Autonomous Line Follower

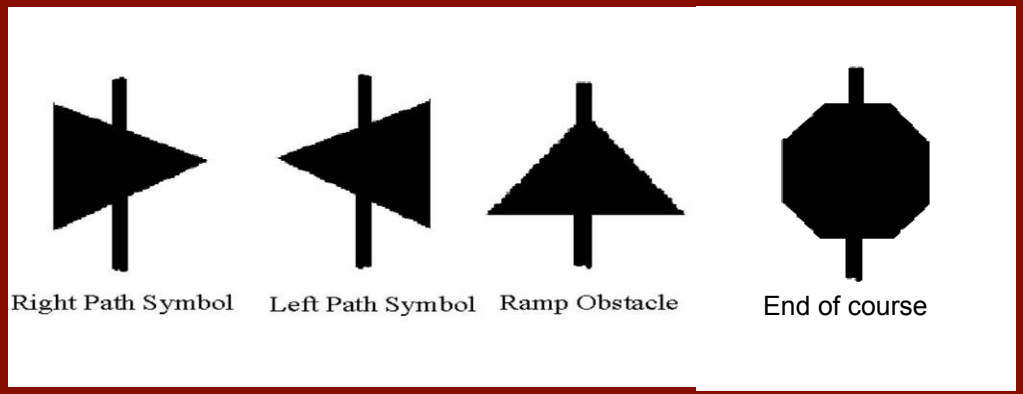
Project Group 25:
Kyle Romero
Matthew Phelps
Christopher Walls
Bilal Bissat
Advisor: Dr. Bredeson

Table of Contents

I. Project Overview

Project Objective

- Design and build a mobile device that will follow a path in the shortest amount of time, while recognizing symbols along the way.
- Tape: ½” Chrome Reflective Tape
- Curvature Radius= Min. 2 feet
- Path Marked By Symbols



Demo Day Information

- Demo Day held outside in bright sunlight
- Track created on top of red brick surface in E.E. courtyard
- Course would have taken approximately 1.5 minutes to complete without problems.
- Random sensor misfirings caused by ambient light and cracks in the brick. A sensor skirt was required.

II. Physical Design

Custom Build

- The department supplied vehicle was rejected on the basis of size and “clunkiness”.
- A smaller RC car modeled after an Aston Martin was used.
- This vehicle was stripped of: Rear Motor, Front steering box, and suspension.

Custom Build cont.

- New chassis made of Plexiglass
- Roll cage made from Erector Set
- Board 10v3 provided by Department
- Originally, a Futaba S3003 was used, replaced by: Hitec HS-322HD
- Sensor Array built using 7 QRB1114's, mounted underneath @ mid-car. More on this later in presentation.

Hitec HS-322HD

Motor Type: 3 Pole Ferrite

Size: 1.57"x0.79"x
1.44" (40x20x36.5mm

Weight: 1.51oz (43g)

Control System: +Pulse Width Control
1500usec Neutral

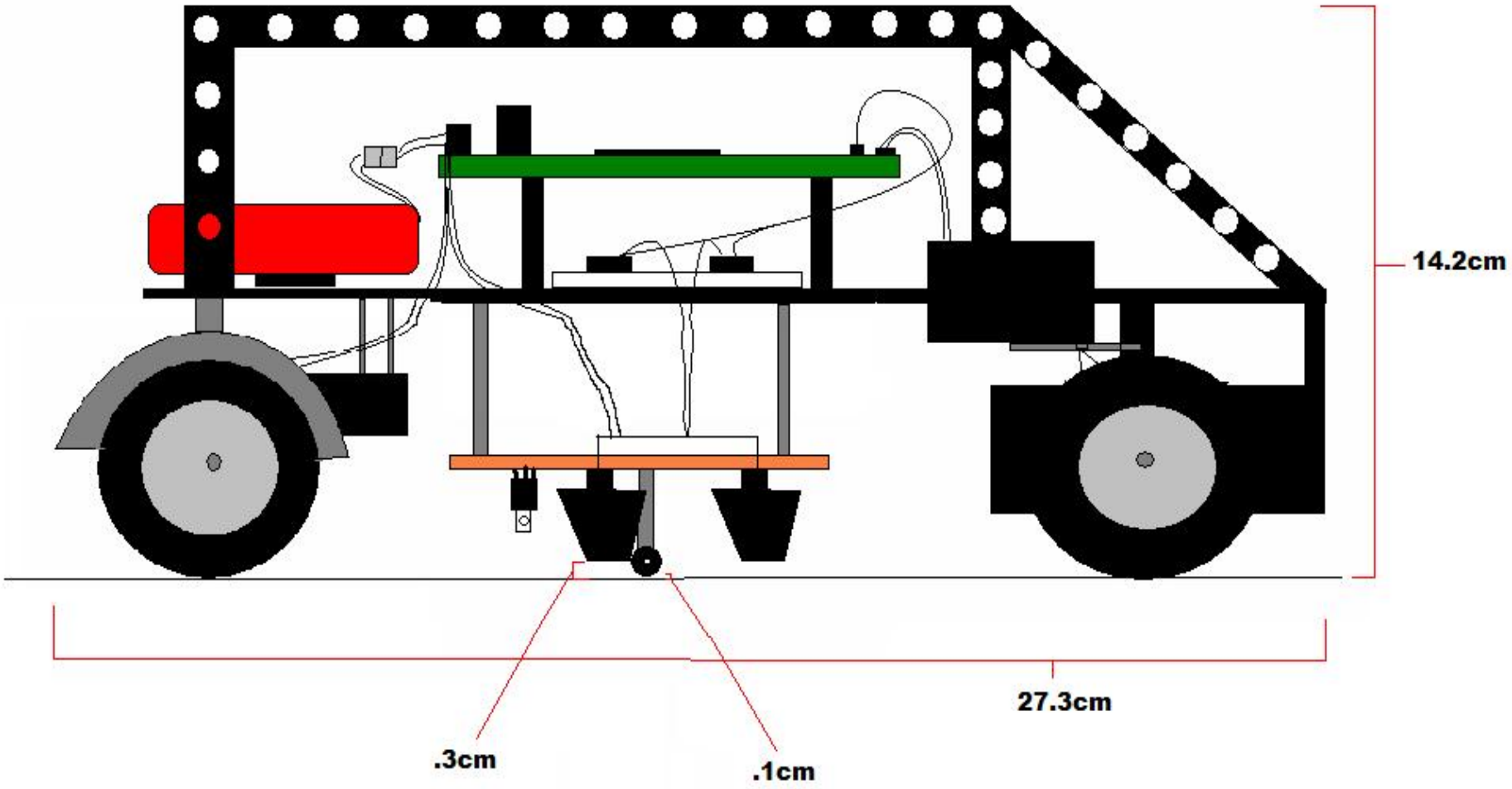
Operating Voltage: 4.8-6.0 Volts

Current Drain (4.8V): 7.4mA/idle and
160mA no load operating

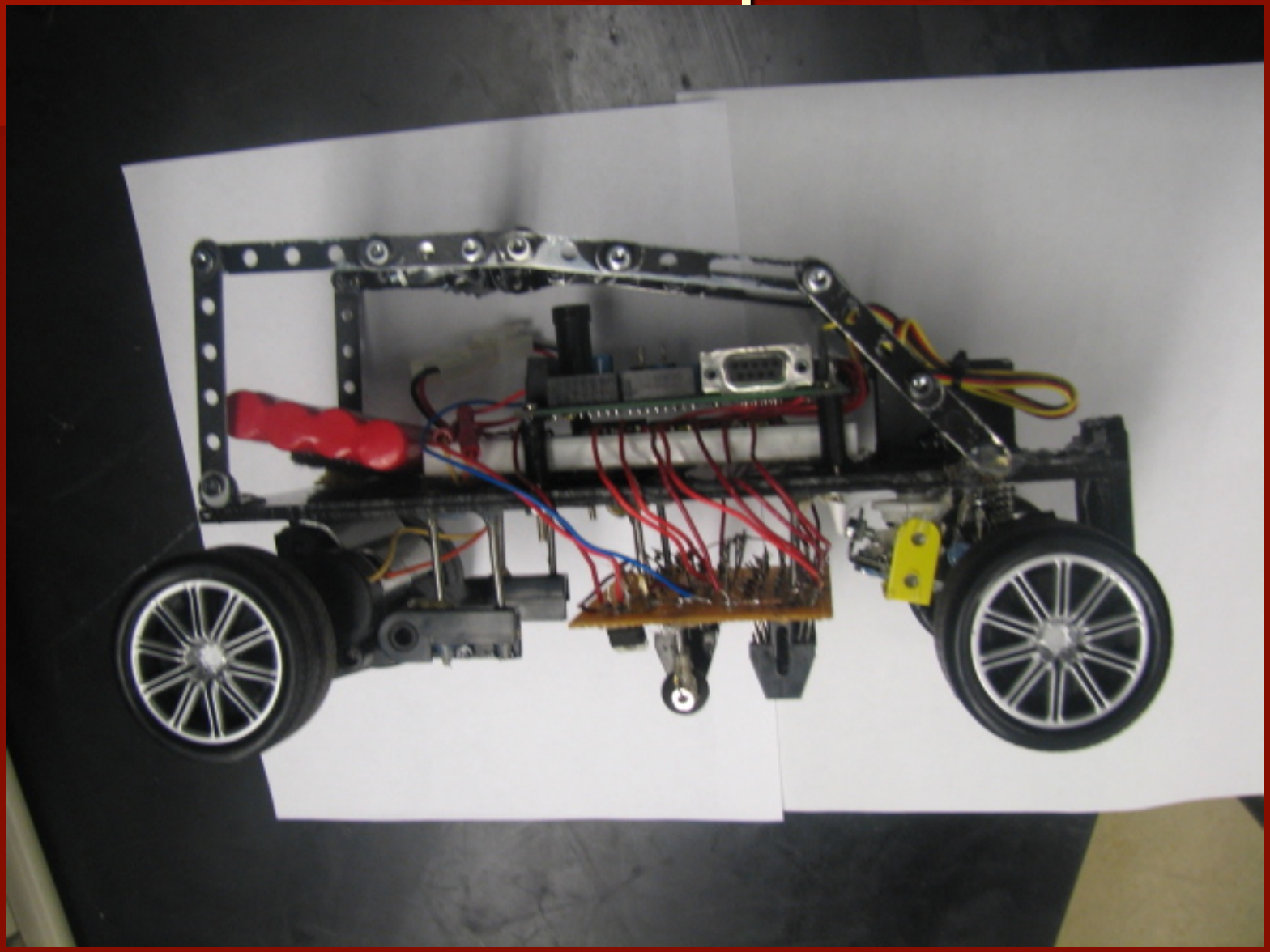
Steering Overview

- Initially, Electrical Wire was used. This turned out to be too stretchable.
- This was replaced with Airplane steering wire. This snapped repeatedly due to bending.
- Finally, an Erector set was used to control steering with no dead zones.

Final Car Design



Picture of Completed Car



Final Car Physical Specs:

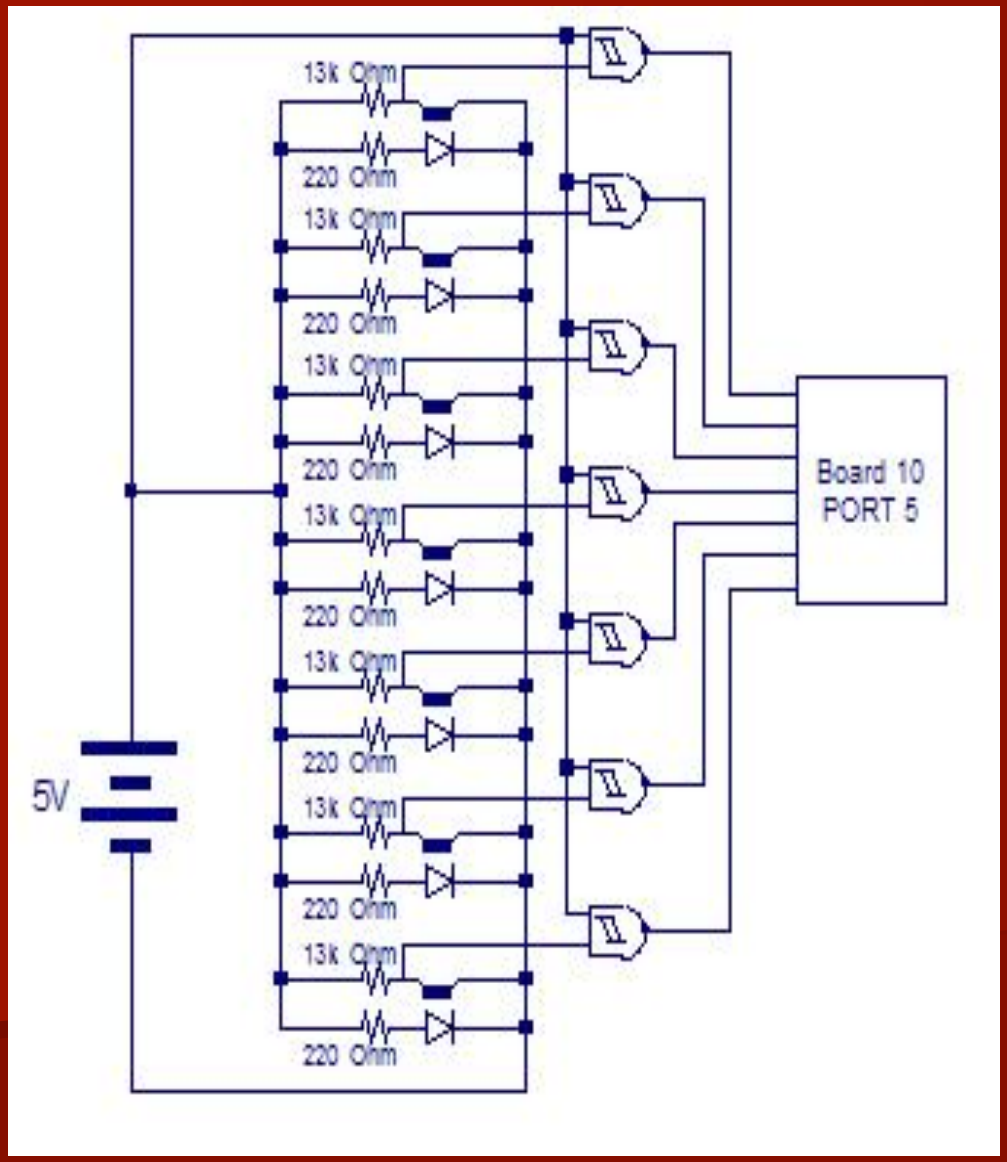
- Battery: 9.6V RC Car Battery w/ Polarized Connector
- Dimensions: (27.3cm) x (15.4cm) x (14.2cm)
- Wheel Diameter: 5.7cm
- Turning Radius: 1.7’
- Weight: .7kg
- Motor Speed: 1100’ / min @ 100%

III. Sensor Array

Sensor Readings

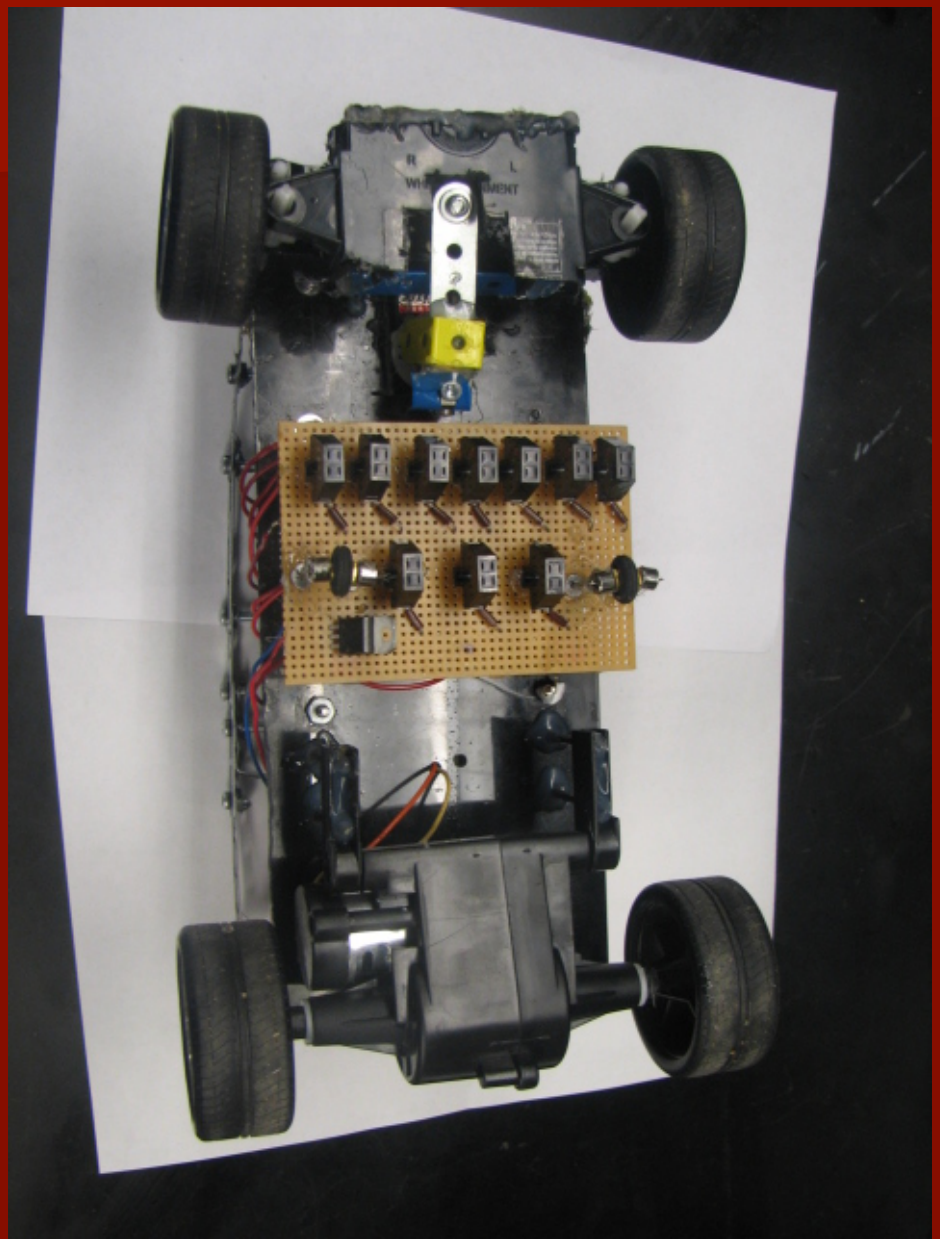
	Red Brick	Pulse Power Lab Hallway	Lankford Lab Area	1st Floor Lab	Basement Lab
Electrical Tape	4.5V	4V	4V	4.4V	3.7V
Duct Tape	213mV	.6V	1.1V	2.3V	.6V
Reflective Tape (Chrome)	124mV	135mV	140mV	155mV	138mV
Masking Tape	190mV	.7V	1.4V	250mV	250mV
Light Colored Duct Tape	245mV	1.4V	3.2V	2.9V	.6V
Surface Itself	3.08V	2.5V	3.8V	3.9V	2.4V

Sensor Array Schematic

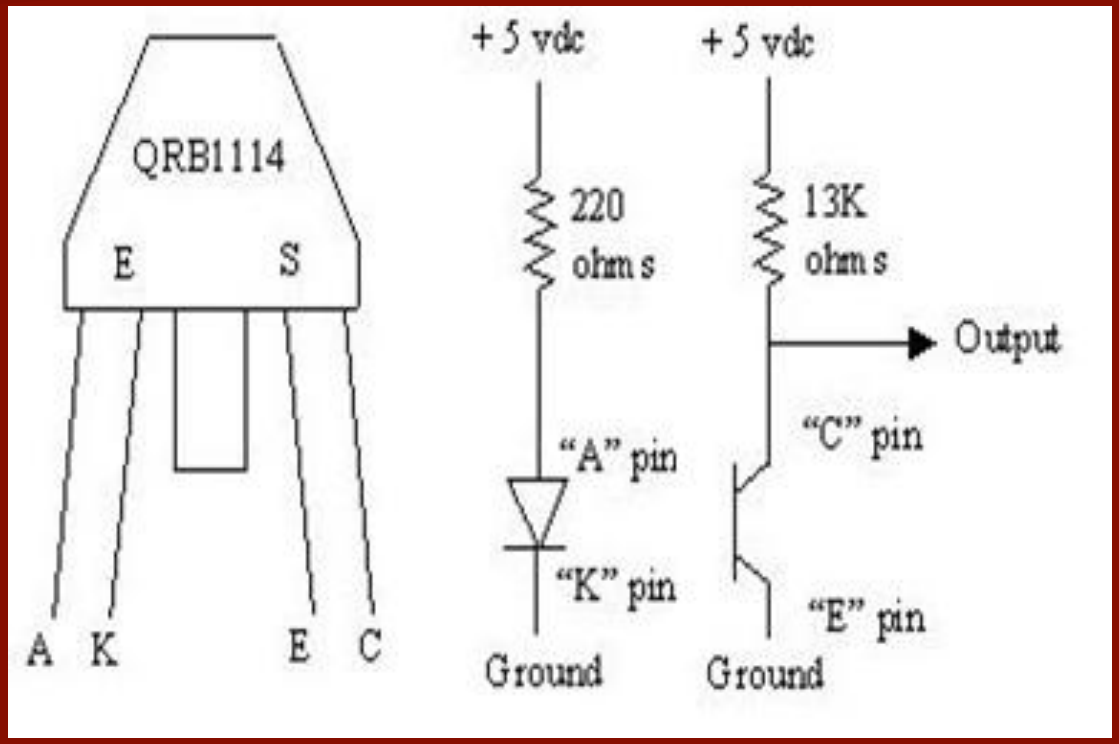


- (2) 4x Schmitt Trigger ICs
- (7) QRB1114 IR Emitter/ Collector Sensors
- Inverts V_{out} of Sensor
- V_{out} of Schmitt Trigger directed to input of Port 5 on Board 10v3

Sensor Array Picture



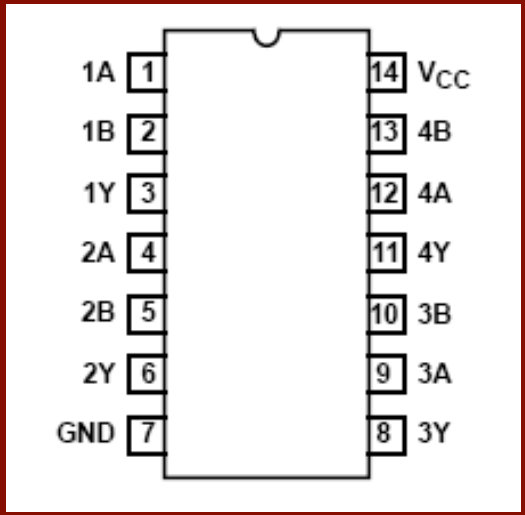
Optical Sensor (QRB1114)

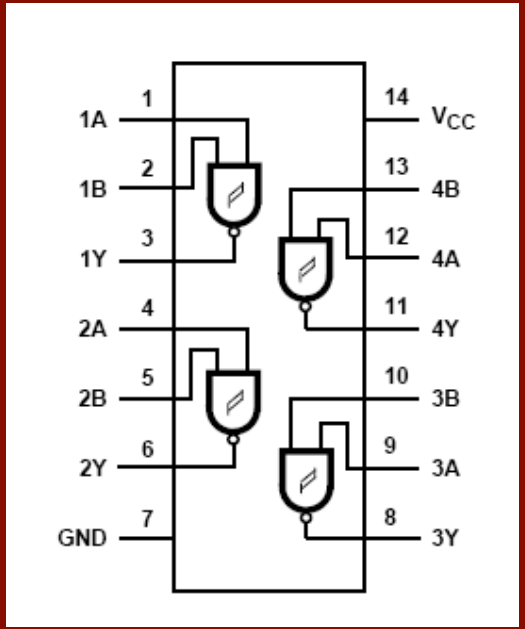


- 13kΩ between NPN phototransistor and V_{in}
- 220Ω Between IR Emitter photodiode and V_{in}
- V_{out} Taken Between 13kΩ Resistor and Collector

Schmitt Triggers

TI CD74HCT132E: 4-Input NAND Gate w/ Schmitt Trigger Inverter





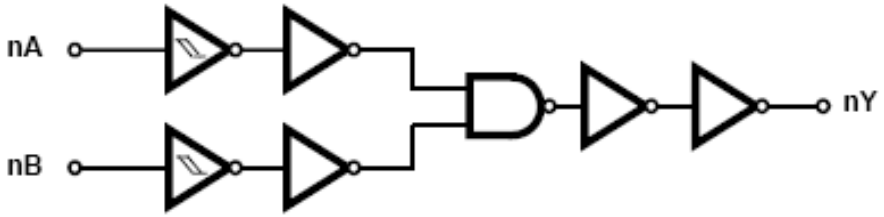
2.4V Hysteresis Level for the Schmitt Triggers

4.5V to 5.5V Operation

Schmitt Trigger Continued

Set High (5.0V)

Logic Symbol



TRUTH TABLE

INPUTS		OUTPUT
nA	nB	nY
L	L	H
L	H	H
H	L	H
H	H	L

NOTE: H = High Voltage Level, L = Low Voltage Level

Sensor Array Design Changes

- Rear row of sensors originally intended for symbol recognition not required.
- Originally, Analog input was intended. Schmitt triggers later added to increase reliability.
- Sensor Height went through several modifications. Final Height: .3cm

IV. Line Following

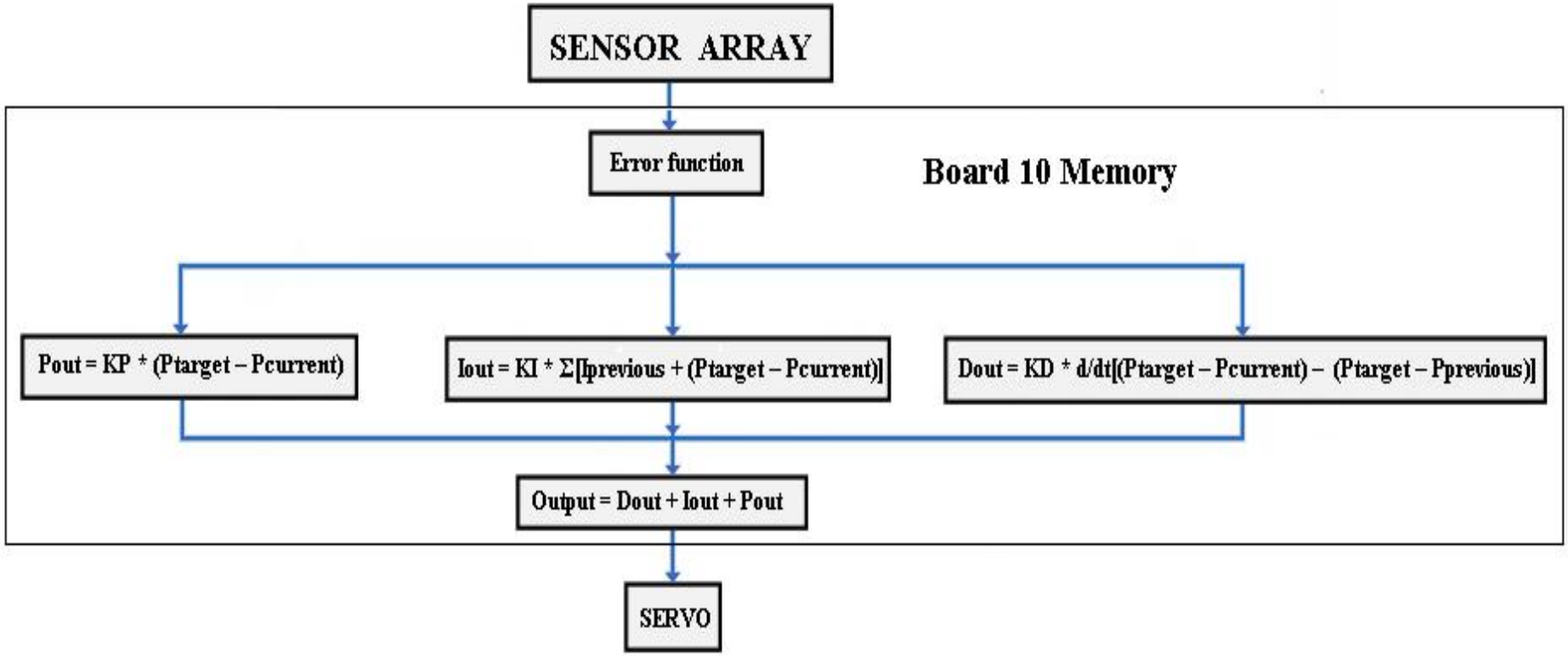
Line Following Ideas

- Originally, the group was divided between a Logic Based line following implementation and P.I.D.
- P.I.D. won due to it's ease of coding and reliability.

P.I.D. : How does it work?

- P: Proportional
  - This part of the algorithm controls steering power as a percentage of max duty cycle
- D: Derivative
  - This part of the algorithm dampens the steering correction, preventing over-correction and oscillations.
- I: Integral
  - This part of the algorithm forces the controller to approach the center point quicker.

P.I.D. Flowchart



P.I.D. Code Overview

```
//==========Algorithm=========================================//

 //----------P.----------------//
 p_out = error * KP;         //Multiply by KP

 //----------I.----------------//
 i_error = error;  //Set Integral Error to Sensor Error
 int_err = i_error + int_err; //Compute Integral Error
 i_out = int_err * KI;       //Multiply by KI
 if(i_out>4)int_err=0;   //Reset int_err when it gets large.

 //----------D.----------------//
 delta_err = d_error - error; //Compute Derivative Error
 d_out = delta_err * KD;     //Multiply by KD

 output = p_out + d_out + i_out; //Combine Output percentages

//========End Algorithm=======================================//

 d_error = error;    //Reset d_error for next sample

 return output;      //Output Percentage
```

Currently:

KP = 17

KD = 7

KI = .0001

V. Symbol Recognition

Symbol Rec. Iterations

- 1st Method: Averaging
  - Averages of P5IN over symbol
  - Almost impossible to cover all cases
- 2nd Method: Three Samples
  - Compare Beginning, Middle, End
  - Need to hit symbol head-on every time
- 3rd Method: Individual Sensor Comparison
  - Chosen Method
  - Compare Left vs. Right side of sensor array.

Modified Din(int pin)

- Included from SAL Compilation
- Send Din the Pin # you want to check
- It then bitwise &'s the current P5IN with a threshold value.
  - EX: To check Pin 1
    - Temp = 0x02;

      Temp &= P5IN;

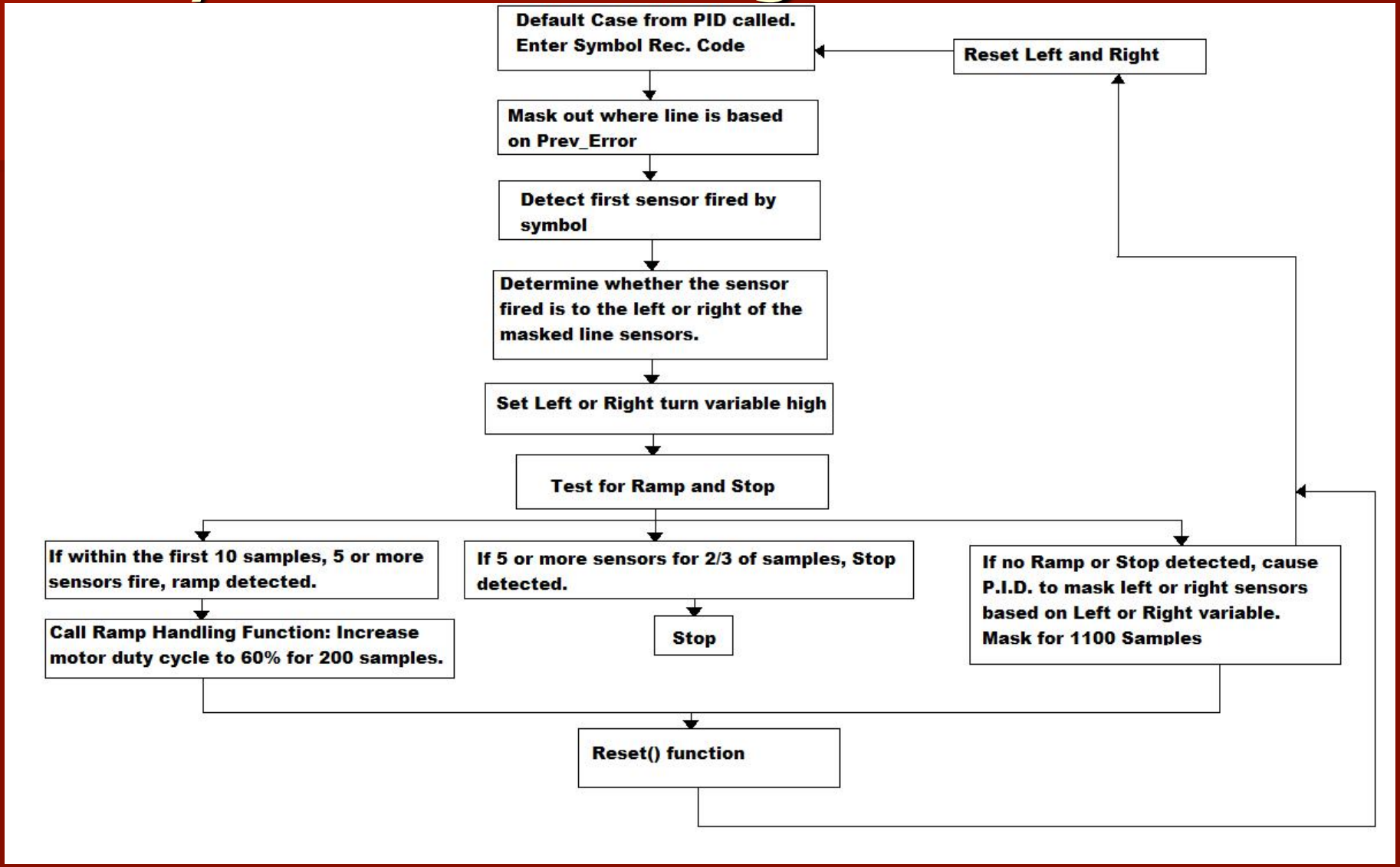
      If(Temp ==0x02) return 1;

      else return 0;
- Similar Conditions exist for all pins with appropriate hex values

Use of Modified Din()

- For every sample, call Din for each Pin
- Store Each Pin State in an array
  - Basically mimicking P5IN, except each sensor is an index of the array.
- Increment values based on Pin states
  - Pins 1-3 for Left Sensors (val1)
  - Pins 5-7 for Right Sensors (val2)
  - Pin 4 for Center Sensors (val3)
  - Number of times 5 or more sensors fire (val4)

Symbol Handling Flow Chart



Symbol Handling

- If Left Symbol Detected
  - Mask Right 4 Sensors to 0
  - Causes car to ignore Right path
- If Right Symbol Detected
  - Mask Left 4 Sensors to 0
  - Causes car to ignore Left path
- If Ramp Symbol Detected
  - Up Power for set time
- If Stop Symbol Detected
  - Stop

VI. Problems, Solutions, and Possible Improvements

Problems Encountered

- Servo connections kept breaking
- Chris Walls played with the Potentiometer on the Futaba s3003 servo. Go Chris!
- Sensor array soldering was problematic
- 4 x Schmitt Trigger IC's fried
- Symbol Rec. Coding difficult
- Outside Ambient Light interfered with Sensors
- Repeated P.I.D. tuning required due to frequent servo changes and repairs.

Problem Solutions

- Finally decided on Erector Set to prevent dead zones and breakage
- We fired Chris…No actually we just replaced the servo
- Sensor array was fine after repeated resoldering
- Breadboard used for Schmitt Triggers to prevent heat damage
- Symbol Rec. Code took many trials and re-codings
- Ambient light cut down with a sensor skirt
- P.I.D. worked better after steering solidified

Possible Improvements

- More sensors in one row to improve P.I.D. sensitivity.
- If back sensors are used, space them far enough apart to cover entire symbol.
- Design sensor array to work in bright light conditions without impromptu additions
- Pulse sensor array instead of continous read to eliminate many errors – John Carroll
- Increase structural soundness. For example, ensure screws and glue will not come off.

VII. Budget and Gantt Chart

Budget, EE3331-002 P25

Payroll

Name	Hrs.	Payrate	Earned
Kyle Romero	135	$10/hr	$1,350.00
Chris Walls	115	$10/hr	$1,150.00
Bilal Bissat	115	$10/hr	$1,150.00
Matthew Phelps	135	$10/hr	$1,350.00

Payroll	Overhead	Total
$5,000.00	$3,750.00	$8,750.00

Part Expenditures

Name	Rate	Cost
RC Car		$27.99
Plexiglass		$2.00
Gorilla Glue		$5.89
Board 10		$150.00
Optical Sensors	$0.88	$8.75
Lab Bench Keys	$0.03	$1.96
9v Battery		$2.99
Futaba		$10.00
Schmitt Triggers	$0.20	$1.00

Total Expendi
$210.58

Grand Total

$8,960.58

Budget Proposed, EE3331-002 P25

Payroll

Name	Hrs.	Payrate	Earned
Kyle Romero	100	$10/hr	$1,000.00
Chris Walls	100	$10/hr	$1,000.00
Bilal Bissat	100	$10/hr	$1,000.00
Matthew Phelps	100	$10/hr	$1,000.00

Payroll	Overhead	Total
$4,000.00	$3,000.00	$7,000.00

Part Expenditures

Name	Rate	Cost
RC Car		$27.99
Plexiglass		$2.00
Gorilla Glue		$5.89
Board 10		$150.00
Optical Sensors	$0.88	$8.75
Lab Bench Keys	$0.03	$1.96
9v Battery		$2.99
Futaba		$10.00
Schmitt Triggers	$0.20	$1.00

Total Expenditures
$210.58

Grand Total

$7,210.58

Gantt Chart – Part 1

ID	Task Name	Duration	Start	Finish	Resource Names
1	EE3331-002 Project Lab 01 : Project 2	**65 days**	**Tue 2/13/07**	**Tue 5/1/07**	
2	**Week 1**	**5 days**	**Tue 2/13/07**	**Mon 2/19/07**	
3	Acquisition of Parts - RC Car	5 days	Tue 2/13/07	Mon 2/19/07	Kyle Romerc
4	Preliminary Information Gathering	1 day	Fri 2/16/07	Fri 2/16/07	Chris Walls
5	Advisor Consultation	1 day	Mon 2/19/07	Mon 2/19/07	Bilal Bissat
6	**Week 2**	**6 days**	**Wed 2/21/07**	**Mon 2/26/07**	
7	**Continue Information Gathering**	**6 days**	**Wed 2/21/07**	**Mon 2/26/07**	
8	Algorithm Ideas	6 days	Wed 2/21/07	Mon 2/26/07	Kyle Romerc
9	Hardware Selection / Ideas	6 days	Wed 2/21/07	Mon 2/26/07	Chris Walls
10	Board 10 - Acquisition / Modification	1 day	Thu 2/22/07	Thu 2/22/07	Matt Phelps
11	Preliminary Budget Design	1 day	Sun 2/25/07	Sun 2/25/07	
12	RC Parts Car - Purchase / Stripped	1 day	Sat 2/24/07	Sat 2/24/07	
13	**Week 3**	**5 days**	**Wed 2/28/07**	**Sun 3/4/07**	
14	**Initial Construction**	**5 days**	**Wed 2/28/07**	**Sun 3/4/07**	
15	Chassis Construction	2 days	Wed 2/28/07	Thu 3/1/07	Kyle Romerc
16	Rear Axle setup	1 day	Fri 3/2/07	Fri 3/2/07	Chris Walls
17	Front Axle Assembly	1 day	Sat 3/3/07	Sat 3/3/07	Matt Phelps
18	Component Connection	1 day	Sun 3/4/07	Sun 3/4/07	Bilal Bissat
19	**Week 4**	**1 day**	**Mon 2/19/07**	**Mon 2/19/07**	
20	**Hardware Testing**	**1 day**	**Mon 2/19/07**	**Mon 2/19/07**	
21	Microcontroller	1 day	Mon 2/19/07	Mon 2/19/07	Matt Phelps
22	Motor / Servo Control	1 day	Mon 2/19/07	Mon 2/19/07	Kyle Romerc

Gantt Chart – Part 2

ID	Task Name	Duration	Start	Finish	Resource Names
23	**Preliminary SAL Programming**	**1 day**	**Mon 2/19/07**	**Mon 2/19/07**	
24	Test Program to test robot functions	1 day	Mon 2/19/07	Mon 2/19/07	Chris Walls
25	**Week 5**	**7 days**	**Sat 3/10/07**	**Sun 3/18/07**	
26	Spring Break	7 days	Sat 3/10/07	Sun 3/18/07	Matt Phelps
27	**Week 6**	**4 days**	**Wed 3/21/07**	**Sat 3/24/07**	
28	Construct Sensor Array	1 day	Wed 3/21/07	Wed 3/21/07	Chris Walls
29	**Programming Phase**	**3 days**	**Thu 3/22/07**	**Sat 3/24/07**	
30	Confirm all functions working correctly	1 day	Thu 3/22/07	Thu 3/22/07	Kyle Romero
31	Preliminary Line follower Algorithm design	1 day	Sat 3/24/07	Sat 3/24/07	Bilal Bissat
32	**Week 7**	**4 days**	**Wed 3/28/07**	**Mon 4/2/07**	
33	Test operation of Sensor Array	2 days	Wed 3/28/07	Thu 3/29/07	Chris Walls
34	Continue design of Line follower algorithm	3 days	Thu 3/29/07	Mon 4/2/07	Matt Phelps
35	**Week 8**	**5 days**	**Tue 4/3/07**	**Mon 4/9/07**	
36	**Final Assembly of Line Follower**	**1 day**	**Tue 4/3/07**	**Tue 4/3/07**	
37	Sensor Array	1 day	Tue 4/3/07	Tue 4/3/07	Kyle Romero
38	Board 10	1 day	Tue 4/3/07	Tue 4/3/07	Chris Walls
39	Chassis	1 day	Tue 4/3/07	Tue 4/3/07	Bilal Bissat
40	Servo	1 day	Tue 4/3/07	Tue 4/3/07	Matt Phelps
41	Preliminary Written Report	2 days	Fri 4/6/07	Mon 4/9/07	Individiual Work
42	**Week 9**	**8 days**	**Wed 4/11/07**	**Fri 4/20/07**	
43	**Programming**	**2 days**	**Wed 4/11/07**	**Thu 4/12/07**	
44	Symbol Recognition	1 day	Wed 4/11/07	Wed 4/11/07	Matthew Phelps

Gantt Chart – Part 3

ID	Task Name	Duration	Start	Finish	Resource Names
45	P.I.D.	1 day	Thu 4/12/07	Thu 4/12/07	Bilal Bissat
46	Test Follower on Course	2 days	Fri 4/13/07	Mon 4/16/07	Kyle Romero
47	**Hardware/Software Revision Phase**	**1 day**	**Fri 4/20/07**	**Fri 4/20/07**	
48	Hardware Revision	1 day	Fri 4/20/07	Fri 4/20/07	Chris Walls
49	Software Revision	1 day	Fri 4/20/07	Fri 4/20/07	Matthew Phelps
50	**Week 10**	**5 days**	**Wed 4/25/07**	**Mon 4/30/07**	
51	**Finalize Programming**	**2 days**	**Wed 4/25/07**	**Thu 4/26/07**	
52	Symbol Recogntion	1 day	Wed 4/25/07	Wed 4/25/07	Phelps
53	Finalize P.I.D.	1 day	Thu 4/26/07	Thu 4/26/07	Bissat
54	**Finalize Hardware**	**2 days**	**Thu 4/26/07**	**Fri 4/27/07**	
55	Wiring Cleanup	1 day	Thu 4/26/07	Thu 4/26/07	Walls
56	Solidify Design	1 day	Fri 4/27/07	Fri 4/27/07	Romero
57	Course Run	1 day	Sat 4/28/07	Sat 4/28/07	
58	Final Report	1 day	Mon 4/30/07	Mon 4/30/07	Individual Work
59	Final Presentation Preperation	1 day	Mon 4/30/07	Mon 4/30/07	Individual Work
60	**Week 11**	**1 day**	**Tue 5/1/07**	**Tue 5/1/07**	
61	Final Report	1 day	Tue 5/1/07	Tue 5/1/07	Individual Work
62	Final Presentation	1 day	Tue 5/1/07	Tue 5/1/07	

References

- ‘Alldatasheet.com’, CD74HCT132E NAND Gates w/ Schmitt Trigger Inverter, http://pdf1.alldatasheet.com/datasheet-pdf/view/27006/TI/CD74HCT132.html

- ‘ABRobotics’, Snuffy Line Follower Sensors: QRB1114, http://abrobotics.tripod.com/Snuffy/line_sensor.htm

- ‘Servocity’, Hitec HS-322HD Servo, http://www.servocity.com/html/hs-322hd_standard_deluxe.html

- ‘Wikipedia’, P.I.D., http://en.wikipedia.org/wiki/PID_controller

Questions?