Queensland University of Technology

EGB220 Mechatronics Design I

Autonomous Line Following Robot

Electronic Sub-System Design

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Abstract

This paper describes an autonomous line following robot, designed to follow a white line against a black background. The line follower has been designed to meet specific requirements based on the final demo track which are explicitly detailed within the project brief. The main components involved in the design of the robot were mechanical design, electronic design and the programming of the device to achieve the desired task efficiently. The sensory control of the robot is provided via infrared light emitting diodes (IR-LEDS) coupled with phototransistors. The basic concept behind the line follower is to detect whether it is on or off the white line based on the amount of infrared light reflected off the surface. PD control was implemented to improve the stability and speed of the line follower, ensuring that the time restraints for the demo were met. Specific engineering design was applied when generating the robot which ensured that all the elements integrated seamlessly when put together, whilst ensuring that the robot could move about efficiently with optimal control. Overall the robot was able to achieve the task at hand however due to time constraints, failed to meet the requirements within the speed zones. The Scrum Project Management technique was an instrumental method utilized by the team, enabling the project to be completed adequately within the given time frame. This paper briefly outlines the control system of the robot and primarily focuses on the electronics sub-system, providing an in depth discussion on the design and operation of each component.

Contents

1 Introduction

A line following robot is an electronic system which is designed to follow a line or path already predetermined by the user. This line is usually highly contrasted against the background it is drawn upon. A white line against a black background is a common setup used. This provides the robot with adequate resolution to create a discrepancy between the two. The robot would detect these markings utilizing its on board sensors. Judgment based on the input from the sensors would then be made accordingly in order for the device to successfully follow the line. Line followers are used extensively in manufacturing plants and are a simple and efficient method of delivery.

1.1 Project Overview

The primary task at hand that the team aimed to achieve was to design and create a robot that could follow lines, straights and detect corners whilst moving smoothly and consistently. The device had to complete an entire track with a specified minimum speed of 250mm/s and had to start and stop between the stipulated markers for a minimum of 2 seconds. Higher functionality specifications of the device required it to visibly slow down at corners upon detection of curvature markers and to act accordingly at speed zones. A speed zone was a section of the track demarcated by a green and red marker within which the robot was to move thorough with a specified speed of 300mm/s +/- 15%. The device had to be created under a strict budget of AUD$120 whilst ensuring high quality mechanical and electronic integrity. In order to undertake such a task within the amount of time given, the team divided up the project task into weekly sprints which had to be completed by the respective member assigned to the role. The individual role focused in this report is the design, testing and creation of the electronics sub-system for the device. The electronics sub-system can be divided in two separate components: the sensor system and the microcontroller breakout-board design. Each component will be explained in detail within the report and the the final performance of the unit will be assessed individually and as an integrated system.

1.2 Challenges Faced

The main difficulties faced in this design was the design of the sensor array. This required adequate testing to determine the correct resistances required in order to obtain the most resolution from the sensors. This would make it easier to manipulate the sensor readings when programming the line follower. The number of sensors to use and their placement relative to the surface, as well as to one another, was another critical aspect to consider when designing the printed circuit boards for the unit. The rest of the sensor system did not pose much difficulty but however, the team did find it challenging to obtain a reliable threshold to differentiate between the green and white side markers.

It was discovered early in the project that the sensors utilized for the line detection drew allot of current which could not be supported by the on-board 5V voltage regulator that the Spark incorporated. This required a separate regulator design with a higher rated 7805 voltage regulator. The design of this will be detailed with this report.

This report will provide a brief literature review on existing line following robots and the underlying concepts behind them. An overview of the chosen final design is summarized later in the report and a detailed description of the electronics sub-system is provided thereafter. The system will then be validated to determine if the all the aims and objects of the team had been met. Finally, the report will also look at the project management strategy of the team, final budget, and project burn down chart, in order to evaluate how well the team managed to track through the semester.

2 Literature Review

2.1 Line Following Robots

Existing line followers range in use from manufacturing plants, hospitals as well as mining. The underlying principle of line following remains the same throughout, however the complexity and cost of the system vary significantly based on the task at hand. The most basic line following robot incorporates the use of Infrared LED and phototransistor sensors to achieve the task of detecting a line. More complex units utilize vision systems such as cameras and multisensory array schemes to sense the line with higher levels of accuracy and reliability [1]. The output from these sensors are usually fed to a comparator circuit or into the ADC of a microcontroller which can then control the driving system. Differential steering is suggested to be the best method to drive a line following robot based on its simplicity and control. This method involves only two sets of wheels on either side of the robot and an additional wheel or castor at the front for balance [5]. The direction of the robot can be changed based on the relative rate of rotation of its wheels and hence does not require any additional steering motion [5].

2.2 Design of Electronics

Most of the literature on existing line following robot designs, recommend the use of an Infrared (IR) LED and a phototransistor to detect the line that the robot is to follow. The underlying principle involves the IR LED to emit infrared light, which will be reflected off a surface and detected by the phototransistor. The output from the phototransistor is highly dependent on the configuration of the circuit as suggested by Wen. Y [2]. The configuration suggested incorporates a pull-up resistor connected to the phototransistor forming a voltage divider circuit. As the current at the base of the phototransistor is controlled by the amount of light falling onto it, the output voltage across the transistor will vary from 0V to the input voltage. In this case, the greater the reflection, the closer the output voltage would be to 0V.

Furthermore, as stated in an article by Spooner, the pull-up resistor should be carefully chosen to control the sensitivity of the output voltage to changes in reflection onto the phototransistor [3]. There are two different modes that the transistor may operate in: active mode and switch mode. In active mode, the circuit will produce an output voltage that is proportional to the amount of IR light reflected on to the phototransistor whereas in switch mode, the linear region is so small that there appears to be an immediate switch from cut-off to saturation with any received infrared.

For the sensors to operate correctly, it was suggested by Spooner, that the distance between the IR LED and phototransistor had to be just right in order for the optimal amount of reflected light to fall onto the sensor [3]. The two components should be placed at most 5mm away from one another and the phototransistor should be encapsulated such that only the reflected light form the surface is detected by it. The positioning of the sensors from the surface is another important aspect to consider as suggested in the paper by B. Beaufrere [4]. The ideal distance recommended was at least 2mm and at most 10mm depending on the type of sensors used. This would have to be further verified from testing of the actual components.

In another article by B. Beaufrere it was suggested that a clean power supply is required in order for any DC motor driven robot to operate correctly [4]. As the motors driving the robot may cause some noise on the input voltage, it is vital to incorporate smoothing capacitors when regulating the voltage supply to the microcontroller. This would ensure a clean signal supply to the unit. This was also an important concept to consider during the design of the 5V supply for the sensors.

3 Proposed Solution

3.1 Design Overview

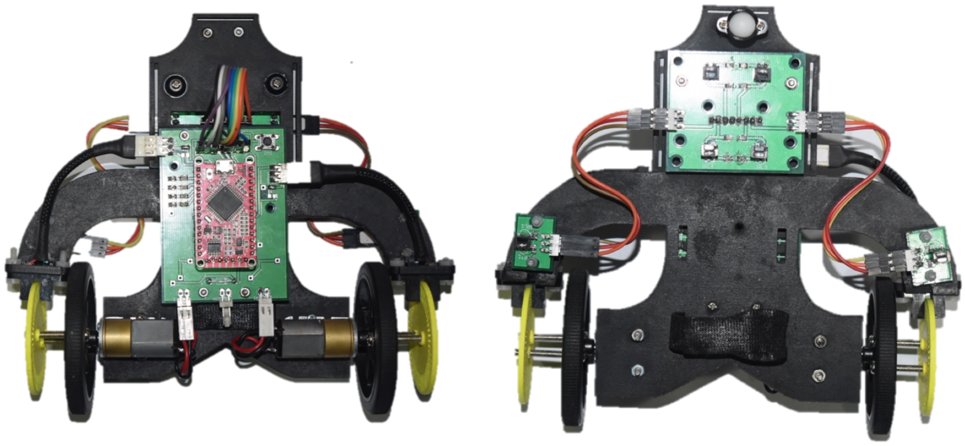

Figure 1: Final Design of the Line Following Robot

The final design of the robot can be seen above. The overall design of the robot was chosen based on a specific design criteria drawn up by the team. The design had to be cost effective, simple to construct with readily available resources whilst ensuring that the robot would perform efficiently for the task at hand. The chassis of the line follower was constructed from MDF which was readily available and could be easily cut to the desired shape and form using a laser cutter. Apart from being relatively cheap, the MDF was also chosen based on its high strength to weight ratio which was a critical factor to consider when it came to the speed of the robot. The final dimensions of the robot were 180 mm wide, 200 mm long with a height of 60 mm. This met the design specifications stipulated by the design brief.

The steering mechanism of the robot utilizes a two-wheel differential driving system with a ball castor at the front for support. This was found to be the most efficient way to drive the robot based on time and complexity. 35:1 metal gear motors were used to power the driving system based on their high torque and cost effectiveness.

The line sensors are located at the front of the robot, consisting of four IR LED and phototransistor pairs as shown above. Each pair was precisely positioned to fit directly above the boundary between the white line and black background, two on either end of the line. The front of the robot was found to be the optimal location for these sensors as it allowed ample time for the robot to react, reducing the amount of overshoot by the robot specifically at areas with sharp changes in curvature. The sensors were placed very close to the surface (3mm), in order to minimize any interference from ambient light ensuring more accurate readings.

Corner and speed markers are detected using two side sensors located underneath the protruding arms of the chassis. These sensors relay the beginning of a curve to the robot as well as the end of the curvature. The sensors also detect green and red speed markers which stipulate a specific area within which the robot should adjust its speed and maintain it until the end of the segment. The sensors used for this were single IR LED and phototransistor pairs on either end of the robot, similar to the ones at the front. Furthermore, 3D printed encoder disks were attached to the wheels of the robot. Each disk was designed to have 100 equally spaced gaps which could be detected by a photo-interrupter. The information provided by these was used to map out the track in order to determine the location of speed zones and curvature markers during the first lap.

Lastly, the line follower incorporated a break-out board which is used to connect the sensors to the microcontroller unit. This allows the microcontroller to easily supply power to the sensors as well as receive the output provided by them. This unit also provides easy access of the microcontroller pins to the rest of the robot. The board was designed based on the location of all the components which were to be attached to it. This meant that all the connectors were in close proximity to the components they were to be connected to, reducing the complexity when troubleshooting faults as shown above. As mentioned earlier, since the voltage regulator found on the Spark could not support the high currents required by the sensors, a separate voltage regulator with a higher power rating had to be incorporated onto the break out board. The output was used to supply a clean 5V to the sensors.

Information from all these sensors would be relayed from the sensory PCBs, to the break-out board connected to the microcontroller. The data will be processed by the unit and the respective output is used to adjust the PWM signal which controls the motors. Specific details on the design of the electronic circuits used to operate the line follower are provided in the following section.

3.2 Sensor Power Supply and Break-Out Board

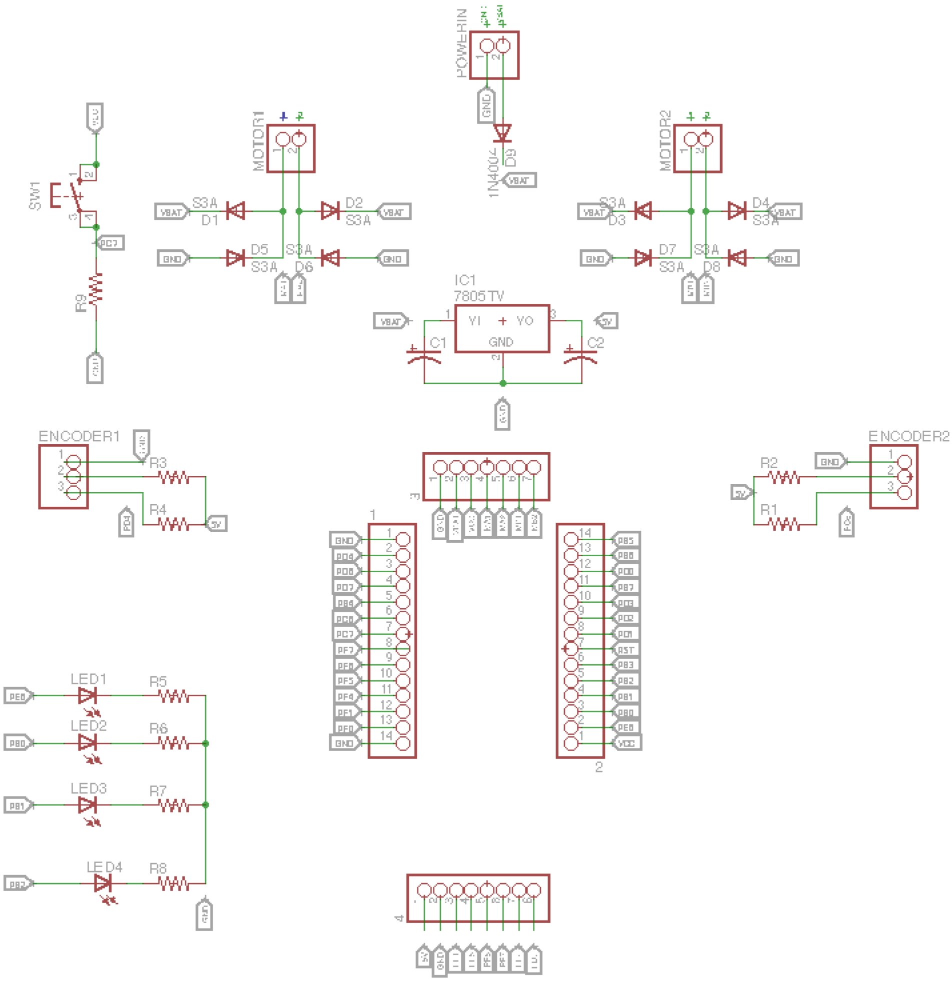

Figure 2: Break Out Board Layout

The chosen power supply for the system was a 2 cell, 7.4V lithium polymer battery with 1000mAH. This capacity was large enough for the design requirements as the robot would only have to run for a maximum of 5 minutes on the demo track. Since the Spark incorporates a 5V voltage regulator to operate the microcontroller, and the chosen motors have an operational range which ranged from 6V to 9V, there was no need for any voltage regulation from the power supply. As mentioned previously, the 5V regulator on the Spark is however unable to support the large current draw required by the sensors. The sensors draw a total of 600mA and the voltage regulator is only rated to support up to 150mA. An external voltage regulator had to be designed with a higher rated component in order to provide the sensors with the correct voltage required.This is labelled as 'IC1' in the image above. The voltage regulator alone was not adequate to remove any noise associated with the power supply. Therefore, two smoothing capacitors had to be incorporated. The first 100uF, C1 capacitor is used to remove AC signals or noise directly from the voltage source. This is necessary as the voltage regulator requires a clean input signal to operate optimally. This capacitor also smooths the input voltage to the motor drivers. The second 1000uF, C2 capacitor is used to smooth out the output from the voltage regulator ensuring that the sensors receive a clean 5V supply.

The breakout board incorporated a reverse protection diode in series with the input from the power supply labelled as 'D9' in the figure above. This served to protect the electronic components of the line follower from burning out if the supply was incorrectly connected to the device. Six headers labelled, '4' received the output from the sensors and relayed the information to the ADC pin of the Spark. Additionally, the encoder circuit was implemented on the breakout board. As this component only required the Spark to detect whether a gap was detected or not, the output from the photo interrupter was connected directly to a general I/O pin of the spark. Suitable resistors were chosen to place the transistor in switch mode such that a 0V reading was obtained when a gap was detected and a 5V was read when the connection between the sensors were interrupted. The chosen resistor values were 56 Ohms for the IR LED and 900 Ohms for the photo-transistor.These components are labeled 'ENCODER1' and 'ENCODER2' in the diagram above

Four debugging LEDs were added to the breakout board each connected to a separate I/O pin on the Spark. To prevent these LEDS from burning out, a 160 Ohm series resistor was added before each LED. Two sliding headers, 'MOTOR1' and 'MOTOR2' were place on the board to provide a physical connection from the motors to the respective motor driver pins on the Spark. Flyback protection diodes were incorporated as shown above in order to protect the electronics of the circuit from any sudden spikes in current due to the motors. This completed the design of the electronic system of the line follower. A block diagram showing the electronics system of the line follower can be seen below:

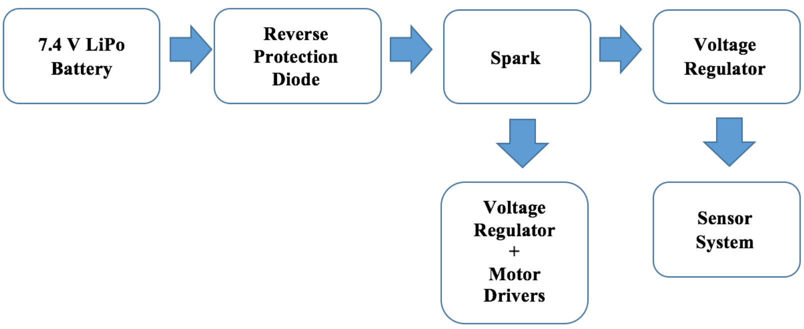

Figure 3: Top View of Final Assembled Device

3.3 Sensor System

The sensory system used consisted of six sensor cells. Four sensors were used to detect the line which the robot was to follow. The four sensors were arranged in a 2 x 2 array as shown below, with the center of each sensor precisely positioned 19 mm apart, directly above the boundary between the white line and the black background. The remaining two sensors were placed on either side of the robot in order to detect the curvature and speed zone markers.

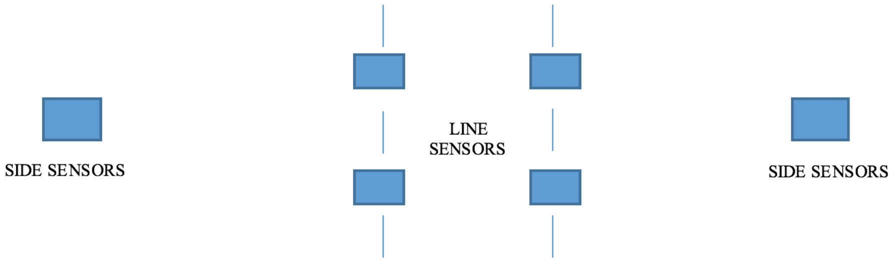

Figure 4: Sensor Board Layout

Each sensor pair was used in a similar circuit configuration. A 100 Ohm resistor was placed in series with the IR LED, and both components were in parallel with a 1587.3 Ohm resistor in series with the phototransistor as seen in Figure 5. The 100 Ohm resistor was implemented in order to drop the 5V supply voltage to a suitable voltage of 0.9 V that the IR LED could handle. From research literature, the ideal mode of operation for the phototransistor was the active region. The phototransistor datasheet suggested that the component did not behave in a linear fashion like a resistor and hence using a voltage divider equation would not be very accurate. However, a more accurate approach would be to use the current flowing through the phototransistor as it behaved in a far more linear fashion.

$$V_{OUT} = V_{IN} - IR_1 \qquad Kirchoffs\ Voltage\ Law$$

This equation is accurate provided that the voltage across the photodiode does not exceed 5V and does not drop below 1V as stipulated by the datasheet. Upon testing, it was found that the lowest voltage across the phototransistor would occur when reading a white surface. To ensure that the voltage across the phototransistor does not drop below 1V, the current running through the phototransistor when 1V was applied across it was recorded to be 2.52mA. This data was used to calculate the value of the pull up resistor, R1 to ensure the largest resolution was obtained whilst still remaining in the linear region of operation. Rearranging the above equation to find R1, when VIN is 5V and VOUT is 1V, the required pull up resistor was found to be 1587.3 Ohms. Based on this value, the voltage input to the ADC of the microcontroller should range linearly from 1V to 5V as the sensor moved over from a white to a black surface. Connectors were added on the side of the main sensor board to connect the two side sensors labelled 'RIGHTHEAD' and 'LEFTHEAD' in the circuit below. As shown in Figure 5, the design incorporates 8 header pins. 2 of the headers would be used to supply 5V and ground to the sensor pins, whilst the other 6 received the output signals from the respective line sensors and relayed them back to the microcontroller via the breakout board.

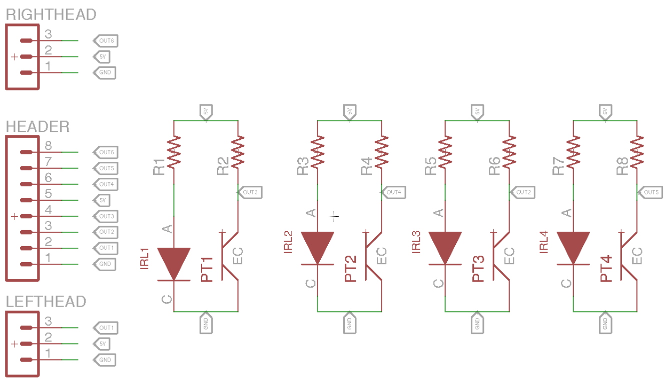

Figure 5: Sensor Board Circuit Design

Finally, the ideal height of the sensor above the surface had to be determined. From literature, it was suggested that the ideal placement of the sensors cells would be 3mm to 10mm above the surface. Placement of the sensor cells directly above the black/white boundary was based upon the sensor receiving a grey value when in this region. This meant that a grey value from both sensors would indicate that the robot was directly on the line. In order to obtain such a value, it was critical to get the height of the sensors from the surface just right. This value was obtained through testing and was found to be approximately 5mm.

3.4 Operation Manual

The electronics system of the line follower requires little to no interaction with the user once assembled. In the event of a loose wire or technical fault it is vital that the user is aware of the function of each components and its feature in order to troubleshoot the problem correctly and efficiently. The fully functional device is shown below:

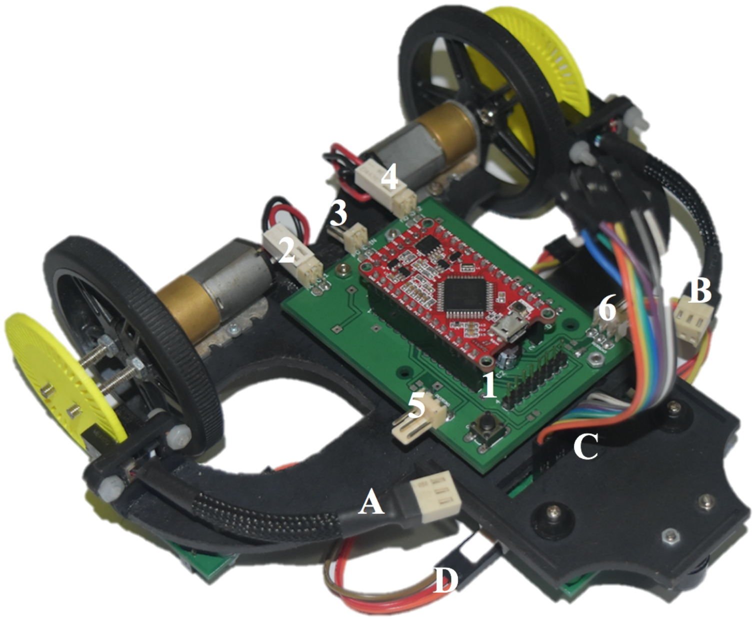

Figure 6: Connection Scheme for Line Following Robot

In the event of a wire coming loose, or the robot having to be reconstructed, the user should refer to the following set of instructions, which indicate the correct method to wire all the components back onto the printed circuit board:

1. Ensure that the battery is disconnected from location 3 when wiring the rest of the robot.
2. Pins 2 and 4 connect the right and left motor respectively to the motor drivers on the Spark.
3. To connect the encoders, connect cable A to header 5, and cable B to header 6.
4. Connect the side sensors to the main sensor board using cable D.
5. The color coded ribbon of jumper cables will connect the sensors underneath the robot to the main break out board. Count the header pins going across from the location of 1 increasing up to 8. Follow the guidelines below:
    (a) Blue wire to header 1 (5V)
    (b) Black wire to header 2 (GROUND)
    (c) Orange wire to header 3 (ADC)
    (d) Yellow wire to header 4 (ADC)
    (e) Green wire to header 5 (ADC)
    (f) Purple wire to header 6 (ADC)
    (g) Grey wire to header 7 (ADC)
    (h) White wire to header 8 (ADC)
6. The battery can be connected to the pin 3 at this stage and the robot should turn on immediately. From this point the the electronics system is self operational and would not require any user input.

4 System Validation

4.1 Sub-System Validation

In order to validate the electronics subsystem, the first step was to ensure that all the designed circuitry operated as expected on the fabricated printed circuit board. Continuity between connections were tested using a multi-meter on both the sensor and break out boards. The sensor board was found to have no errors. There was however a route missing on the breakout board, which connected one of the ADC pins on the Spark to the sensor board. Due to time and cost limitations, a second break out board could not be fabricated. The solution however was to manually route the pins from the under side of the board using a jumper wire.

The sensors were validated by testing how well they were able to differentiate between black and white surfaces. To do this, the output from the ADC of the Spark was transmitted via an external USART module, which enabled the digital output from the sensors to be read directly off the computer. The sensor board was held a few millimeters above the testing board and slowing switch across from a black surface to a white surface. 5 mm was found to be the optimal height to place the sensors above the surface, producing the most linear results. The respective outputs from the USART were recorded and are depicted in the graph below:

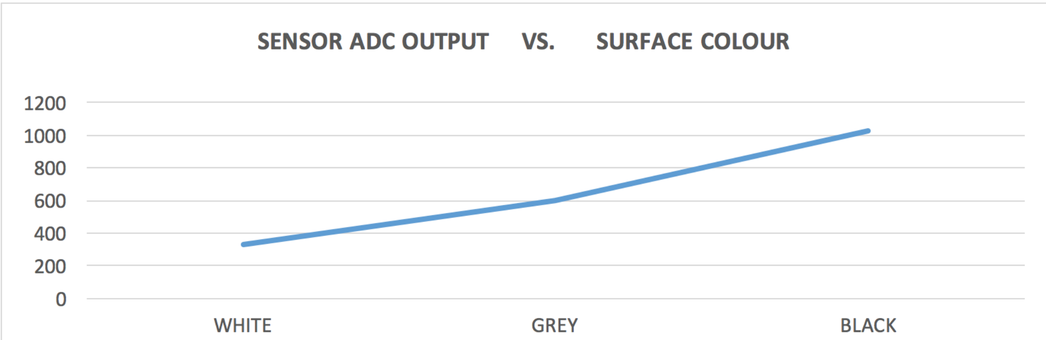

Figure 7: Graph Showing the ADC Values Obtained VS. Surface Colour

The data validated that the sensory system of the line follower worked as expected and produced a significant different between the black and white surfaces of the track. As seen in the graph above, the threshold for white was about 330, whilst for black it was approximately 700. The data also suggests that the sensors were able to pick up the black/white boundary as a grey value which was desired by the team in order to smoothly follow the line based on the sensor configuration.

There was some difficulty however in the detection of the green markers using the side sensors. The value read off the green marker was found to be in close proximity to that read off the white markers. This was a critical issue as the robot had to differentiate the corner markers and speed marker solely based on the color. The value read off the green markers was about 350 which was very close to that of white. This value also varied significantly as the surrounding lighting changed since it was a fairly reflective surface. Various iterations were made to the threshold to try and differentiate the white markers from the green ones but the results were unreliable. The solution to this was to calibrate the green threshold just before the track run, by placing the sensor over the green marker, reading and saving the value obtained. This was tested for numerous runs and produced consistent results each time, meeting another requirement from the task specifications.

The voltage regulator designed to supply a clean 5V to the sensors was also tested. The output from the regulator was connected up to an oscilloscope and found to be 4.98V with an insignificant ripple of 2mA. This was consistent even with the motors running at varying speeds. From this data it can be concluded that the 5V power supply meets the requirements for the line follower to operate efficiently. Lastly the encoder was also tested to see how well it was able to read the values off the disk. The motor was set to run at full speed and the output from the encoder was also connected up to an oscilloscope. The values produced were found to be very accurate providing data at up to 500 Hertz.

4.2 Final Device Validation

While it is important that the electronics sub-system operates as required and meets the design specifications, it is imperative to demonstrate that it can integrate cohesively with the rest of the system. To test whether the sub-system integrated well with the rest of the components on the robot, the final device was tested and evaluated based on its performance. If the device was able to perform as expected based on the project specifications, it can be concluded that the integration was successful.

The test was to assess the device on the demo track made available. Based on the written code the robot was expected to perform exactly as specified within the design brief. On the first lap, it was expected to move slowly mapping out the location of each green speed zone marker and storing the encoder ticks up to that point. The device was seen to successfully navigate around the track smoothly and consistently which validated the line sensor integration with the rest of the sub-systems on the robot.

Using the encoder, the team found that there was no need to detect the curvature markers which made the mapping of the track easier. The reason for this was based on the velocity readings obtained from the encoders. If there was a difference significant difference between the velocities of the right and left wheel, the robot would assume that it was at a corner and hence would adjust its speed accordingly. This was found to be a very efficient method with the robot slowing down at every corner from the first lap. In this case the encoder system designed worked seamlessly with the control system of the robot and overall the device was able to meet the specification of slowing down at all corners on the track.

The final test was to determine whether the side sensors were able to effectively determine the location of the speed zones. Once on the second lap, the speed of the robot was measured across the speed zones. The reason for mapping the track was to ensure that the robot could adjust its speed a small distance before it reached the speed zone to ensure it had ample time to accurately set its speed to the required 300mm/s. From the number of ticks counted in the first lap till the green marker, a fixed value was subtracted from this counter, indicating the new number of ticks till the robot should adjust its speed on the laps thereafter. The outcome was successful, with the robot accurately achieving the required speed within the speed zones. Overall the electronics system can be validated to successfully integrate with the rest of the sub-systems on the final device.

5 Project Plan and Management Review

5.1 Project Plan Review

In order to effectively achieve the goals of this project within the time frame given, the team divided up the entire project into weekly sprints. Tasks for each sprint were determined from a product backlog drawn up by the team during the second week. The product backlog divided the task into three main sub-systems: mechanical design, electronics design, and software. Tasks based on each sub-system were listed out, with each task building up on the last until a sub-system was complete and ready for integration. The full product backlog can be viewed in Appendix B of the report.

The semester was divided into ten sprints. Weekly sprints were populated with a certain number of tasks to be completed by each team member. The team divided these tasks based on each others individual strengths. The mechanical design was handled by Max and Rick, whilst Richard initially focused on the software required by the line follower. The electrical sub-system was primarily designed by Krishan. The software design became more difficult towards the final sprints and hence was usually delegated amongst two or more team members.

The time estimates for each task were typically inaccurate towards the beginning of the semester, as this was a fairly new method of project planning to the group. Progressively through the semester this delegation became more accurate, making the task more manageable for each member. The burn down chart below summarizes the progression of the project through the ten sprints.

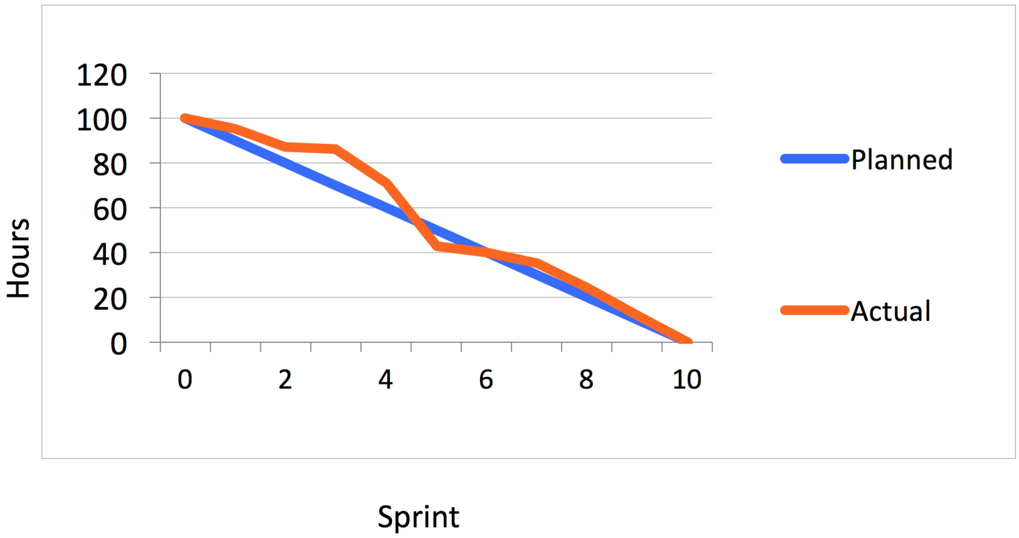

Figure 8: Project Burn-Down Chart

As seen from the burn down chart above, from sprints 1 to 5, the team did not adhere to the planned task completion too well. This was primarily due to the delay in parts order from the suppliers as some of the components had to be shipped from America. The team also used this time to get over the steep learning curve as the majority of the required skills for the task completion were novel to the team. From sprint 6, the primary task at hand was the coding of the line follower and the implementation of the breakout board. This was the most difficult task but was achieved much faster as the sprints were usually delegated amongst two to three team members. Once PD control was implemented, the remaining two sprints focused primarily on getting the speed zone and corner detection working reliably.

The team underestimated the time required to assemble the break out board. The process was not technically difficult but however was time consuming and required an extra team member to reduce the overall time required to complete the task. This set the team back during week 9 as the break out board was required to continue testing. In the end, the team managed to get the line follower to accurately achieve the task at hand however were unable to get the speed zone detection reliable enough. More time could have been allocated to this task as the team underestimated its complexity during the planning stage.

The final team budget can be viewed in Appendix A of the report. The team managed to keep within the overall project budget of $200 but however did not manage to stay within the budget for the final product. The team went just over $2 and can be attributed primarily due to the supplier of the parts. As the team did not have adequate time to search for the best possible deal on the required parts, the majority of parts were ordered from Core Electronics. Element 14 were found to have the exact same products, specifically the phototransistors but at half the price. This would have reduced the the final cost of the device. The cost of the product could have been further reduced by removing the encoders from the device. This would reduce the reliability of the line follower but however could be compensated using suitable algorithms, given enough time.

5.2 Project Management Review

The project was undertaken using the Scrum Project Management technique. This was a helpful technique which focused on the completeness of the task rather than the performance. The sprints each focused on generating a functional product that could complete the task at hand. The consecutive sprints built up on the last and each sprint ended up with a product with slightly more features. Before each sprint ended, a review scrum meeting was held with the team to reflect upon what each team member had achieved and what still had to be done. This enabled the team to determine how well the project was tracking overall and which tasks were posing more difficulty than expected. The team was then able to reallocate the work load and assign more or less time to specific tasks to ensure that the project was completed within the set deadline. This management method required each team member to update their progress on a burn down chart on a daily basis rather than once a week, ensuring that each member of the team was aware of the progress at any given time. This allowed members who had completed their task early to move in and assist those who were still behind.

While the Scrum Project Management method was an effective method for the project, there was a disadvantage that the team faced from it. As the method required tasks to be completed within a short space of time, team members found it quite demanding particularly when they had other workloads to complete. This did not pose much of an issue at the beginning but however as the project progressed, the sprint tasks became more difficult and and more time had to be allocated in order to complete it. This resulted in a slight delay in the completion of sprints towards the end of the project. In future projects, this should be considered and greater amounts of tasks may be allocated towards the beginning of the project time-line.

6 Conclusion

This report aimed to provide an overview of the project task, which involved the design process of an autonomous line following robot. The control system of the robot was outlined in the report, with a primary focus on the electronic sub system, involving the design and operation of each component. Testing was conducting on each of these components in order to validate their functionality before integration with the final product. This allowed minor faults to be amended. The electronic sub-system was then connected to the other components and the performance of the line follower as an integrated system was evaluated against the project specifications. The report then went on to evaluate the project management and assessed how well the team tracked through the semester against the planned time-line. The budget was reviewed and appropriate measures to improve it in future work were suggested. Overall this was a great learning experience for the team, introducing the members to real world skills which would go a long way within the Mechatronics Engineering field. The scrum management technique was found to be an effective instrument to organize group projects into manageable tasks making it easier to meet project deadlines in the future.

Future work on this project would be to implement full PID control to the robot to improve its efficiency and accuracy when line following. Better optical sensor, with higher resolution may be used to improve the detection of different colored markers, particularly in varying lighting conditions, allowing for a more reliable line follower. The team dynamics overall could be improved in future projects by organizing team sprints where team members would meet up and work on the more difficult segments of the project together. This would enable teams to complete difficult tasks more efficiently within shorter spaces of time.

7 References

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8 Appendices

8.1 Appendix A

EGB220 MECHATRONICS DESIGN 1 GROUP 11 | PRODUCT BUDGET					
ITEM	UNIT PRICE ($)	QUANTITY	TOTAL($)	PRODUCT NUMBER	WEBSITE
Wheels (Pair)	8.97	1	8.97	POLOLU-1420	http://core-electronics.com.au/pololu-wheel-60x8mm-pair-black.html
Castor Ball			0.6	POLOLU-950	http://core-electronics.com.au/pololu-ball-caster-with-3-8-plastic-ball.html
Break-Out Board	-	-	12		-
Chassis	-	-	9		-
Encoder Disks	4	2	8		-
Photo-Interrupters	0.481	2	0.962	KTIR0411S	http://au.element14.com/kingbright/ktir0411s/photo-interrupter/dp/2079959?CMP=KNC-(
Motors	20.13	2	40.26	POLOLU-1597	http://core-electronics.com.au/35-1-metal-gearmotor-15-5dx30l-mm.html?___S
LiPo Battery	5.75	1	5.75	T1000.2S.20	http://www.hobbyking.com/hobbyking/store/__20841__Turnigy_1000mAh_2S_
MicroController	15	1	15		-
PhotoTransistors	1.2	6	7.2	SEN-00246	http://core-electronics.com.au/optical-detector-phototransistor-qrd1114.html
LEDS	0.1	4	0.2	654-5818	http://au.rs-online.com/web/p/visible-leds/6545818/
Resistors	-	-	0.2	683-2749	http://au.rs-online.com/web/p/through-hole-fixed-resistors/6832749/
Diodes	0.15	8	1.2	486-2947	http://au.rs-online.com/web/p/rectifier-schottky-diodes/4862947/
Sensor Board			9		-
Screws/Nuts/Bolts	-	-	0.6		-
Motor Mounts			2	SF-ROB-11278	https://littlebirdelectronics.com.au/products/motor-mount
Push Switch	0.05	1	0.05	MC32863	http://au.element14.com/multicomp/mc32863/switch-tactile-spst-no-50ma-though/dp/171
Voltage Regulator	0.9	1	0.9	298-8514	http://au.rs-online.com/web/p/linear-voltage-regulators/2988514/
Capacitors			0.12	715-2436	http://au.rs-online.com/web/p/aluminium-capacitors/7152436/
Total (Product)			**122.012**		

EGB220 MECHATRONICS DESIGN 1 GROUP 11 | OVERALL BUDGET					
Demo 1 Chassis	-	-	13	-	-
Photo Transistors	1.2	2	2.4	SEN-00246	http://core-electronics.com.au/optical-detector-phototransistor-qrd1114.html
Resistors	-	-	0.7	683-2749	http://au.rs-online.com/web/p/through-hole-fixed-resistors/6832749/
70 mm Pololu Wheels	10.65	1	10.65	POLOLU-1425	http://core-electronics.com.au/pololu-wheel-70x8mm-pair-black.html
Encoder Disks (Prototype)	-	-	12	-	-
Total (Overall)			**160.762**		

Figure 9: Final Project Budget

8.2 Appendix B

Product Backlog	Sprint	Name	Estimated	Wk. 2	Wk. 3	Wk. 4	Wk. 5	Wk. 6	Wk. 7	Wk. 8	Wk. 9	Wk. 10	Wk. 11
Research	Existing line followers and how they operate	Krishan	5	2	3								
	Possible Designs for the line follower	Max	5	3	2								
	Type of wheels required	Rick	2	2									
	Create a feature list	Rick	2	2									
	Create a parts list	Max	2		2								
	Check costs of various parts	Max	4	2	2								
	Draw up a budget	Krishan	2		2								
Obtain required parts and info	Chassis Design	Krishan	4		2								
	Get Chassis laser cut	Krishan	3			3							
	Design sensor circuit	Richard; Max	2		2								
	Interface sensors with Teensy (testing)	Rick	2										
	Design PCB of sensor circuit using Eagle	Richard; Krishan	5		2	1							
Build and Code for first demo	Motor control - continuous	Richard and Krishan	8				3	6					
	Coding and Debugging	Richard and Krishan	5				3	4					
	Solder Components onto PCB	Richard	0.5				0.5						
	Assemble Line Follower	Max	2				2						
	Start designing the breakout-board	Krishan	2					2					
	Testing	All	4					4					
								2	2				
Design of Final Robot	Design Break-Out Board	Krishan	3							3			
	Attach the side sensors onto the device	Max	1							1			
	Adjust design of chassis	Rick	2							1			
	Write code for the final demo	Richard and Krishan	10							4			
	Encoder Costs	Max	1							1			
Implementation of Final Robot	Submit Breakout Board for fabrication	Krishan	1								1		
	Submit Solidworks drawings for laser cutting	Krishan	1								1		
	Test encoder and determine division size	Richard	1								1		
	Finalize design of encoder for 3D printing	Max	1								1		
	Implement PID control to existing robot	Richard	3								4		
	Side marker detection	Richard, Max	3								5		
	Build new robot	Krishan	2									2	
	Write code for speed zone markers	Richard	2									2	0
	Get robot to slow down at curvature markers	Richard	2									1	
	Implement encoders	Max and Rick	1									2	
	Write report	all											
	Final testing	all	4										6
Ideal - Remaining efforts in uninterrupted working hours			97.5	87.75	78	68.25	58.5	48.75	39	29.25	19.5	9.75	3.75
Actual - Remaining efforts in uninterrupted working hours			97.5	86.5	69.5	65.5	57	39	37	27	14	7	1

Figure 10: Product Back-Log