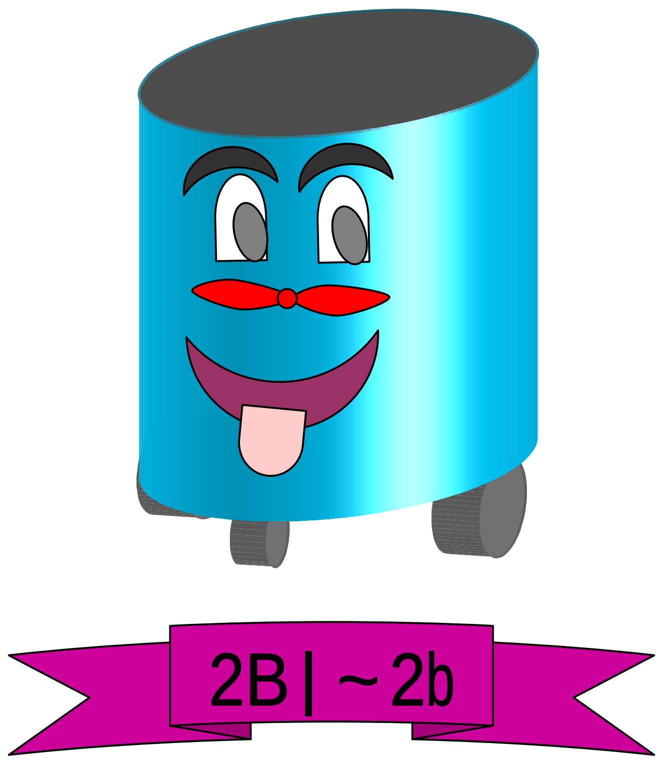
EE382 Final Report

2B|~2b (Bleep)



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Section 0. Abstract and Introduction

Abstract

The goal of this project is to design and build a maze-navigational robot to find a candle and extinguish it. This project also prepares us to get into the field of Electrical Engineering as well as to work as a team.

As for the robot, its first task is to be able to navigate through a maze. With a flame sensor, it is supposed to find the flame in one of the rooms in the maze as quickly as possible. Once it finds the flame, it has to extinguish it before running back to its home base.

Introduction

In order to build an effective robot with an efficient design, we spent a few weeks alone on research. Most of our research focuses on circuit designs, their effectiveness and their flaws.

Our group objectives are to build a neatly designed, efficient, and fully functional fire-fighting robot. Those are the main targets that we wanted to achieve during this semester. As the semester went, we managed to get two objectives out of three that we planned. All the circuits are placed with careful planning so that everything can work together without having a lot of interference from one another. Our robot's body can be considered *quite empty* though we have all the circuits put together. In other words, there is a lot of space for expansion if needed. Sadly, the fully functional fire-fighting robot that we dreamt of has not come true. We had a few problems that took us weeks to figure out and that had put the robot building on hold for quite some time.

At first, our group was divided into two parts to work on the hardware designs and the software programming. But, along the way we dynamically changed our plan to accommodate each team member strongest points. At the beginning of the semester, we assigned Sean Banteah and Najib Fahim to work on the hardware designs. Software programming was assigned to Mohammad Saeed Shams and Anthonius Sulaiman.

At the final plan after a few modifications, the contribution of each team member is as follows:

- Sean Banteah: 2B|~2b's body design and hardware testing.
- Najib Fahim: Hardware maintenance and debugging.
- Mohammad Saeed Shams: Algorithm and sensor designs.
- Anthonius Sulaiman: Software programming, hardware and HC11 testing and integration.

Basically, almost everything in this report is based on the order above. In this report, we include our designs as well as our results.

First we will show our 2B|~2b's body design, our consideration when we chose its current design, its advantages and its flaws. Then the next few sections are circuit subsystem implementations including the motor and H-bridges, frequency-to-voltage conversion, power distribution, and sensor implementation. The last technical section is about the programming experience that we had with our HC11.

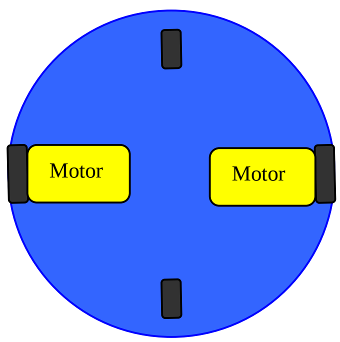
Our final budget is shown right after our HC11 discussion. For the last section, we put our conclusions and impressions on this course physically and mentally. Of course, the block diagram of 2B|~2b can be found in the Appendix.

Section 1. Body Design

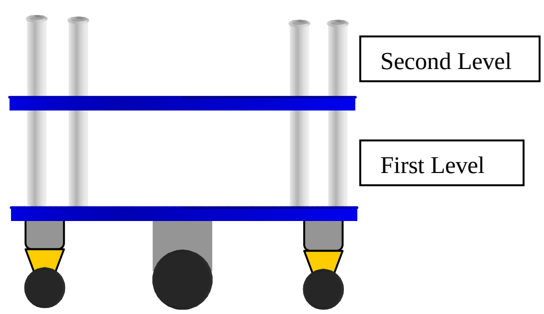
Chassis Design

The design of our chassis was carried out in such a way as to leave us with the maximum amount of space possible for the easier layout of our separate components. With a larger area of space we could arrange our components in a neat and orderly fashion. We also opted for more room so that the finished product would have a nicer appearance. This design turned out nicely when it came time to finding a place for all of our devices. In the end we even ended up with plenty of empty space.

To begin from the bottom up we decided that two levels would give us enough room for component placement. The first level would be made of aluminum and the second layer would be made of plexi-glass. Our two-level design was built on top of the 9¾-inch diameter circular aluminum base. The whole chassis then maneuvers about by utilizing a four-point differential drive configuration. Since we only had two motor wheels that came with the platform we had to add swivel casters in the front and the rear of the base to maintain the balance of 2B|~2b (see Figure 1.1).



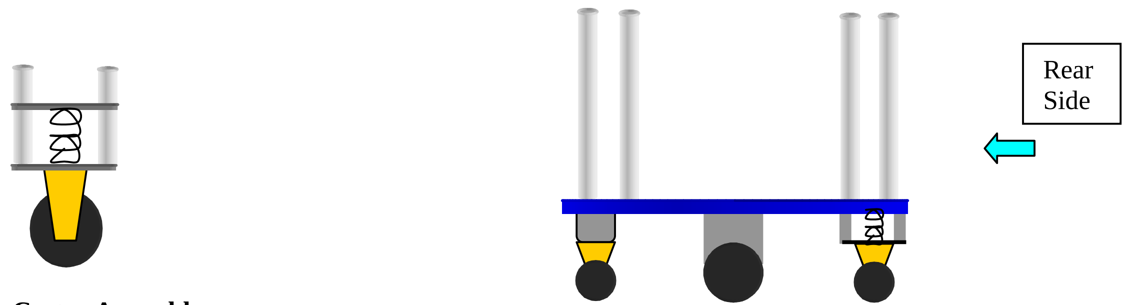
Placement of Casters



Side view

Figure 1.1: Chassis Design

In addition to maintaining balance we also wanted 2B|~2b to have the capability of traversing a ramp without having the two motor driver wheels losing contact with the floor surface. In order to achieve this feat it was decided that a simple spring suspension system would to the trick. Our first attempt was to add a spring to the rear swivel caster as shown below in Figure 1.2.



Spring Caster Assembly

Figure 1.2: Casters

This configuration would leave a fixed swivel caster in the front so that when a ramp was encountered the upward force from the ramp would be compensated for by the spring in the rear. We changed this idea by utilizing the spring caster for the front of the robot and the fixed caster for the rear (see Figure 1.3). Our reason for the change was simply a greater range of ramp climbing ability. With the spring caster on the rear the range of tilt we could get was only about 7 °– 10 ° and the upward force had to be pretty strong. With the second configuration, however, the robot could remain in a level position until the motor wheels took hold of the ramp and the front swivel caster could take on a ramp up to 25° slope easily. We also found out that a swivel caster for the rear would not be very good for the motor control since it can drag the robot to the left and right uncontrollably.

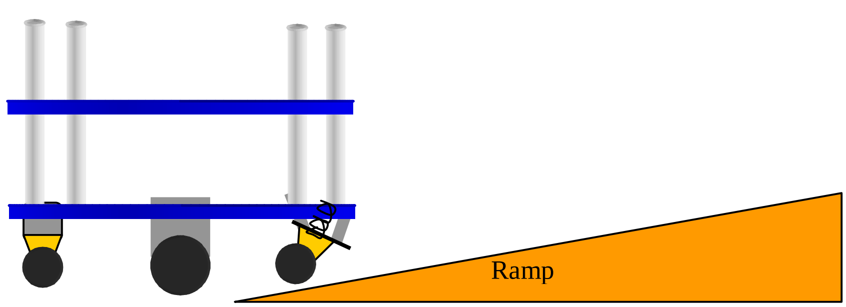
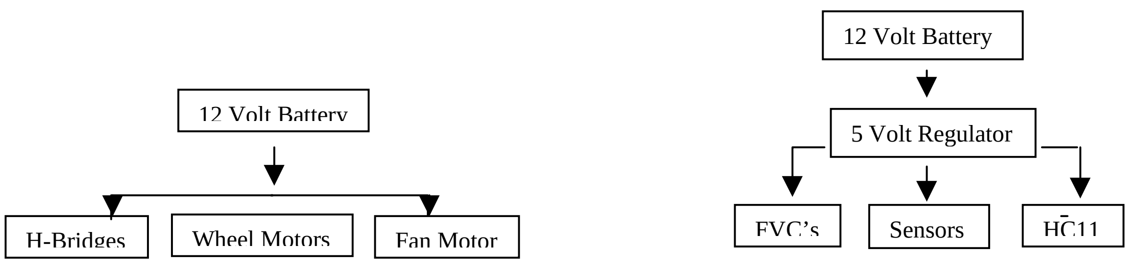


Figure 1.3: 2B|~2b's Ramp Climbing Ability

Placement of Components

When it came time to decide where to place our devices we came to the conclusion that the separation of the high power components from the low power components was essential in order to reduce any noise interference or “cross-talk” between components. Before we could separate our devices we had to categorize them as high or low power. Basically all of our low power components were classified as devices running off of less that 6 volts of power. The category was comprised of the four wall sensors, the flame sensor, the white line sensor, the frequency-to-voltage converters, the 5-volt regulated power strips and of course our HC11. As for the high power components we listed those as anything running off of more than 6 volts. This category contains the H-bridges, the wheel motors, the motor fan and the two 12 volt lead acid batteries used for our power source. . Figure 1.4 below shows the hierarchy of the low and high power components.



High Power Components **Low Power Components**

Figure 1.4: Power for Components

Although separation was our main intention there were some situations where low power devices were placed near high power devices. One such situation came up in the layout of devices for 2B|~2b’s first level. In the first level we placed our H-bridges and our 12-volt batteries, but we also had to place our white line sensor near the wheel motors along with a wall sensor near the H-bridges (see Figure 1.5). There was some concern as to whether the sensors would behave themselves when the motors were running but after several runs by the robot it was observed that no significant noise problems arose.

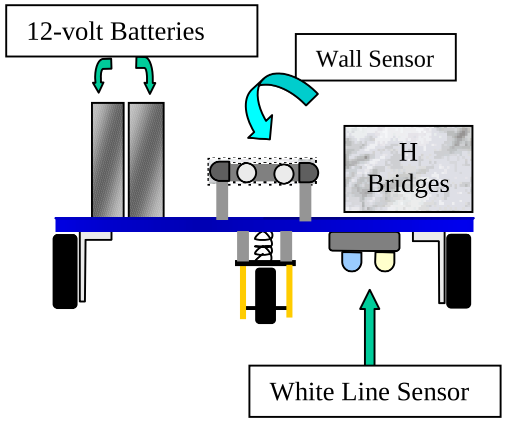
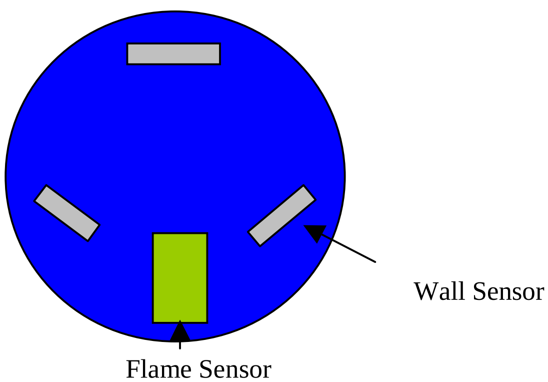
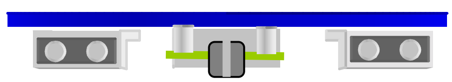


Figure 1.5: First Level

On the underside of the second level we decided to place our three additional wall sensors and our flame sensor in the following configuration shown below. Our wall sensors are placed one in the rear and two on the sides at 45° angles. The three wall sensors are placed at a distance of 1½ inches from the edges of the plexi-glass platform. The flame sensor itself is located front and center 6½ inches from the floor. The diagram on the right is how the front of the second level looks so far (see Figure 1.6).





Front view of Second Layer

Figure 1.6: Bottom Side of Second Level

On the top of the second layer we placed the HC11, the 5-volt regulated power strips, the frequency-to-voltage converters and the motor fan along with its switch in the following manner. The fan motor was located directly above the flame sensor at a height of 7¼ inches from the floor since the candle would be kept at a height between 6-8 inches. The HC11 and the frequency-to-voltage converters were located as far from the fan motor in the attempt to again reduce electromagnetic interference from the motor.

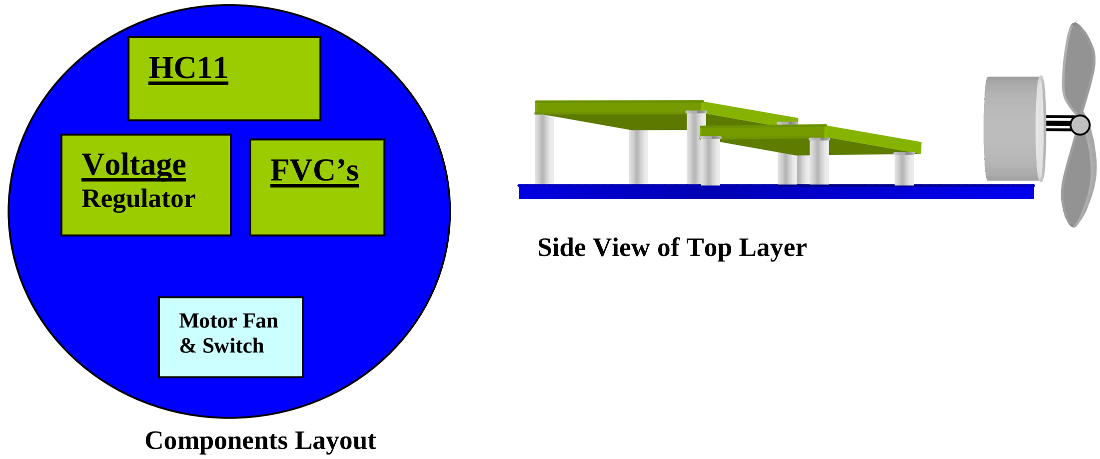


Figure 1.7: 2B|~2b's Top Layer

For component protection we threw in a third plexi-glass layer for the very top, a sort of hard hat for 2B|~2b's brain (see Figure 1.7). Most of our connections between components were comprised of multi-strand wire to ensure maximum signal transmission.

Section 2. Hardware Subsystems

2.1 Motor Control and H-Bridges

This course provided us with two motors at the beginning of the semester. The motors are Pittman series 9000 Servo motors. Since we figured that motors like these would take most of our budget away, we decided to use these motors. From the information that we got, these motors do not give out much electromagnetic interference.

Each of these motors has five wires connected to it. Two are inputs from the H-bridges delivering the 12V V_{cc} and ground. These voltages can be swapped to enable the forward and backward moving directions. With this capability, 2B|~2b should be able to rotate on its axis and run backwards if it has to. The other three wires behave as the encoder to send out frequency information of how fast the motors are turning, V_{cc} and ground.

At first we figured that a forward moving capability is enough for our robot to navigate the maze, but for expansion and algorithmic purposes we might as well add the backward moving capability. In order to accomplish this, we use a device called an H-bridge. We use one H-bridge for each motor. The H-bridges that we use come from National Semiconductor model LMD 18200.

The H-bridges take pulse-width modulations (PWM) and direction voltage digitally from the HC11. The PWM will be connected to pin 5 and the direction input will be connected to pin 3. The H-bridges also require a power input and ground connected to them. We use the 12V battery directly to supply the V_{cc} and ground to the H-bridges. Figure 2.1.1 shows the pin configuration of the H-bridges.

The duty cycle of the PWM from the HC11 will be processed within the H-bridge to determine how fast the motors are turning. The direction line will determine where the motors should turn. If the direction line is showing a ground input, then the H-bridge will send a forward moving signal. If the direction line is showing 5V input, the H-bridge will send out a backward moving signal.

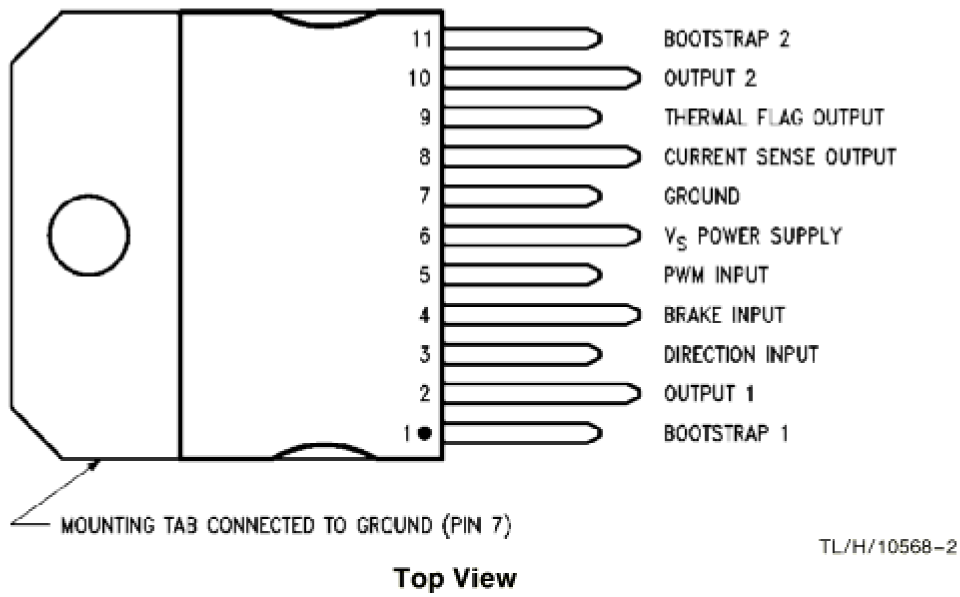


Figure 2.1.1: H-Bridge Pin Configuration

The way we build the H-bridges for the motors is very straightforward. The H-bridges do not require any components to be connected to them. From the data sheet we know that we should have put filter capacitors to bypass the supply rail and at the bootstrap to allow high output switching. But, even without the filter capacitors the H-bridges work fine. So as the result, we put the H-bridges in sockets and connect the pins directly to the HC11, sources and the motors.

After a few tests, we also added a heat sink to each H-bridge because they seem to get hot quite easily. We also put them in a metal box as a shield near the batteries on the first level to prevent noise interference from the motors as well as from the H-bridges themselves that might affect the other circuits.

2.2 Frequency to Voltage Conversion

In order to know how fast our robot is going, we put frequency to voltage (F2V) conversion circuits for the two motors. The circuits are using a National Semiconductor model LM 2917 in conjunction with a 5V regulated power supply.

The results of each circuit are quite satisfying. The output voltage varies from 0V to 3.65V as the frequency varies from 0kHz up to 5kHz. We cannot get more than 3.65V output in our tests; this is caused by the op-amp inside the LM 2917 that limits the output.

Before we chose this configuration, we also had an option to build a circuit with 12V unregulated power supply which can give a nice and linear output voltage to 11V as the frequency goes to 11kHz. We do not use this circuit since we will not use a 100% duty cycle for our motors and anything above 5kHz is most likely too fast to handle.

Frequency to Voltage Converter			
Left Frequency (kHz)	Output Voltage (V)	Right Frequency (kHz)	Output Voltage (V)
0	0	0	0
0.244	0.16	0.244	0.17
1	0.65	1	0.71
2	1.31	2	1.44
3	1.97	3	2.16
4	2.64	4	2.88
5	3.28	5	3.6
6	3.65	5.044	3.65

Figure 2.2.1: F2V Converter Result

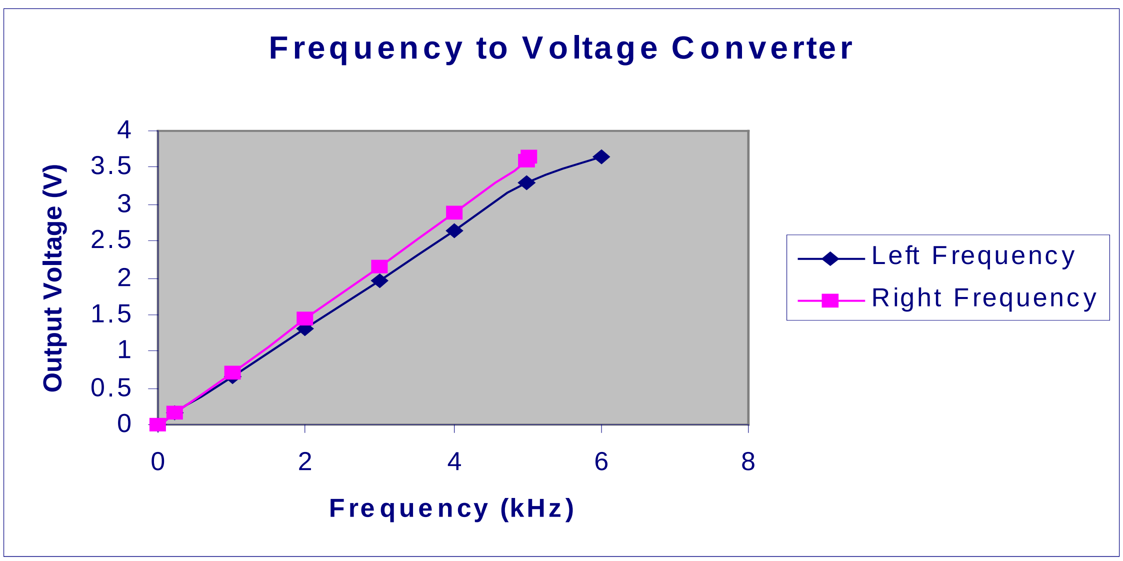


Figure 2.2.2: F2V Converter Chart

The way our F2V converter is configured is shown in Figure 2.2.3. The frequency of the motor turning comes from the encoder. Building this circuit is quite simple as the data sheet already provides us more than enough information and formulas to be used in the calculation. The main formula is:

$$V_o = f_{in} * C_2 * (R_3 + R_5) * V_{cc}$$

With the formula shown above, we only need to choose the correct combination of resistors and capacitors to provide good approximation of the frequency. The output voltage then can be transferred to the analog to digital converter in the HC11 to measure the speed.

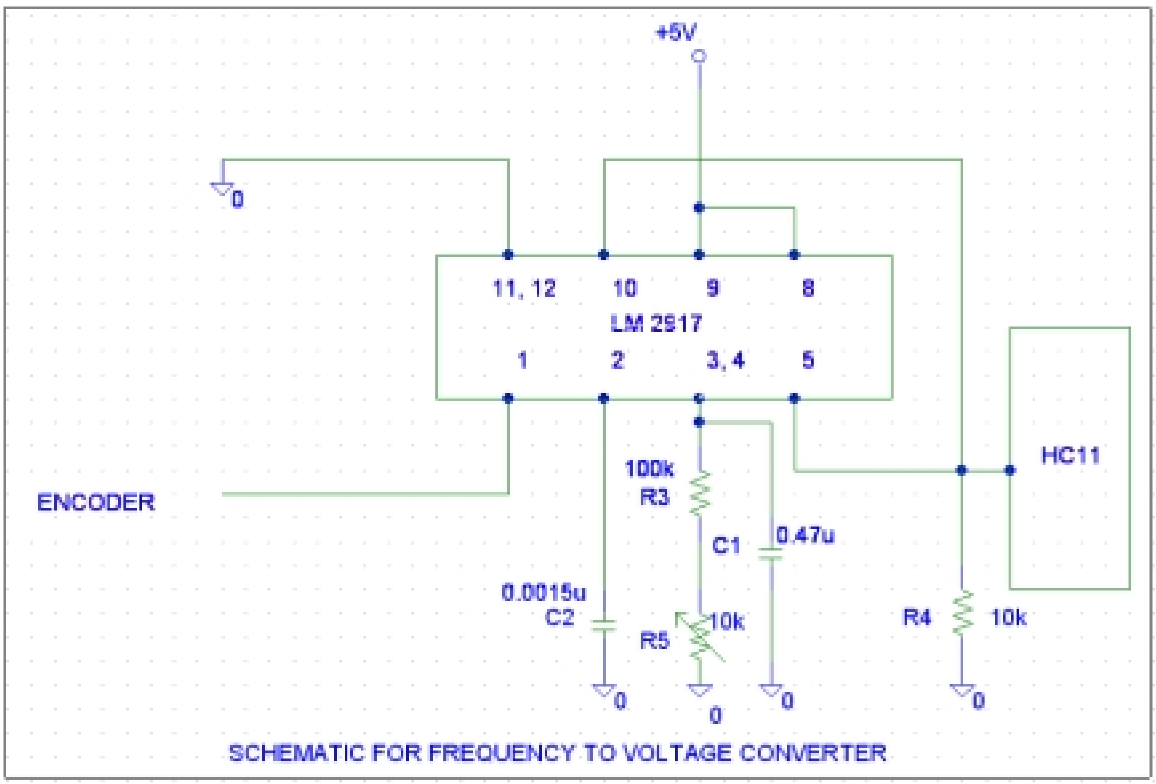


Figure 2.2.3: F2V Converter Circuit

We had quite a lot of problems concerning the F2V converter circuit. At first it was working perfectly when we used the signal generator as the input. It showed a really nice result as shown in Figures 2.2.1 and 2.2.2. Somehow, when we put the circuit together with the motor encoder, it did not work at all. It only showed a constant value. We checked all the connections to make sure everything is in place with no satisfying result.

Finally after spending quite some time, we figured out that the circuit does not work with a positive unipolar square wave ranging from 0V to 5V like what the encoder sends to it. On the other hand, it seems to accept a negative unipolar square wave ranging from –5V to 0V. This is caused by the waveform having a constant in its Fourier Transform to bring it up above the ground line. To avoid this constant, we put a Schmitt Trigger and a capacitor in series with each encoder to filter out some noise problems and to cut out the constant to bring the waveform back to a bipolar square wave ranging from –2.5V to +2.5V.

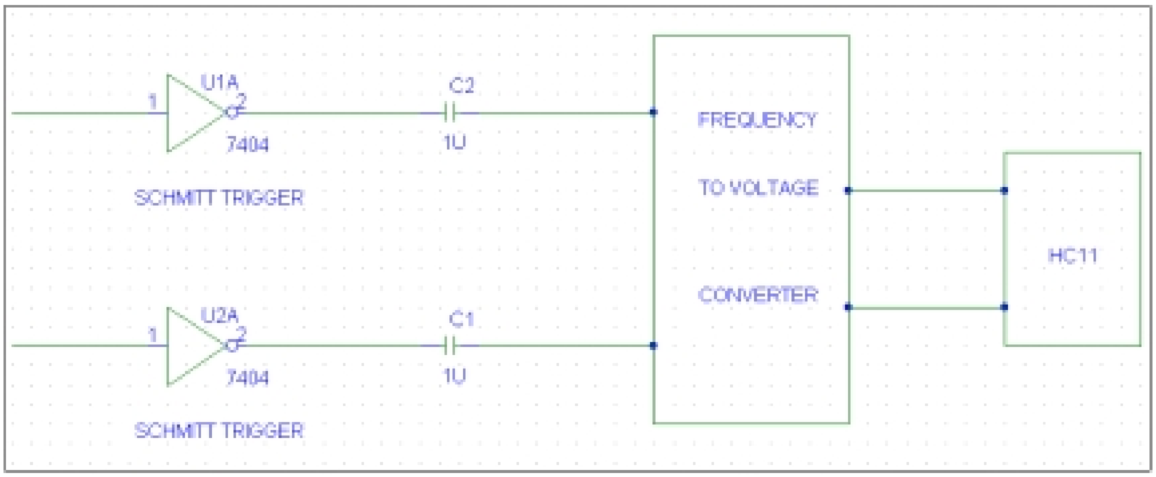


Figure 2.2.4: Fix for F2V Converter Circuit

After applying this new circuit, the F2V converter works with the motor encoders beautifully when we run the motors with a nice ramp function. We still have some problems of the F2V converter not giving the correct output when we put in a less than perfect ramp function. Overall, the F2V converter can work as long as the HC11 can be programmed to run a smoother ramp function.

2.3 Power Regulation and Distribution

In order to have a robot that can move on its own we must have a power supply for it. In our case, we use two 12V rechargeable lead-acid batteries. This way, we do not require to buy a lot of new batteries when the power has run out.

The two batteries are put in parallel to each other with both V- grounded together with the plate. We do this in order to have the same voltage ground all over the circuits and to prevent the plate from interfering with the circuits nearby.

Both batteries are also connected to switches to turn them on and off, each switch for each battery. We do not use one main switch for the whole circuit to prevent unnecessary recharging of one battery when we only use the other battery.

As noted in section 1, we use one battery for our high power circuits and one for the low power circuits. What we consider as the high power circuits are the motors at the bottom of the robot, the H-bridges, and the fan motor. The low power circuits include the HC11, the F2V converters, the white-line sensors, the wall detecting sensors, and the flame sensor. See Figure 1.4 on page 8 for schematics of high and low power distribution.

The low power circuits require 5V at their V_{cc}, so we have to build a 5V-voltage regulator. In our case we use LM 317 to build our regulator. We chose this component because of the simple configuration. It has only three pins of input, output, and adjustment. The circuit for our voltage regulator is shown in Figure 2.3.1 below.

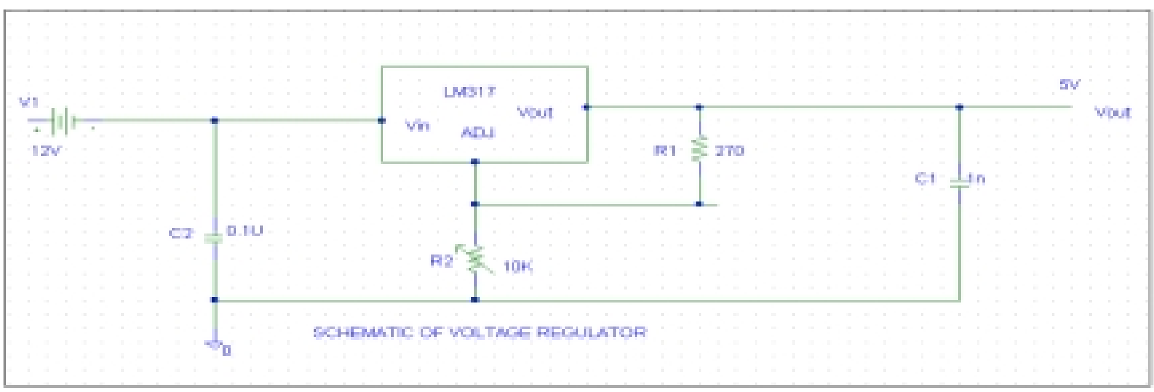


Figure 2.3.1: Voltage Regulator

We also considered using another component called LM 3805, which regulates all kind of sources into a 5V output. We decided not to use it for expandability reasons. If somehow we need other voltage regulating, we will still be able to use the LM 317 in another circuit to provide 6V or 7V output for that matter.

We currently build two voltage regulators for our robot. One is used for solely the HC11 while the other is used for the rest of the low power circuits. The reason for dividing the power regulation is that we were worried about the HC11 not having enough current flowing through it with all the sensors in parallel with it.

In our tests, the HC11 power regulator gets hot very easily and it draws a lot of current from the battery that we have to recharge the battery after about three hours of testing. We suspected a current leakage in the circuit. One method that we try to cool down the LM 317, we put a heat sink to each LM 317. After a few more tests, the power regulators seem to cool down a little bit and they also seem to last longer too.

2.4 Wall Detecting Sensors

For our wall detectors, we use Sharp model GP2D12 analog sensors as opposed to the model GP2D15 digital sensors. The reason that we chose to use the analog version for our wall detectors is simply the measuring range. We want to make sure that 2B|~2b can detect the wall and sense how far it is up to ten centimeters from the wall instead of sensing too far or too close like the digital version does.

The configuration of these sensors is also very straightforward that we only require connecting pins 2 and 3 to ground and V_{cc}. Pin 1 is the analog output voltage to be sent to the HC11.

The output voltage varies from 0V to about 2.5V at the distance of 10cm. The sensors sensitivity is capable to detect down to 10cm range so we have to make sure that the robot does not go closer than that in the HC11 programming. We do not amplify the signal because we figured it would be wasting space in our robot with quite unnecessary circuits. Besides, the wall detectors already give a good approximation of the distance.

Since we are putting the output voltage into an analog to digital converter in the HC11, we only need to set up the HC11 so that it can read the voltage digitally.

Wall Detecting Sensors

Distance (cm)	Output Voltage (V)
0	1.8
4	1.79
6	1.99
7	2.28
8	2.38
9	2.59
10	2.15
12	1.73
15	1.6
18	1.42
20	1.26
21	1.24
24	1.11
25	1.04
28	0.97
30	0.94
44.45	0.67

Figure 2.4.1: Wall Detecting Sensors Result

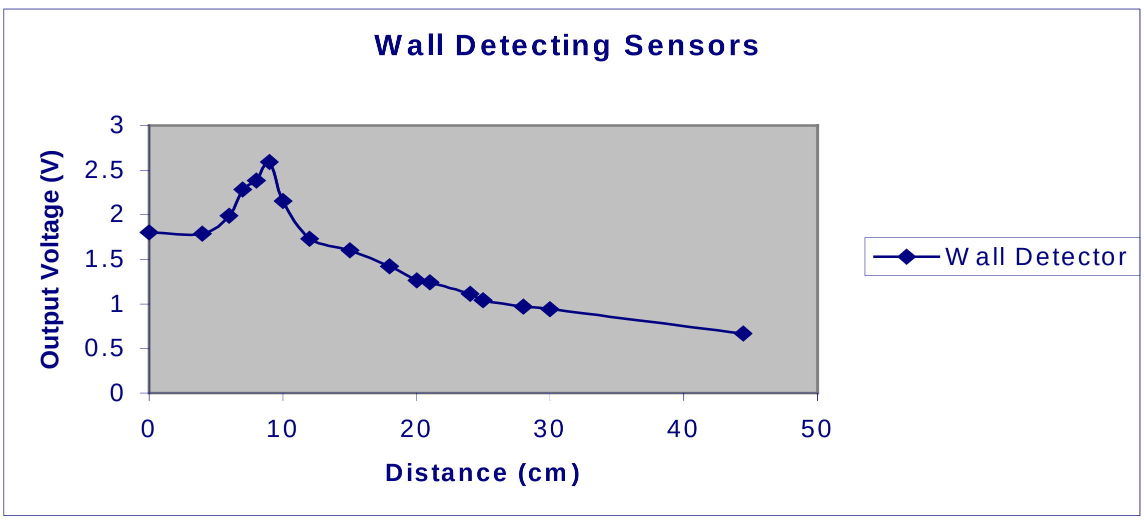


Figure 2.4.2: Wall Detecting Sensors Chart

As shown in our body design at section 1, we are currently using four wall detectors: one at the front, one at the back, and two at the sides at 45° angles from the front.

2.5 White-Line Sensor

Our white-line sensor mainly consists of an infrared LED (*light-emitting diode*) and a phototransistor. The infrared LED is connected as shown in Figure 2.5.3 and the phototransistor is set up to receive the light when the robot reaches a white line. When the phototransistor receives the light, it will change the voltage in its emitter leg.

Again, from a series of tests, we have a very good result. The phototransistor gives a 0.75V at the emitter when the robot is running on a black ground of the maze. As the robot reaches a white line, the phototransistor quickly changes its value into 4.5V.

White-Line Sensor and Schmitt Trigger		
Sensor Voltage (V)	Output Voltage (V)	Meaning
0	0	Black
0.75	0	Black
1	0	Black
2	0	Black
2.81	5	White
3	5	White
4	5	White
4.5	5	White
5	5	White

Figure 2.5.1: White-Line Sensor Result

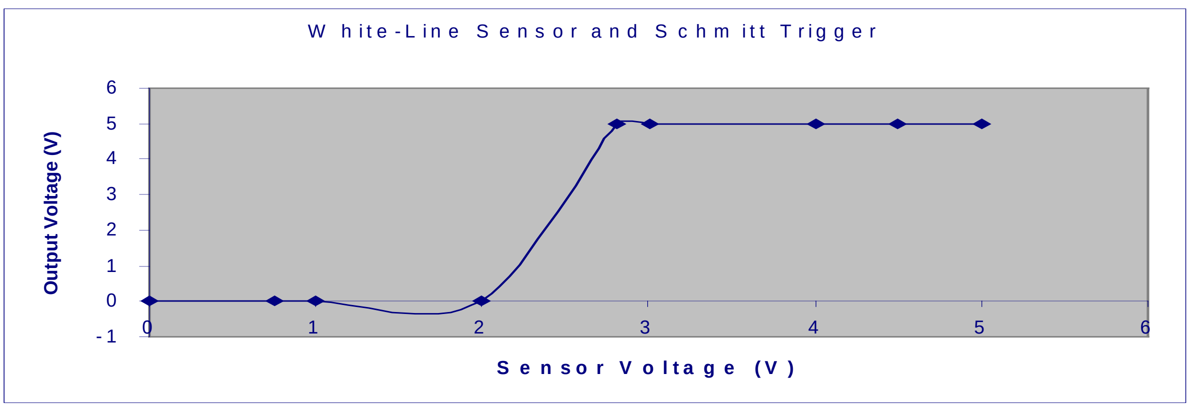


Figure 2.5.2: White-Line Sensor Chart (Note: The wave is caused by Excel)

From the very beginning, we actually want to put a digital sensor to detect the white line. The reason is that we only require either a 5V output as an indicator of a white line or a 0V output as an indicator of a black ground to go to the HC11.

So to accommodate this requirement, we put two Schmitt Triggers in series at the emitter leg. A Schmitt Trigger behaves like an inverter, so we have to put two of them in series to get a non-inverting result. The Schmitt Triggers will switch values from 0V to 5V and vice versa at around 2.81V, its hysteresis point. As shown in Figures 2.5.1 and 2.5.2, we actually get a convincing result of black and white detection. MS Excel causes the flaw in the chart, not our sensor.

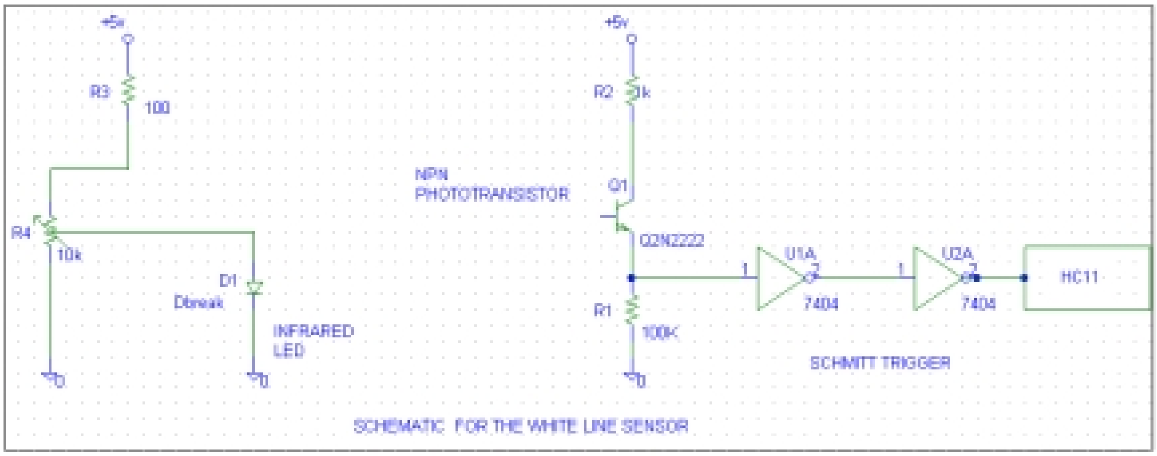


Figure 2.5.3: White-Line Sensor Circuit

Since we put this sensor at the bottom of the robot near the motors, it is bound to have some electromagnetic interference from the motors. Having two Schmitt Triggers in the circuit also has advantages other than giving out a nice 5V output. One advantage is that the Schmitt Trigger actually filters the noise coming from the motor.

2.6 Flame Detecting Sensors

We decided to use a phototransistor as our flame sensor. We managed to get a pretty good result out of the phototransistor ranging from one foot to about six feet flame distance. The voltage result ranges from 3.78V at the closest range to 80mV if it does not see any flame. It does not give us 0V because it still sees the light from above the room.

As the phototransistor gets a light, it creates a very little voltage at its emitter leg, not enough information to determine the distance of the flame. So we have to put an amplifier with about 11V/V non-inverting gain on its emitter. We use an op-amp LM 324 to accomplish this since it requires 0V and 5V as its limiting voltage. If we use LM 411 for instance, we have to provide –15V and +15V instead, which are not very easy to do.

Flame Sensor	
Distance (cm)	Output Voltage (V)
184	0.28
150	0.34
120	0.48
100	0.74
90	0.94
70	1.5
60	1.85
40	3.5
30	3.78

Figure 2.6.1: Flame Sensor Result

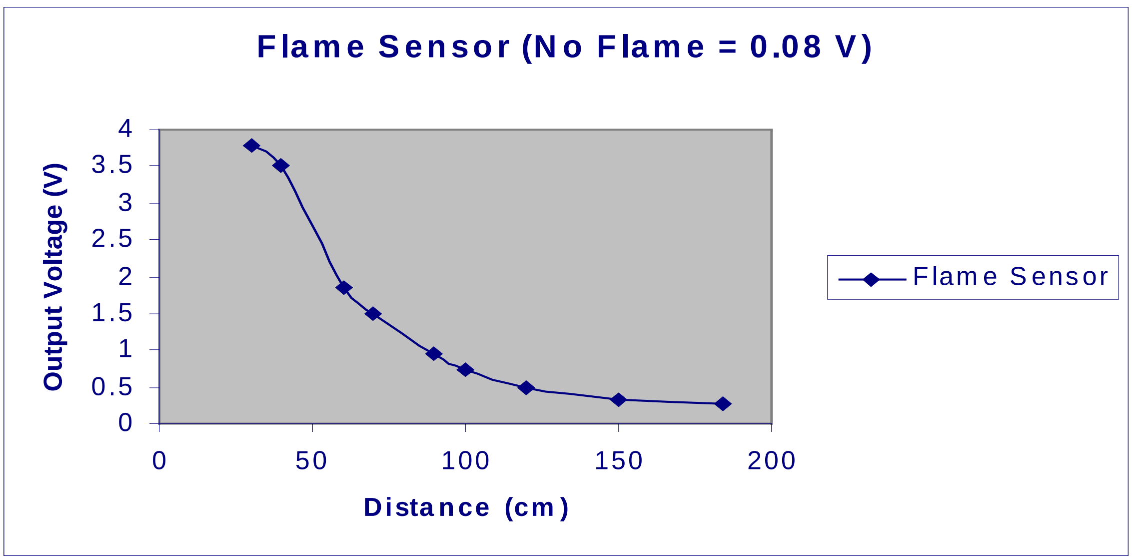


Figure 2.6.2: Flame Sensor Chart

The phototransistor is very sensitive. In order for us to get a better resolution, we put the phototransistor in a black tube with a tiny slit in front of it. To prevent even more unnecessary light coming into the tube, we put a cover from a floppy disk in front of it. In this condition, the phototransistor can only see the flame from the candle and can barely see the light from the room.

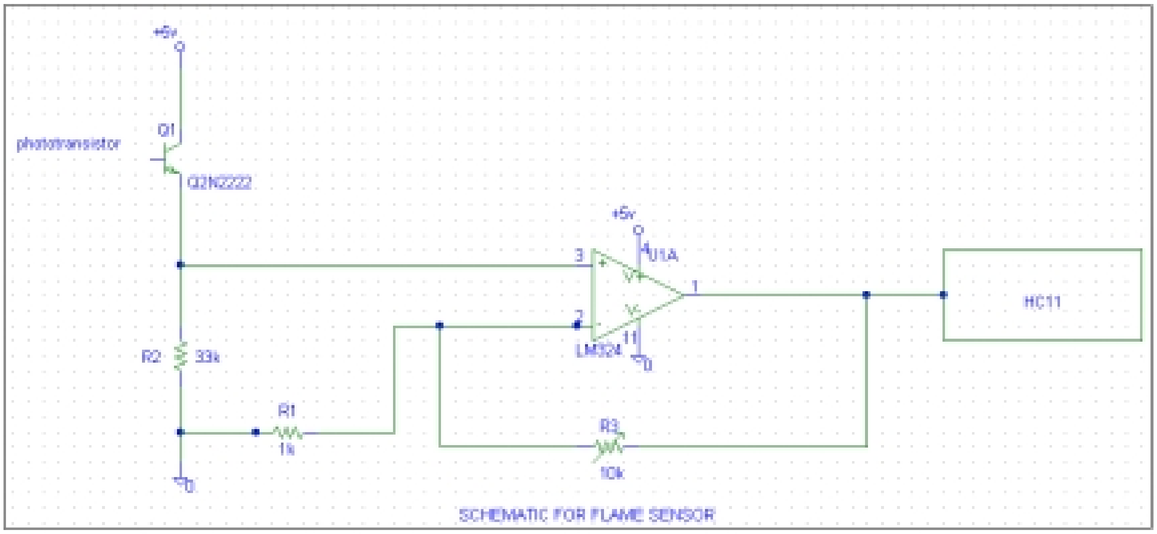


Figure 2.6.3: Flame Sensor Circuit

However, with this configuration we cannot get a full 5V output as it sees a very bright candle flame in front of it. It saturates at 3.78V, equivalent to a foot distance. This phenomenon makes sense since the op-amp will also draw some current out of it and reduce the output voltage.

2.7 Fan Motor

There are a lot of options on how we are going to put out the candle once the robot finds it. Some of the popular ones are using a fan or a water pump. We tried to avoid using the water pump because if something goes wrong in the water pump circuitry, the water might damage the other circuitry especially the HC11.

That left us with the fan. Our fan is not very hard to set up. In fact, we did not need to set it up at all at first. The basic idea is to have the Vcc connected to a pin from the HC11. This way whenever the HC11 sends out a 5V signal, the fan will turn on.

Our first test did not go as planned. Using only 5V to drive the fan motor did not seem to be enough to put out the candle. We changed to our second plan, which is using the 12V power supply to drive the fan motor while maintaining the 5V signal from the HC11 to turn it on and off.

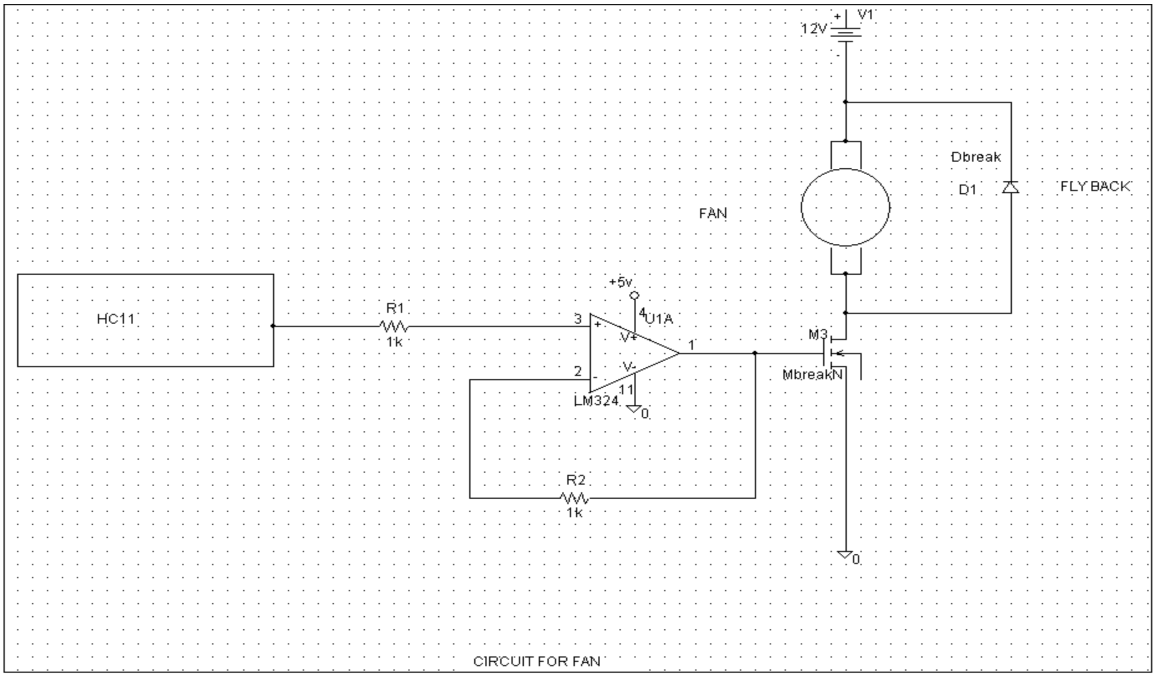


Figure 2.7.1: Fan Motor Circuit

By putting a MOSFET between the HC11 and the fan, we managed to build a 12V-powered fan with a 5V switch. We also added a 1V/V amplifier, as a buffer to make sure that both the HC11 and the fan motor does not cross into each other's path. So currently we have the fan motor hooked up to the 12V-power supply as shown in Figure 2.7.1 above. The flyback diode connecting the MOSFET and the 12V-power supply is used to protect the MOSFET from blowing up.

Section 3. HC11 Programming

HC11 programming somehow can look pretty easy and straightforward when we were thinking about what algorithm we wanted to use. However, in real life HC11 programming can be a pain, especially when we were setting up all the ports. Our method to keep files in smaller size and perhaps easier to look is to cut the failed program out to streamline the process. The program itself might not be as big as we thought before, but the bugs it contains may be beyond our estimation. The debugging takes most of the time in the programming process, although at some points we could not find the bugs while it was still not working. At some later time, we found out that the problems also originated from the hardware. We have not completely finished the sensor integration, navigation, and flame extinguisher functions because of some problems that we have in the F2V converter. But, so far we have our motor control program and a basic wall following finalized.

Motor Control

As far as the motor programming goes, we are proud to say that we are one of the groups that does not require an additional Altera chip to drive the PWM for the motors. We have considered using an Altera chip in the beginning, but since we are very limited on our budget and it is very time-consuming to order an Altera chip, we had to think of another way to drive our motors. We finally were able to use the HC11 to send out the PWM. This is also an advantage to our robot's physical design as more space can be saved for other circuits.

Our HC11 programming basically is a continuation from our EE308L (Micro-controllers Lab) which had prepared us for a simple motor control with the HC11. Then to accommodate the requirements for our Pittman motors, we started the HC11 programming with a set of pins on the HC11 to be connected to the H-bridges.

From the information that we have about motor control, we use pulse-width modulation to control the speed of our motors with a specific duty cycle for each motor to make certain that both motors are running at the same speed. From a series of testing, we figured that the motors do not require a high percentage of duty cycle. A thirty-percent duty cycle is about enough to drive the motors at a manageable speed. If the duty cycle percentage somehow reaches more than sixty percent, the robot will be running too fast that the HC11 will not be able to get ample information to control the motors anymore and more importantly we cannot catch the fast-moving robot very easily.

The H-bridges configuration can be found in section 2.1. The pin requirements are two pins to supply the directions for each of the motors (forward and backward directions) and two pins to supply the pulse-width modulation to the left and right motors. We use two lines from TOC3 and TOC4 to drive the PWM while keeping the direction lines on reserve. The direction lines work as in: negative PWM means moving backward and positive PWM means moving forward.

Wall Following

Our wall following is still in preliminary stages. The main cause, as noted earlier, is our problem with the F2V converter circuit that did not give out the correct value. We solve this problem almost at the end of the semester that we could not continue much on the programming except finishing the basic wall following that we had started.

Using the three sensors at the front and the sides of our robot, we managed to build a simple left-wall following and a right-wall following without using the F2V converter to accommodate the motor control. As for the motor control, we simply use PWM lines directly.

In this basic wall following, we still use a fixed duty cycle for the PWM lines. We have not included the proportional or integral control that we planned at the beginning of the semester, although we already started testing the proportional control a little bit.

Section 4. Final Budget

Source	**Category**	**Price**
Stockroom	Robot's body	$12.20
DigiKey	LM 2917M-ND (F2V Converter)	$2.56
	PN 334PA-ND (Photodiode) – Not used	$1.35
All Electronics Corp.	OKI TeleCom #64-42081 (Battery)	$9.50
	AMSECO PAL-328 (Buzzer) – Not used yet	$3.75
	Motor with Gear Box – Not used yet	$6.50
	Multi-Connection Connectors	$4.80
Sterling Sensors	Sharp GP2D12 (Wall Detecting Sensors)	$17.67
Radio Shack	Phototransistors, Op-amps	$13.07
EE 382	Chassis, Pittman Motors, H-Bridges, HC11	$0.00
	Boards, resistors, pin headers	$0.00
Personal Budget	Tapes, switches, fan, miscellaneous items	$25.00
Total		**$96.40**

As shown from the table above, we are very fortunate that the EE Department provides most of the expensive parts as they open this course for the students. We estimated that we could have spent about $150.00 for the HC11, motors, and H-bridges. So all we need to buy are additional items like the sensors, op-amps, and transistors.

Our most expensive items are the Sharp GP2D12 wall detectors, especially because we bought four of them to be used for all directions of the robot. At the end of the semester, we calculated that we almost spent the entire provided budget of one hundred dollars, so the verdict is that we are still roughly under our budget.

Section 5. Conclusions

The course has finally come to an end. We have learned some of the most important aspects of Electrical Engineering even though this is not an official practical training. We have to use all our knowledge in analog and digital electronics to reach our objectives for this course. On the other hand, we also learned to work with teammates effectively and efficiently, which some of us have to learn it the hard way.

Our little project does not come out as we expected at the beginning of the semester, but this project has made us realize of our timing too. We estimate that we are off by two or three weeks to get the finished product. The project timeline did not go as we predicted. We figured that we would have finished building the robot's body by midterm so that the rest of the time could be used as software debugging.

Physically, we built the robot up to the point of integration between motors, sensors, and the fan. Mentally, since we got most of the quirks fixed up that we finally could get our wall following program to be tested correctly during the final week of this semester, we got really excited that some of us decided to continue working on the robot if the department allows us. Some things that we learned during this time are as follows:

- We have to make sure everything that needs to be connected is actually connected.
- More importantly, we have to make sure everything that is not supposed to be connected is not giving us a short circuit.

We have said almost everything that we have to say. So to finally conclude our semester, we can only say that 2B|~2b will somehow continue to live in our memory as knowledge and experience even though we have not had a chance to see it grows.

Appendix

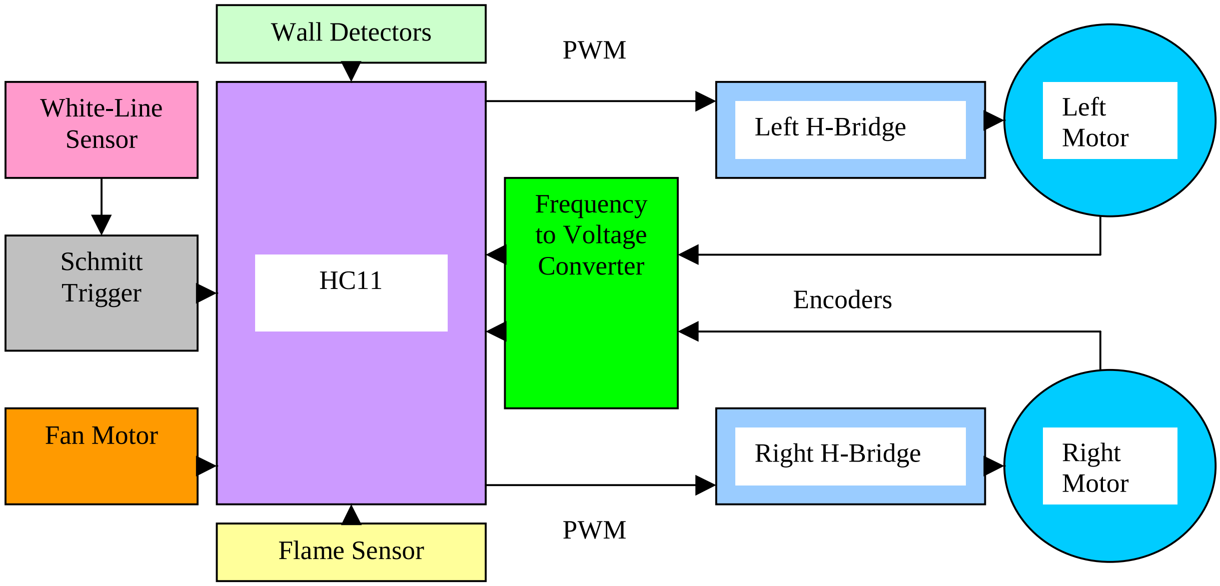


Figure A.1: Block Diagram

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