Electrical & Electronic Design - Line follower Project - Group Report

ENRNG2099

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Date Due: 18/04/2007

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2 Introduction

2.0 Introduction

This report will outline the design, construction and testing of our line following robot. It will show detailed sections on the design stage and how each individual's tasks came together to make the robot function.

The report will stress the difficulties that we as a group have faced throughout the module as well as the changes that we needed to make to achieve a functional product.

2.1 Aims

The aim of this module was to work as a group to design and construct a robot capable of following a white line.

We will be aiming to improve our knowledge of robotics as well as electronic circuit design and construction.

We will be working as a group, and thus should improve our skills of working together to achieve goals.

2.2 Objectives

Construct a Line Following Robot:

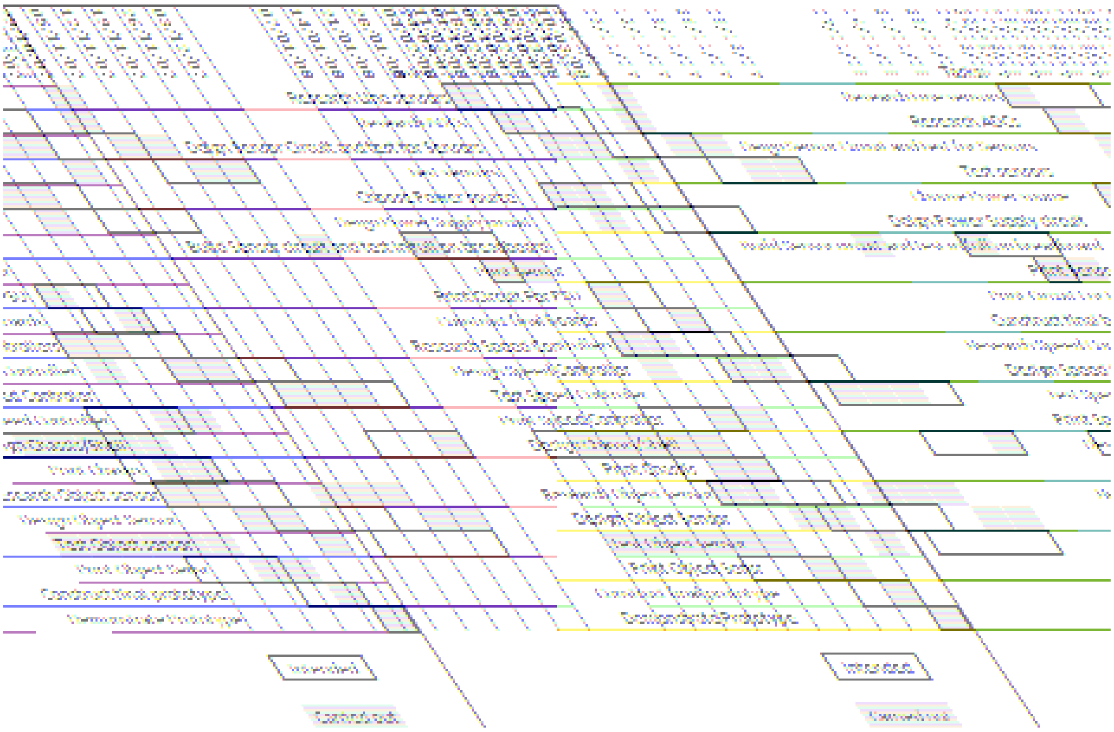
- That will follow a white line path on the floor.
- Give a warning when it is moving.
- Stop within safe distance of an object in its path.
- Give a warning or notification that it has sensed an object over the path.
- Automatically continue when object moved.

2.3 Project Restrictions:

- It has to be battery powered and be able to operate for up to 2 hours without having to be recharged.
- Must be no larger than 20x20x20cm in dimensions.
- Must be made within a budget of £25.00.

2.4 Design Schedule

Here is the group Gantt chart, showing when we intended to do the tasks over the year, and when they were actually carried out:



(table 2.4.1)

2.5 Individual Tasks

****:

- Line Sensor.
- Power Supply.

***:

- Body/Chassis.
- Motor Control.

***:

- Obstruction Sensors.

2.6 Line Sensor

This is a circuit which is able to see the white line on the floor, and translate the vehicles location in relation to the line into a 2 bit digital signal. Where 00 means “off the line”, 01 means “ to the left of the line”, 10 means “to the right of the line” and 11 means “on the line”.

2.7 Power Supply

This is a circuit which supplies the necessary voltages to all the circuits and systems on the vehicle. The power source will be a 9V PP3 Battery. The 2 voltage “rails” initially planned are 9V – to drive the motors, and 5V to drive the low power and logic circuitry.

2.8 Body/Chassis

The body is constructed from ABS plastic. It was designed on SolidWorks a 3D CAD programme and built on an automated Rapid Prototyping printer.

2.9 Motor Control

The motor control circuit controls the speed of each motor therefore steering it around the line. The circuit is built around two NPN transistors.

2.10 Obstruction Sensors

The circuit for this task is effectively two circuits; one circuit for the ultrasonic transmitter, and one circuit for the ultrasonic receiver.

3 Sensor Circuit Research and Development

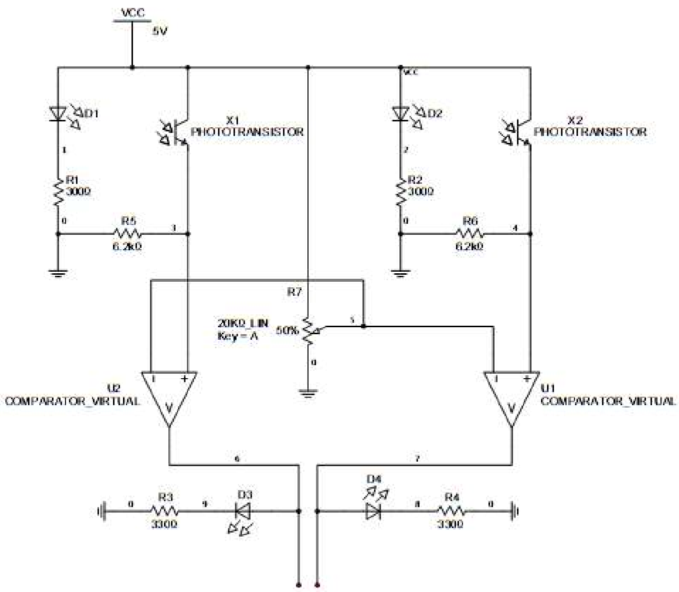
3.0 Initial Designs

The research done on the line sensors showed that there are two main methods used:

- A Light dependant resistor picking up light reflected off the floor from an LED.
- A Phototransistor picking up light reflected from an infra red LED.

The Infra Red option has 2 major benefits over the visual spectrum solution. Firstly that the Infra Red Spectrum is a lot cleaner than the visual spectrum, there is a lot less potential for interference. The other advantage is that phototransistors will react much quicker than Light dependant resistors. However, what appears white and black to the naked eye, may not be distinguishable in the Infra red spectrum.

For the analogue to digital conversion of the signal from the sensors, the plan was to use an AND gate as an analogue to digital Converter. But research showed that a component exists specifically for this purpose, a comparator, where if the input voltage is higher than a reference voltage, the output would go to logic high. This was used in the 1st prototype:



(fig 3.0.1)

The vehicle follows inside the line, if one sensor leaved the line, the vehicle turns to return to the centre of the line, the vehicle moves forward if both sensors are on the line, and the vehicle stops if both sensors leave the line when the line finishes.

3.1 Testing and Alterations

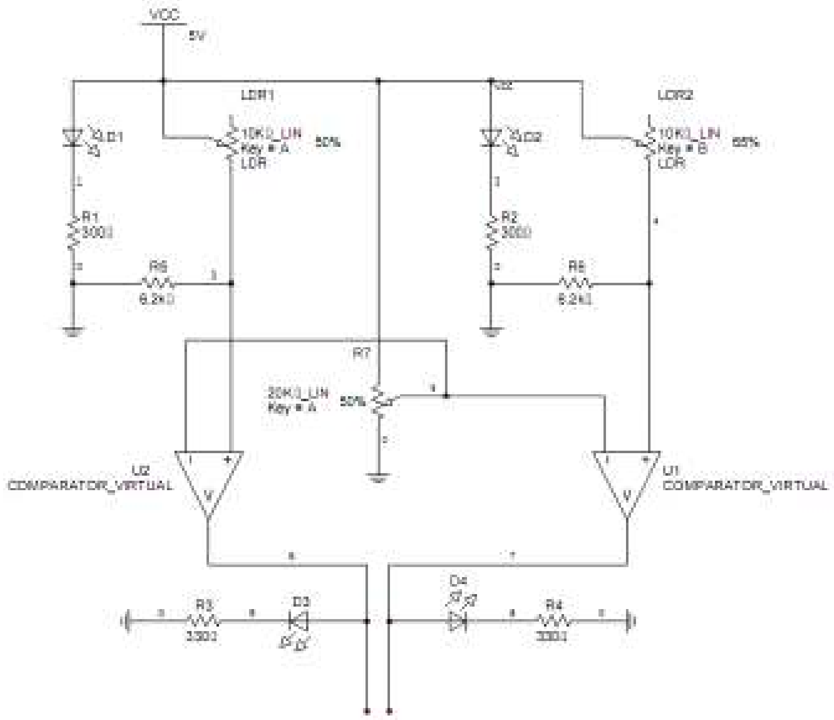
Testing of this circuit proved that it was not a viable solution as, as the sensors showed no response to the amount of reflected light:

Surface Shade (%)	Phototransistor emitter-ground voltage (V)
White 0	0.027
10	0.026
20	0.026
30	0.027
40	0.026
50	0.026
60	0.027
70	0.027
80	0.027
90	0.026
black 100	0.026

(table 3.1.1)

The phototransistors will be abandoned in favour of a visual spectrum alternative, however; the sensors did show promise as a proximity sensor, they will be passed on to the Ojbect Sensor Team.

The circuit design has been modified to use Light Dependant Resistors instead of Phototransistors, and LEDs that optput light in the visual spectrum.

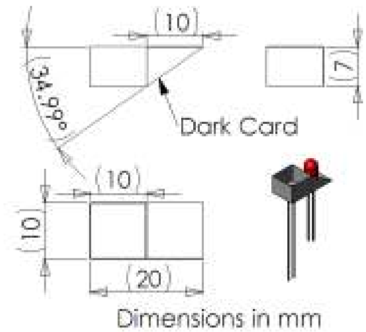


(fig 3.1.1)

When the resistance of the LDR's changes de to the increased light reflected from the surface, the voltage at the positive inout to the comparator increases. When it passes the reference voltage at the negative input to the comparator, the comparator outputs logic one to the sopeed controller.

The LDRs are sensitive to a band of light with dominent a wavelength of 550nm[ref 1]. The LEDs output a dominant wavelength of 569nm[ref 2], this is very close.

To enable the sensors to pick up light reflected from the surface, and not directly from the LEDs; a cowling will be used:

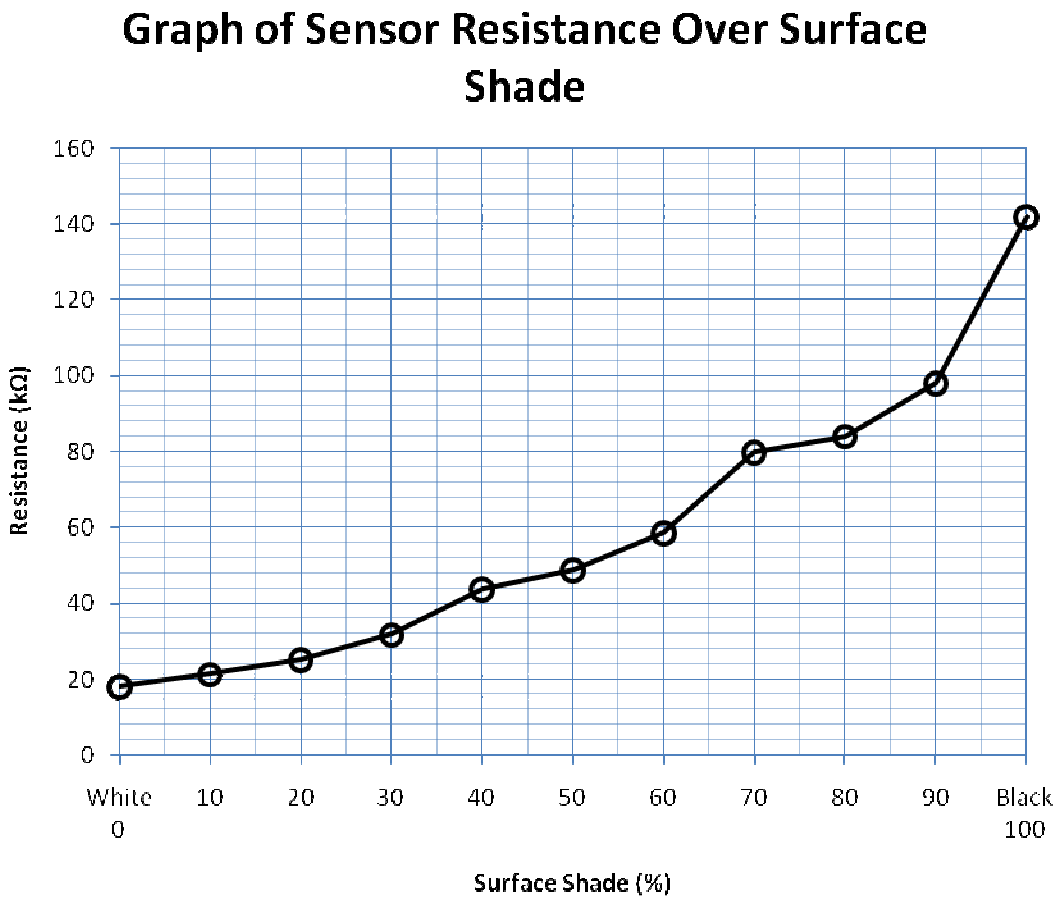


(fig 3.1.2)

These sensors were constructed and tested, 5mm appears to be the optimum range, considering variance in the sensors and ground clearence, this is the sensors output at 5mm:

Surface Shade (%)	5mm 1 (kΩ)	5mm 2 (kΩ)	Average (kΩ)
White 0	18.65	17.36	18.01
10	21.28	21.27	21.28
20	25.54	24.73	25.14
30	32.83	30.56	31.70
40	43.54	43.8	43.67
50	48.41	48.88	48.65
60	51.6	65.52	58.56
70	72.03	87.56	79.80
80	83.49	84.47	83.98
90	92.82	103.34	98.08
Black 100	153.59	130.17	141.88
Total variance:	134.94	112.81	123.88

(table 3.1.2)



(fig 3.1.3)

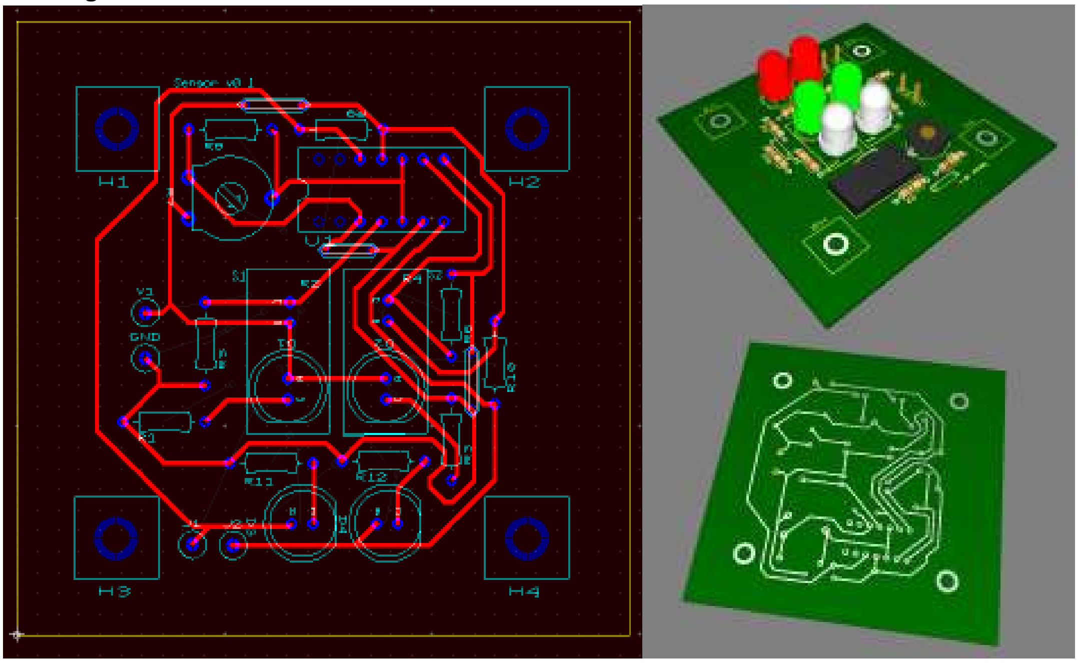
Based on these results, these sensors are suitable for the vehicle.

Taking a cutoff of 50% on the comparator's range to allow for maximum tunability, this being 2.5V. And aiming for the centre of the tuning potentiometer, resistors R2 and R4 in the above circuit should be approximately 50kΩ, I will use the standard resistor value of 47kΩ.

3.2 Final Designs

The next step in this part of the project was to construct the complete circuit on breadboard, and test it on the official line. Once varified as working on breadboard, a PCB layout was designed, and a board produced on the CAM (Computer Aided Manafacture) milling machine.

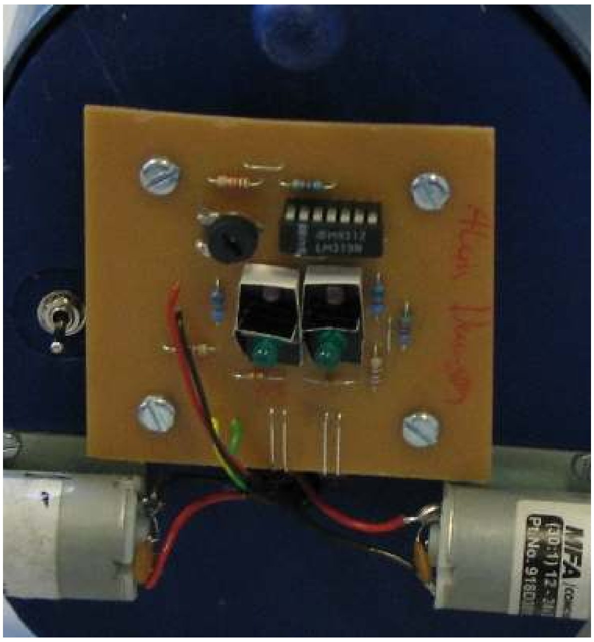
The design of the final PCB is as follows:



(fig 3.2.1)

3.3 Implimentation

This circuit was then tested again, and built into the vehicle:



(fig 3.3.1)

The Circuit works fully in the final prototype, and causes no problems in other circuits.

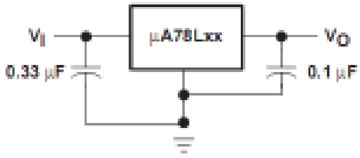
4 Power Supply Research and Development

4.0 Initial Designs

There is a range of ICs which will step a range of voltages down to a specific voltage, For 5V, the µA78L05ACLP can be used[ref 3].

Proporly configured, it will convert anything between 5V and 30V, to 5V. There is however a rated maximum current of 100mA on the 5V output.

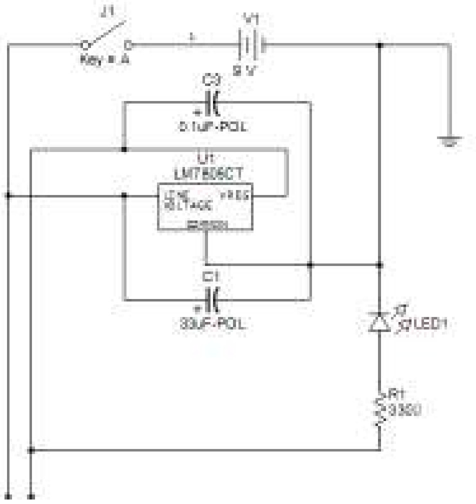
The Data sheet provides a suggested circuit:



[ref 3]

(fig 4.0.1)

From the suggested circuit, a design has been formed; featuring a 9V rail, and a 5V rail with an approximate 100mA limit. There is an LED on the 5V rail to indicate that the 9V rail is over 5V, and the 5V rail is sufficient.

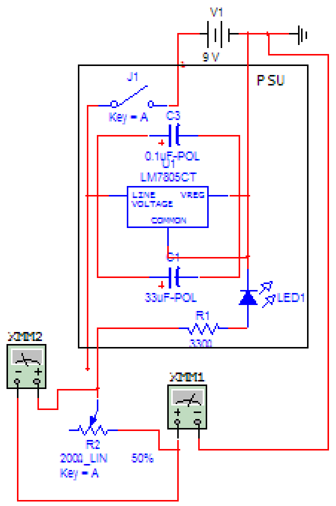


(fig 4.0.2)

4.1 Testing and Alterations

Next, the Power supply circuit was constructed on breadboard, and tested thoughroughly.

The max current draw (not including the internal LED) was measured with the following circuit:

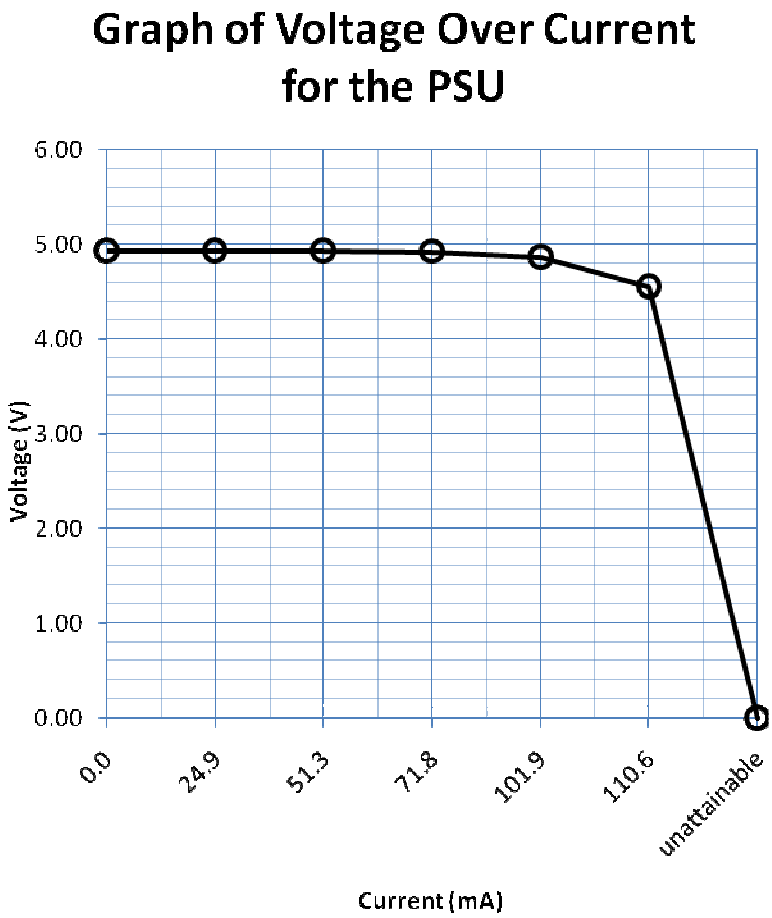


(fig 4.1.1)

The veriable resistor was altered to a chosen current and the voltage measured, the temperature of the voltage regulator was also measured by feel:

Target Current (mA)	**Current (mA)**	**Average Voltage (V)**	**Temperature (Temperature with heatsink)**
0	0.0	4.93	ambient (not measured)
25	24.9	4.93	ambient (n/m)
50	51.3	4.93	warm (n/m)
75	71.8	4.92	hot (warm)
100	101.9	4.86	n/m (warm to hot)
125	110.6	4.55	n/m (hot)
150	unattainable	0.00	n/m (n/m)

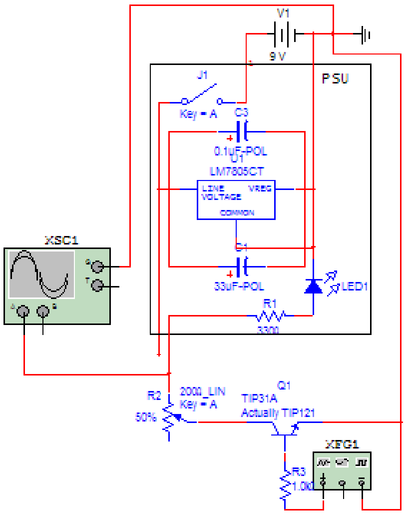
(table 4.1.1)



(fig 4.1.2)

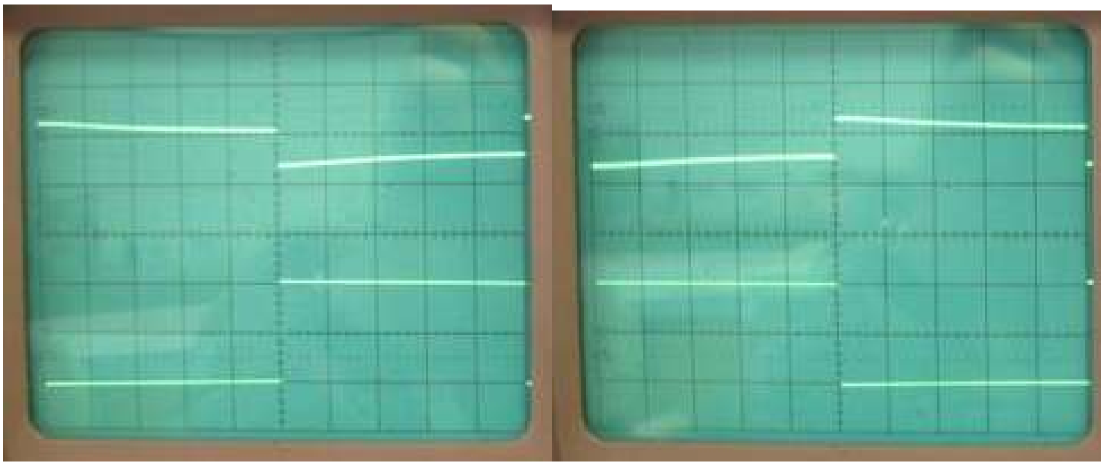
From this testing, a provisoinal maximum current draw of 100mA had been allocated, to keep the deviation within 10%.

The PSU was then tested in a shock loading/shock unloading situation, using the following circuit:



(fig 4.1.3)

With the function generator set to alternate between 0V and 1Vat 100Hz, and the pot. Tuned to 100mA when the transistor is on. The resulting scope. trace shows negligable drooping/spiking of the voltage:



Top: 5V Rail (50mV/cm)
Lower: Function generator (0.5V/cm)

Top: 5V Rail (50mV/cm)
Lower: Function generator (0.5V/cm)

(fig 4.1.4)

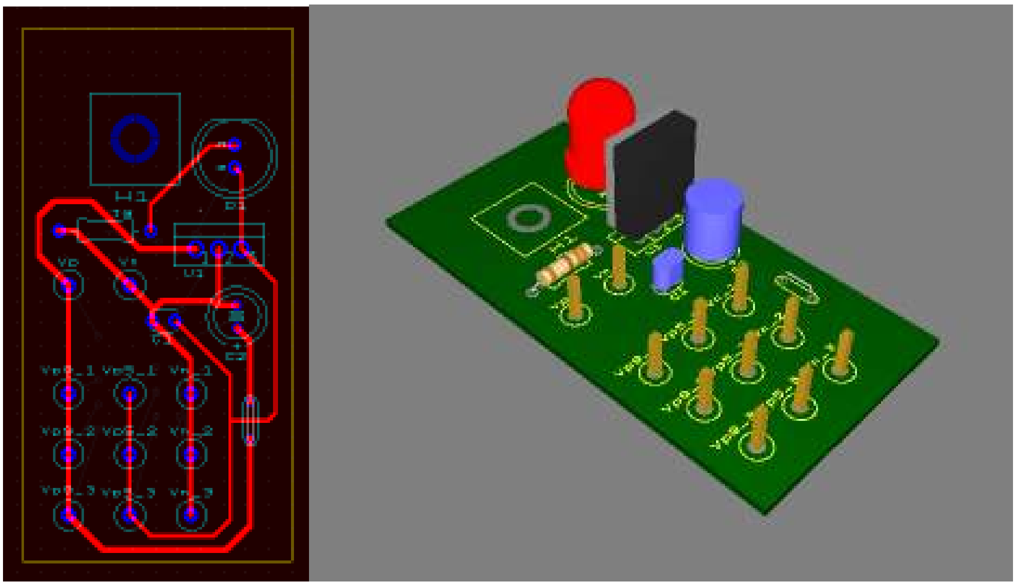
This shows that the voltage droops by 0.03V when shock loaded, and peaks from steady state by 0.05V when shock unloaded, howeverm it only peaks to 0.02V over 5.00V. These vaslues are all comfortably within 10% deviation, the 100mA maximum current was validated with this experiment.

The initial design functions adequately, no changes were made before producing the final prototype.

4.2 Final Designs

The next step in this part of the project was to construct the complete circuit on breadboard, and test it on the official line. Once varified as working on breadboard, a PCB layout was designed, and a board produced on the CAM (Computer Aided Manafacture) milling machine.

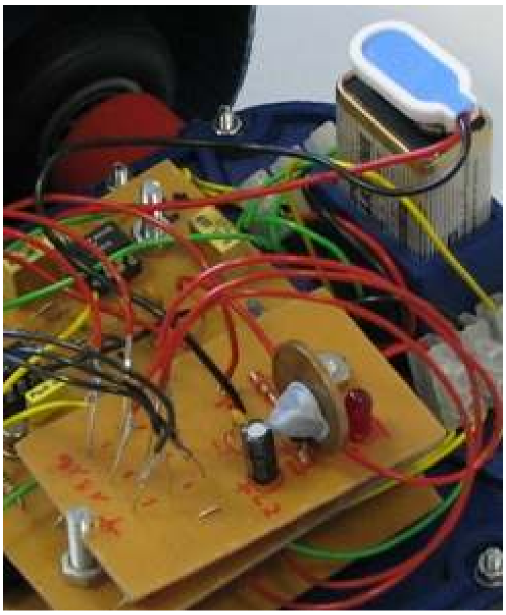
The Design of the PSU is as follows:



(fig 4.2.1)

4.3 Implimentation

This circuit was then tested again, and built into the vehicle:



(fig 4.3.1)

The PSU was able to supply enough power for all the other circuits without drooping or overheating. The design of the 20.32mm diameter, 3.56g, copper heatsink can be seen in the above image.

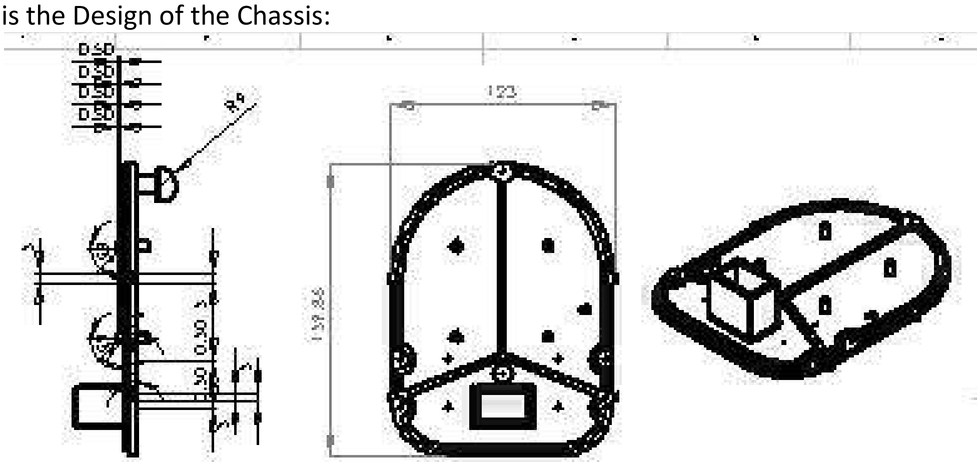
5 Chassis Research and Development

5.0 Initial Designs

The size of the buggy was determined by the circuitry which is to go inside it. Once we had got a basic idea of the electronics side of the project we could then start to construct the chassis. This determined the positioning of the sensors, motors and the front skid. We decided to position the line follower sensor in such a way to enable it to handle the tightest corners.

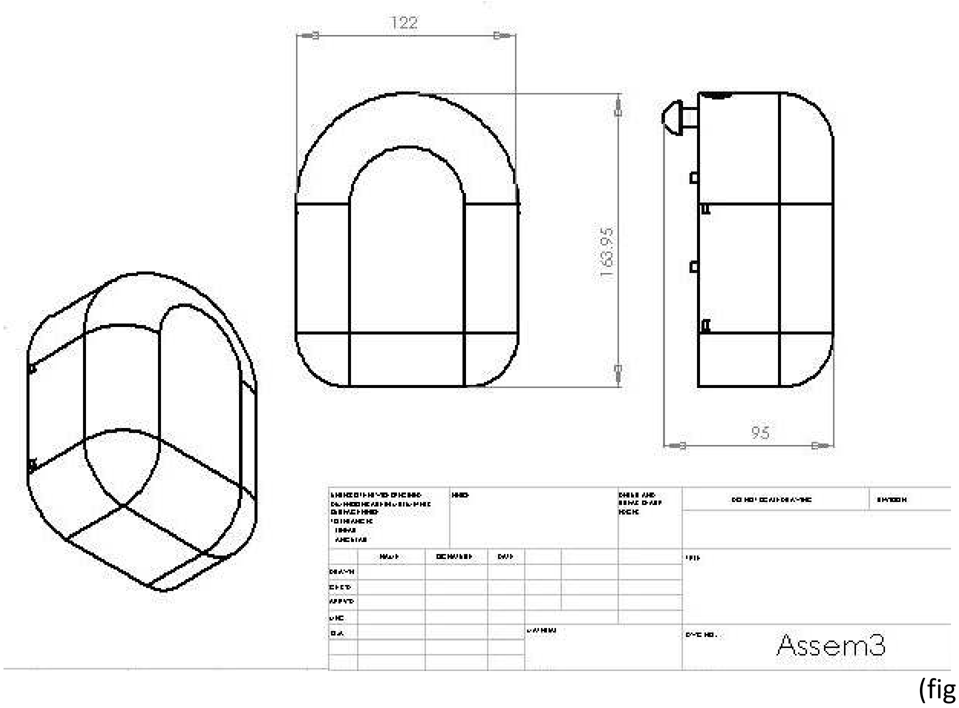
The boards are mounted to the chassis using M4 50mm bolts these bolts hold the circuits a safe distance from each other. There are 4 lugs in the chassis, and 4 holes in the body, to hold the two together.

Here is the Design of the Chassis:



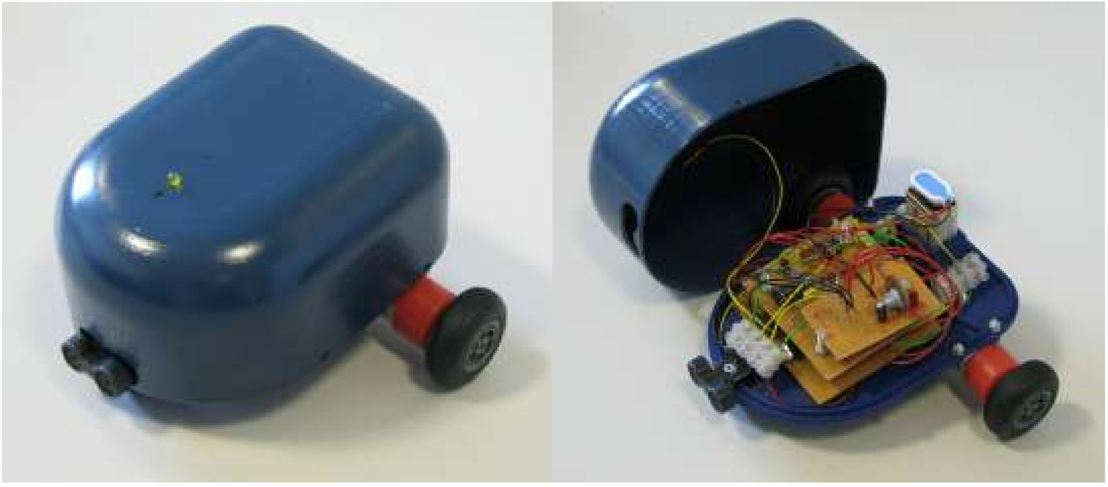
(fig 5.0.1)

Here is the Design of the body:



(fig 5.0.2)

5.1 Final Designs



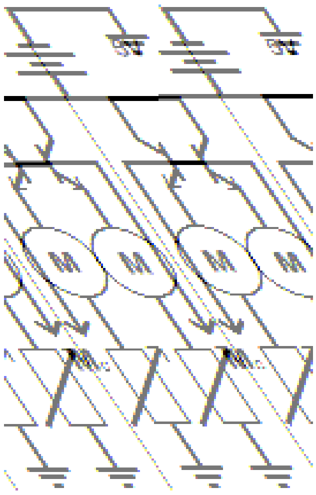
(fig 5.1.1)

From the above photos it is possible to see both the chassis and the body. As described, the body was printed on the Rapid Prototyping printer, the final product would be injection moulded, and thus is of very high quality. Luckily we were able to get the design printed as one of the first groups. Most groups were not allowed to print a body, just the chassis.

6 Speed Controller Research and Development

6.0 Initial Designs

Below is a development diagram for the motor circuit, it shows the basic circuit for each motor being controlled by its own variable resistor.



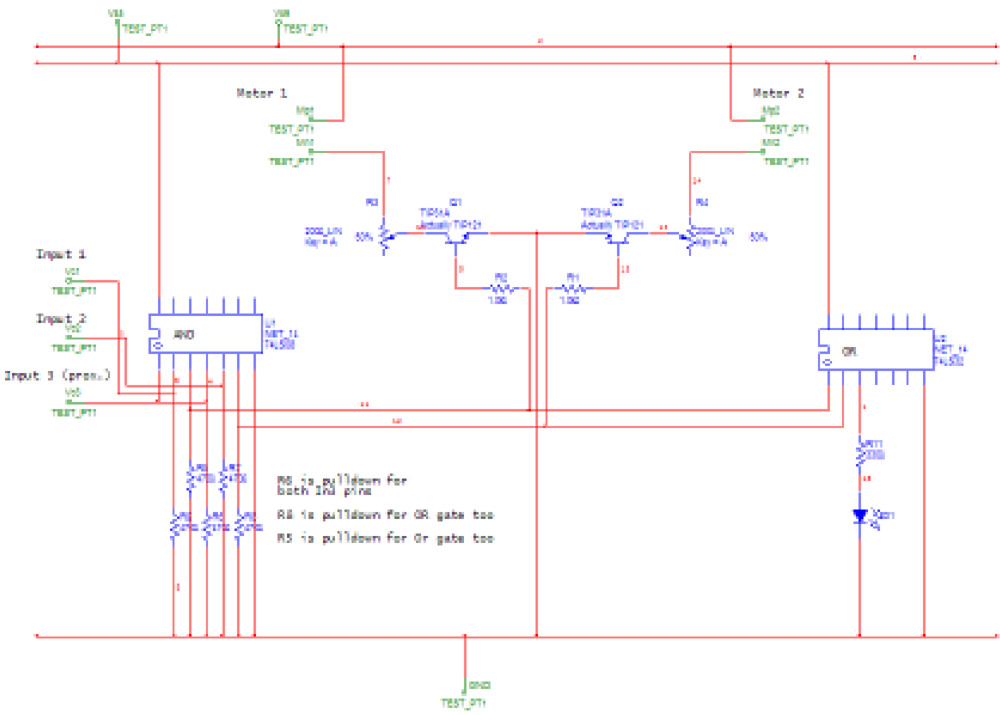
(fig 6.0.1)

6.1 Testing and Alterations

Using the simulation program Multisim, I was able to fully test this circuit to verify the design. It worked as predicted, and each of the Variable Resistors changed the speed of the motors as I had planned them to do.

The motors are controlled using TIP121 NPN transistors. We originally designed the circuit to use Bc337 transistors however these were damaged. We found that the transistors worked better with as 1kΩ resistor on the base.

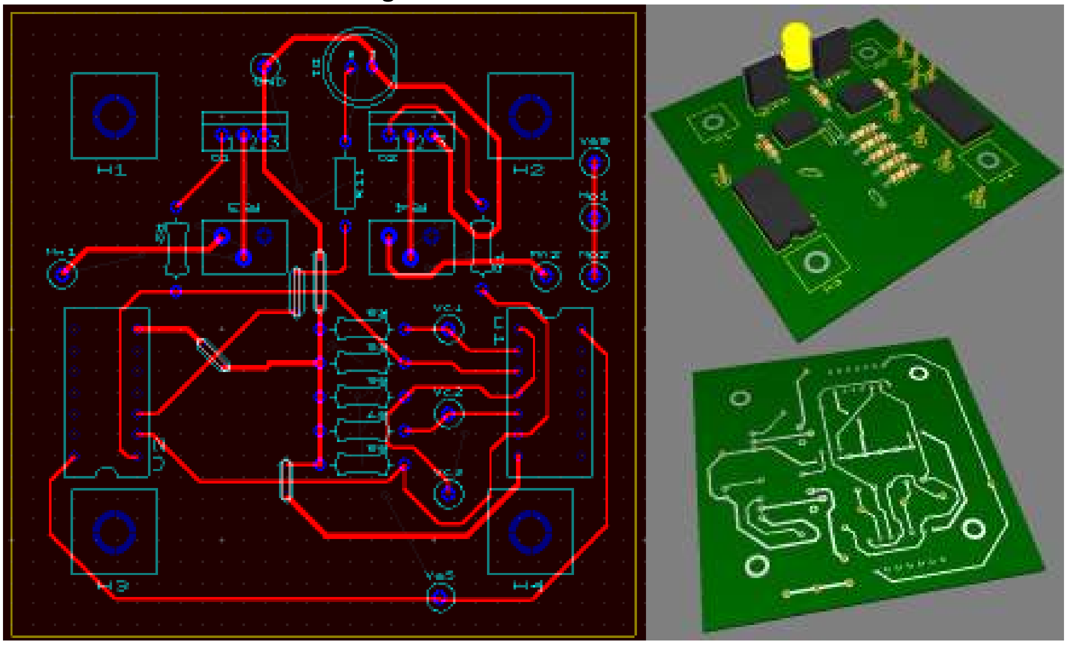
This is the new Design, ready to be exported to Ultiboard to design the PCB:



(fig 6.1.1)

6.2 Final Design

The board which we sued for this circuit was damaged during the cutting process, due to a blunt bit. However, once we cleaned the loose copper from in-between the tracks and it worked fine. Here is the final Design:



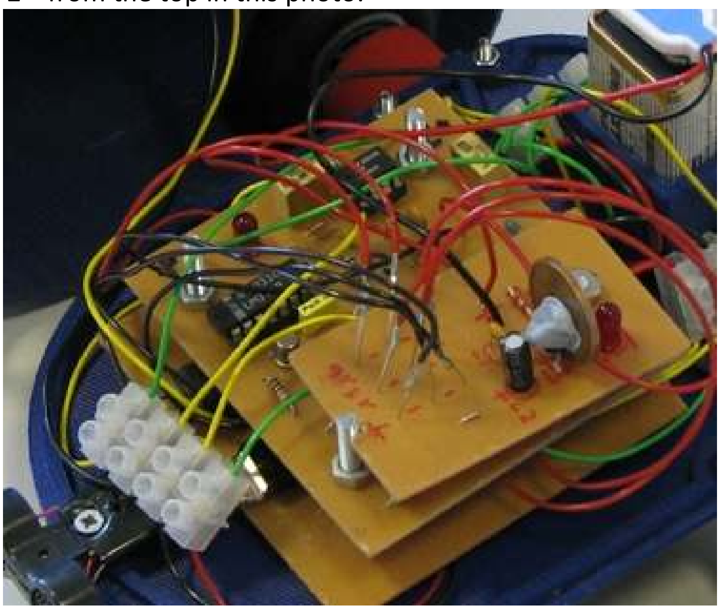
(fig 6.2.1)

This includes a yellow flashing LED, which flashes while the vehicle is in motion, either forward, or turning.

6.3 Implementation

The board worked as intended in the final prototype, but only once we had repaired the PCB, which became damaged again during installation.

The Board is the 2nd from the top in this photo:



(fig 6.3.1)

7 Object Sensor Research and Development

7.0 Initial Designs

Various research for suitable obstruction sensors, pointed towards two main types:

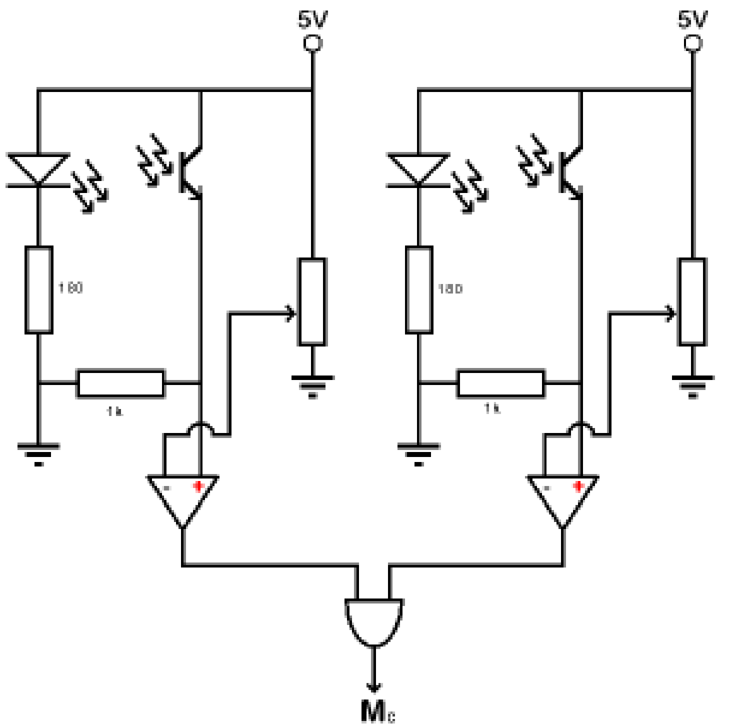
- Infra-red.
- Ultrasonic.

Either of the two kinds would be more than sufficient, although the ultrasonic sensors would require a more complex circuit to control them.

The Line Sensor project's sensors were dysfunctional, but showed promise as a proximity sensor, those sensors have been handed to the object sensor project at no fee. Here is the design for, and operation of the object sensor using IR Transceivers:

When the sensor picks up that there is an object ahead, its voltage should theoretically increase, making its voltage higher than that of the variable resistor branch, giving a value of 1 when passed through the comparator. When both comparators give out a value of 1, it is passed through the AND gate to give a final outcome of 1 to the Motor Control Circuit, thus making the robot stop.

When the object is moved, the voltage through the receiver will again be lower than that of the variable resistor, so the output of both comparators will be zero, giving a logic output of 0, so the robot can carry on moving. All this is illustrated in Figure 4 below:

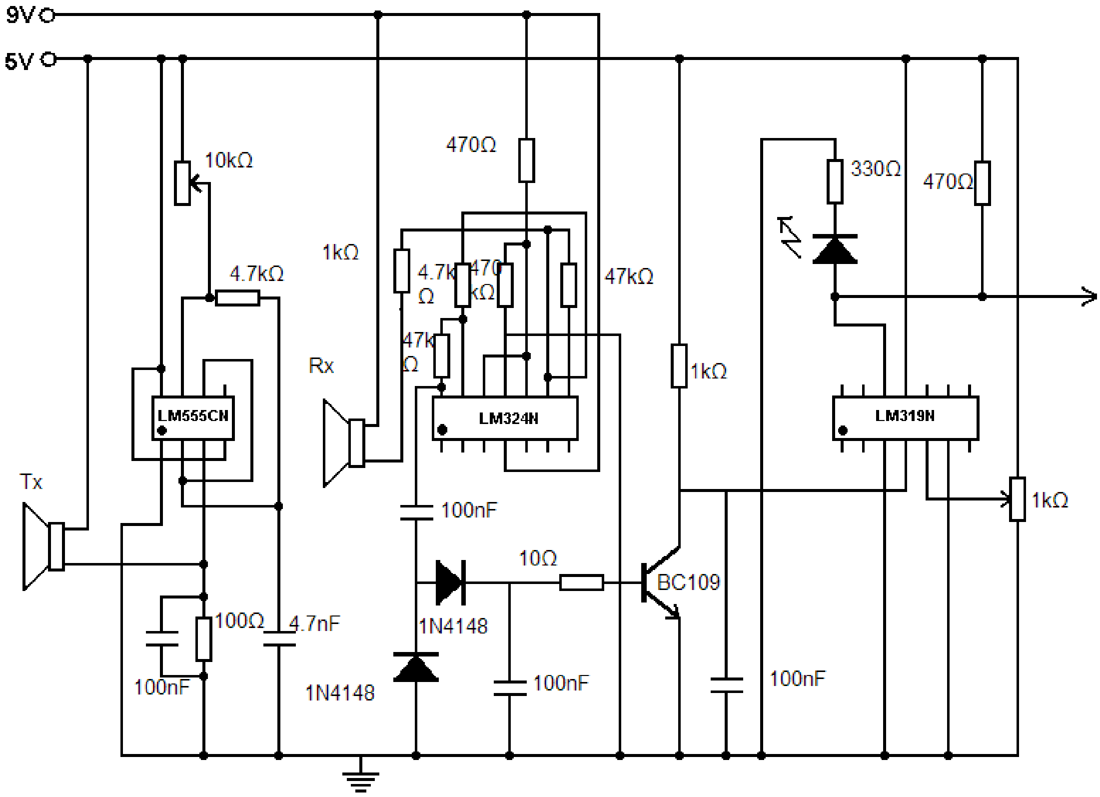


(fig 7.0.1)

7.1 Testing and Alterations

The IR transceivers showed no potential as a proximity sensor beyond 1cm, the robot is unlikely to stop in such a short space, for this reason, we are changing to ultrasonic sensors.

Below is the final detailed diagram for the Ultrasonic circuitry. The diagram shows the emitter and receiver circuits, the circuits are fed from both a 5V and a 9V power source.



(fig 7.1.1)

To emit a detectable signal, the emitter needs a signal of 40kHz to be generated from the circuit. This is made possible from using the 555 timer in an astable oscillator application.

The equation used to calculate the frequency of the circuit is as follows:

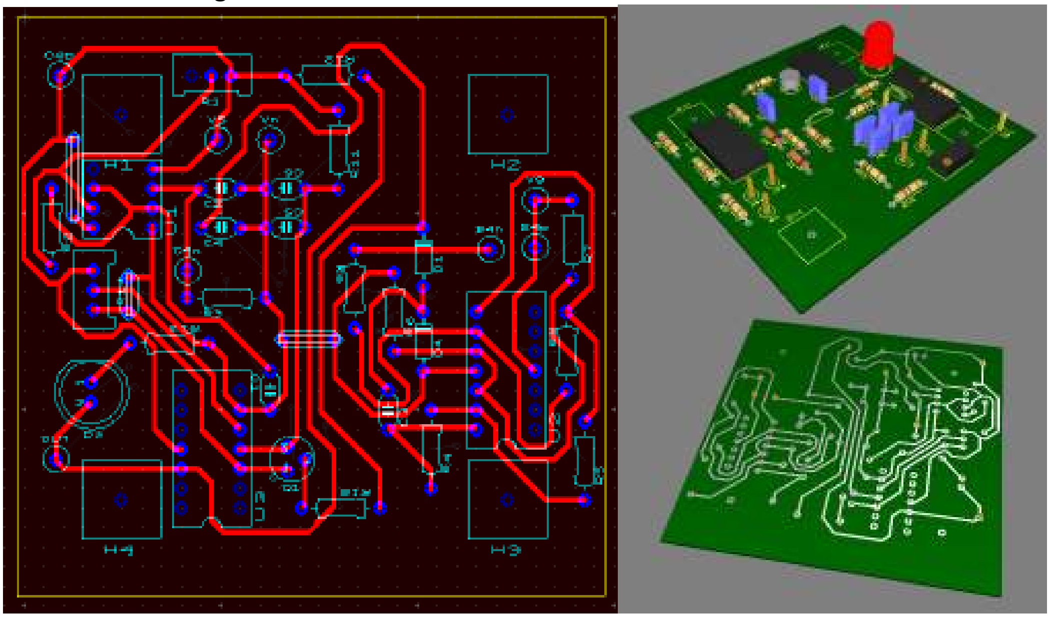
$$F = \frac{1.44}{((R_1 + 2 * R_2) * C)}$$

The receiver circuit is essentially in five parts.

- One part using a 9V supply and a LM324N Quad OPAMD Chip to amplify the received signal twice.
- The next a diode clamp to rectify one half of the AC signal into a DC level, using a 1N4148 diode.
- Then a diode pump to rectify the other half of the AC signal and produce a clean DC level, proportional to the amplitude of the AC signal, using a 1N4148 diode.
- Then a BC109 transistor to amplify the DC level to more than one volt so that the compotator can function properly. The DC level varies in the 0.0V to 0.7V region, perfect for turning on and off the transistor.
- The final part is a simple comparator circuit, which feeds the speed controller with logic 1 and 0, depending on if there is an object in the way or not.

7.2 Final Design

Here is the final design for the PCB:



(fig 7.2.1)

7.3 Implementation

Once transferred from breadboard to a PCB, the circuit stops working. It's possible that the resistance of the breadboard formed an essential part of the circuit, this circuit would need tuning to work in a final prototype, and unfortunately we ran out of time to do this.

8 Financial

8.0 Budget

The bidget for the development of the prototype was £25.00.

The following is a breakdown of all expendature:

Date	Item	Project	Unit Price	Quantity	Row Price
01 October 2007	12-24V Motor w/ 30:1 Gearbox	Chassis	£0.00	2	0.00
01 October 2007	Buzzer, 6V	All	£0.00	1	0.00
01 October 2007	Assorted Switch Gear	All	£0.00	1	0.00
22 October 2007	IR Reflective Sensor, RS:194-4018	Line Sensor	£1.93	2	3.86
22 October 2007	Quad AND gate, SN74HC08N	Line Sensor	£0.33	1	0.33
22 October 2007	Red LED, 10mA, RS:826-363	All	£0.16	5	0.80
22 October 2007	25k Linear Pot., RS:548-7705	Line Sensor	£0.20	5	1.00
22 October 2007	NPN Transistors, RS:131-1430	Speed Controller	£0.12	2	0.24
09 November 2007	Comparator, LM319N	Line Sensor	£0.94	1	0.94
09 November 2007	LDR, RS:596-141	Line Sensor	£0.44	2	0.88
09 November 2007	Green LED, 10mA, RS:826-379	Line Sensor	£0.08	5	0.40
03 December 2007	270R Resistor	Line Sensor	£0.05	2	0.10
03 December 2007	56k Resistor	Line Sensor	£0.05	2	0.10
03 December 2007	12k Resistor	Line Sensor	£0.05	1	0.05
03 December 2007	470R Resistor	Line Sensor	£0.05	2	0.10
03 December 2007	330R Resistor	Line Sensor	£0.05	2	0.10
28 January 2008	TIP121 Transistor	Speed Controller	£0.94	2	1.88
28 January 2008	200R Pot.	Speed Controller	£0.20	2	0.40
28 January 2008	Comparator, LM319N	Object Sensor	£0.94	1	0.94
28 January 2008	Assorted Resistors	Line Sensor	£0.05	9	0.45
28 January 2008	Line Sensor PCB	Line Sensor	£0.00	1	0.00
01 February 2008	5V Regulator	PSU	£0.51	1	0.51
01 February 2008	PP3 Clip	PSU	£0.142	5	0.71
01 February 2008	100nF cap.	PSU	£0.10	1	0.10
01 February 2008	33uF cap.	PSU	£0.10	1	0.10
11 February 2008	Assorted Resistors	PSU	£0.05	1	0.05
11 February 2008	Heatsink	PSU	£0.01	1	0.01
25 February 2008	Assorted Resistors	Object Sensor	£0.05	11	0.55
25 February 2008	Assorted Potentiometers	Object Sensor	£0.20	2	0.40
25 February 2008	100nF Cap.	Object Sensor	£0.10	4	0.40
25 February 2008	LM555CN timer	Object Sensor	£0.31	1	0.31
25 February 2008	LM324N OPAMP	Object Sensor	£0.35	3	1.05
25 February 2008	1N4148 Diode	Object Sensor	£0.18	2	0.36
25 February 2008	Yellow Flashing LED	Speed Controller	£0.35	3	1.05
25 February 2008	Assorted IC Sockets	All	£1.91	1	1.91
25 February 2008	Rx, Tx, Ultrasonic Tranceiver Set	Object Sensor	£0.00	1	0.00
25 February 2008	PSU PCB	PSU	£0.00	1	0.00
25 February 2008	Speed Controller PCB	Speed Controller	£0.00	1	0.00
25 February 2008	Object Sensor PCB	Object Sensor	£0.00	1	0.00
			Total Expendature:		£20.08

(table 8.0.1)

As is shown in the table, the project falls well within budget.

9 Finalities

9.0 Discussion

There were several difficulties throughoght the design we had to overcome:

- The Ultrasonic object sensor - Once transferred from breadboard to a PCB, the circuit stops working. It's possible that the resistance of the breadboard formed an essential part of the circuit, this circuit would need tuning to work in a final prototype, and unfortunately we ran out of time to do this.
- The IR sensors – The IR Transceivers failed as a line sensor, as there was no difference at all in their properties with a black or white surface. The reasons for this are unclear, two possibilities are:
    - In the frequency of IR used by the transceiver; the line looks no different to the background.
    - The line was either under-lit or "blown out" by the light source in the transceiver, the latter is more likely, as we verified that it was transmitting by viewing the component through a low quality digital camera, who's sensor is sensitive to the frequency of Infra Red used by the sensor.

  The IR sensors had shown promise as an object sensor capable of sensing up to 30cm, however this had reduced to 1cm by the time the time they were tested as an object sensor, it's possible that this is because the photodiode/phototransistor in them is altered in its 1st few hours exposed to light, or that it was an anomie of the test circuit/s used.
- Several of the PCB's were damaged while soldering or fitting to the chassis, bending them can break tracks, and overheating pads lifts them, these breakages were possible to fix, and would probably not occur in a mass produced PCB.
- The motor Transistors – The motor transistors were – in theory – capable of powering the motors, but – in reality – despite the use of suppression capacitors within the motors; the start up current was too high and one of the transistors blew. The TIP121 transistors are capable of handling much larger motors than ours.
- The use of potentiometers to control motor speed – although this works, the idea received external criticism because the resistors consume power. However they do also restrict current flow and the current draw of the restricted motor and resistor is less than that of the motor alone. The positioning of the potentiometers is poor, we had to remove the PSU and object sensor boards to tune the motors. A better design, used in the object sensor is to have the potentiometers adjustable from the side, and to place them on the edge of the board.
- Ultrasonic sensor isolation – The Ultrasonic Transceiver was free, provided by **** ******, and came with its own housing and sponge material to isolate the transmitter from the receiver, despite this a large component of the received signal was directly received from the transmitter through the housing. This was a large contributing factor to the object sensor circuits fragile nature, and ultimate failure.
- Wheel position – It was a mistake that the gearboxes extend beyond the chassis. However it turned out to be a better design as a wide track causes a slower angular velocity in the turns, and better line holding.
- The Body mounting – Although the mounting technique of four lugs works, it's very hard to fit, the body should be thinner.
- Wiring is not very neat, this problem was solved by using connector blocks to link circuits above and below the board. This means the circuits can be removed from the chassis with no soldering.

9.1 Conclusions
From the construction of this prototype, we can arrive at several conclusions for the final prototype:

The Line Sensor should follow the presented design using visible (green) light.

The Chassis should follow the presented design except for allowing for other modifications to the design. It should either be injection, or vacuum moulded in ABS.

The Speed controller should follow the presented electrical design using TIP121 transistors, and have the PCB redesigned to place potentiometers at the front, left, and right edges, using side adjustable potentiometers.

The Object Sensor should use more a more separated set of transmitter and receiver. It's electrical design should be tuned so as to be suitable on a PCB.

The PSU should follow the presented design, and should use a heatsink on the voltage regulator as shown to prolong component life.

All circuits should be produced on PCB, unless further work on the Object Sensor shows that a PCB is unsuitable.

The Body should be vacuum formed in polycarbonate to the design presented, or made by another technique which produces a thin plastic piece.

9.2 References

1. LDR Datasheet, see appendix.
2. LED Datasheet, see appendix.
3. Voltage Regulator Datasheet, see appendix.

9.3 Appendix

1. LDR Datasheet.
2. LED Datasheet.
3. Voltage Regulator Datasheet.