. Our group felt that was an adequate amount given to us. If we had to build our robot without sponsorship, we would have had to spend $700-800. With the New Mexico Tech Electrical Engineering Department sponsoring our class, most of the parts came in surplus or in stock. This reduced the price of our robot dramatically. The items we purchased with the money from our class budget is as follows:

Item Purchased	Quantity	Price Per Item	Total Cost
12V Battery	1	$23.00	$23.00
Relay/Tone	1	$15.00	$15.00
Magic Bond Epoxy	1	$8.05	$8.05
White Plate	1	$4.50	$4.50
8 Watt Fuses	4	$1.50	$6.00
All Thread bolts	4	$1.25	$5.00
Switch	1	$0.75	$0.75
Spade Terminals	4	$0.12	$0.48
1/2" Spacers	10	$0.10	$1.00
Single Connector	2	$0.10	$0.20
1/4 Watt Resistors	2	$0.10	$0.20
6/32 1/2" Screw	4	$0.03	$0.12
Total Amount Spent			$64.30

The donated items assisted our group immensely in keeping our spending within our budget. Some very expensive items were given to us as samples directly from the manufacturer, i.e. the Hammamatsu was donated; therefore, saving us approximately $60. Thus, several of the products we used would have been inaccessible had they not been donated, for they were too costly. The donated items are as follows:

Items	
Aluminum Plate	Molex 2 Conductor
Battery	Motors
Capacitors	Op Amp
Caster	Pin Contacts
Connectors	Pin Headers
Extinguisher	Pins
F/V Converter	PN168s
Hammamatsu R2868	Resistors
H-Bridges	Schmitt Trigger
HC12 Connector	Sharp GP2D120s
Heat Sinks	Switches
Honeywell SDP 8407s	Voltage Regulator
Housings	Wheels
LEDs	
Estimated Value	$755.00

Results/Conclusions

After a little more than five months of hard work, some sleepless nights and headaches it was time to see if our hard work paid off. We decided to at least attempt to finish the robot in time for the EE departments fire-fighting robot competition on April 29, 2000. The competition was held in Workman Center 101. Some of the robot's features had to be adjusted because of the different lighting in this room. After working for twelve straight hours fine tuning the robot we decided that it was ready and we entered. Our robot did very well, finding the candle three out of four times. The missed candle was due to a simple programming error that was changed for the final design review.

On May 2, 2000 it was time for the grades to be handed out. Unlike the competition, which was for fun, this time we had to prove the robot's functionality and discuss all of it's features with our professors. Over all we got at least 90% on all of the requirements that we faced which we were very happy with. Based on these results we were very happy as to where the project ended up and declared it a success.

The systems that I was personally responsible for worked very consistently and correctly and I felt gave me a great learning experience. I had never had been faced with a project of this magnitude. I had to learn a lot about different components and exactly how they worked to be able to pick the distance sensors, design the white line sensor and write software for it all. I learned a huge amount about programming, more than I ever thought that I could learn. At times, the project seemed to be to hard but as I look back I feel that the experience was incredibly valuable.

Included with this report is an appendix of technical data specific to the distance sensors. The first appendix is the data from the sharp sensors. There is also data from the frequency to voltage converters. The next appendix is the code for Homer the robot. The final appendix contains diagrams of component placement.