The University of Manchester

School of Electrical and Electronic Engineering

# Embedded Systems Project

## DESIGN REPORT #3

## Title: Proposal Report

## Group Number: 37

| Group members name: | ID Number | I confirm that this is the group's own work. |
|---|---|---|
| Federica Donald | 10095518 | ☒ |
| Alkinoos Sarioglou | 10136315 | ☒ |
| Elvis Taimal Gongora | 10146823 | ☒ |
| Kai Guo | 10201372 | ☒ |
| Ruoning Mi | 10431554 | ☒ |

**Tutor: Dr. Emad Alsusa**

**Date: 07/02/2019**

## Contents

# 1. Introduction, Aims and Objectives

The Embedded Systems Project is a great opportunity to be an active part of a team designing and constructing a technological system. This process poses many challenges on the way. However, a well-constructed team will be able to effectively overcome these difficulties and gain valuable experience in the field of engineering project management. The members can develop both technical and personal skills. On one hand, skills in software design, circuit design, DC motors, control algorithm and many others can be greatly enhanced. On the other hand, experience in project management, teamwork, leadership, communication is also gained, giving an accurate idea of what is like to work in the engineering industry.

All the above are achieved by working towards the main aim of the project: To construct a buggy that can follow a white line around a track in the best time possible. To fulfil the technical requirements of the project, knowledge acquired during the first year and the topics covered in the second year of the course will be used. To accomplish this, a clear schedule needs to be designed with well-allocated tasks for the members of the team. For maximum efficiency to be achieved tasks are allocated according to each member's skills. This schedule includes many deliverables over time, which will ensure that all the small parts composing the system are well-designed and fully-functioning in order to shape a successful assembly. These deliverables include:

- Reports
- CAD Design
- PCB Design
- Motors working
- Sensors working
- Buggy Assembly
- Successful movement/steering
- Code development

Moreover, the upcoming milestones of the project can be summarized as:

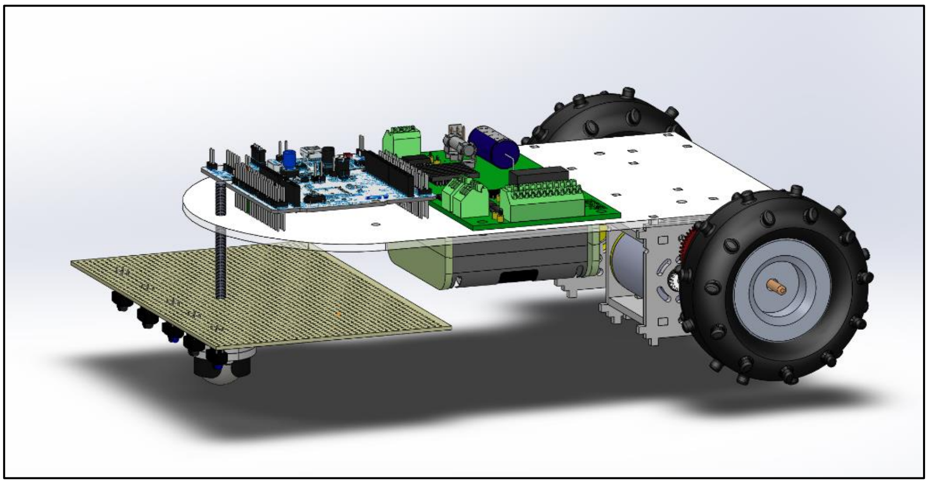
- Motor Control Demo
- Sensors Demo
- PCB Fabrication Submission
- Steering Demo
- Heats
- Final Report
- Race Day

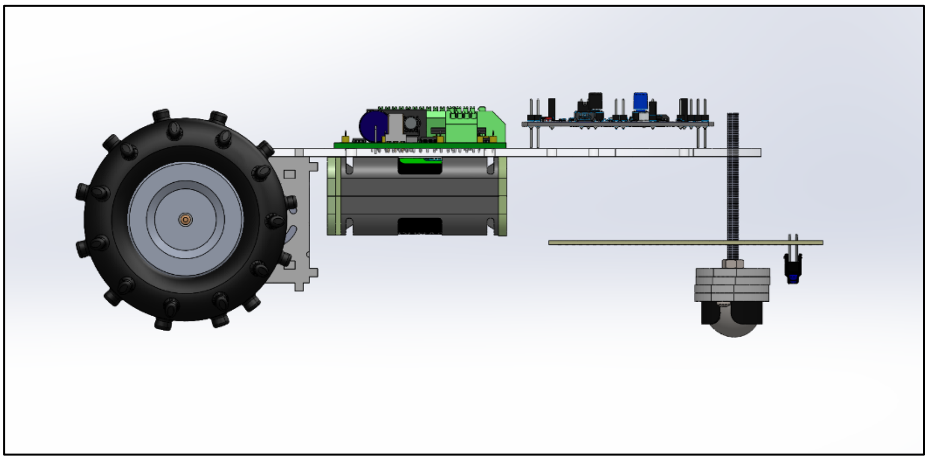
The proposal report represents an important part for the development of the project. It gives a good summary in the work that has been done until now and the objectives that have been delivered while also setting new goals. A carefully constructed report will result in a good guide for the implementation and delivery of the project.

Firstly, the technical overview gives an extensive summary of all the technical specifications of the buggy. The aim is to demonstrate the functionality of all the parts of the system, both hardware and software. Another important part of the project is the organisation of the team. This part gives insight into the roles and responsibilities of each team member along with the means of interaction and communication to guarantee the progress of the project.

As a final point, the planning and schedule of the second semester is introduced with a Gantt Chart. This tool helps in organising tasks over the second semester but also allows monitoring of the progress of each stage in a timeline representation. Furthermore, the possible risks and setbacks that may occur during the Final Race Day are evaluated in a Health and Safety Risk Assessment. It is explained who or what could cause them and how to prevent them to make sure that everyone stays safe. Finally, an estimate of the cost of the project is calculated and therefore the financial sustainability of the project is evaluated.

At this point of the project, a clear image of the buggy is shaped and shown in the following CAD pictures:





Figures 1 and 2: CAD Design of the Buggy

Figures 1 and 2 show how the components are placed on the designed chassis of the buggy. More specifically, the microcontroller with the motor drive board are placed on top to ensure effective communication with the sensors and the motors, while the batteries are placed underneath to save space. Finally, at the front of the buggy the castor ball with the straight array of the sensors will be placed allowing it to detect the white line.

The effective collaboration between the team will ensure the above design will be implemented successfully on-time and the learning experience will be appreciated.

# 2. Technical Overview

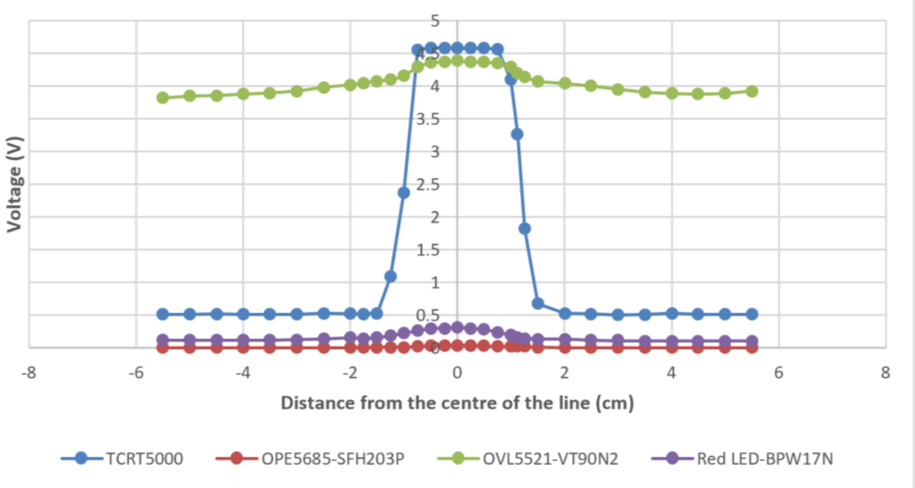
## 2.1. Introduction

For all the aims, deliverables and milestones to be achieved the technical specifications of the system need to be clearly identified. In this section the features of all the different parts of the system are discussed. Successful delivery of these will secure that a competitive buggy will be constructed.

## 2.2. Sensor Characterisation

The most important component of the system used to track the position of the line is the reflective sensor. The measurements showed that the TCRT5000 sensor with integrated LED and phototransistor gave a stable and large output voltage when it detected the white line. The change of voltage level was more obvious and significant when compared to the results from the other choices (Figure 3). Therefore, the chosen sensor is the TCRT5000 sensor.

Figure 3: Response of different sensors in height of 2.55cm




A complete sensor specification includes the height above the line in which the sensors will be placed and the value of the output resistor. The measurements for the selected sensor showed that a height of 2.55 cm gave the most rapid increase in the output voltage between the white and black part. Furthermore, intermediate voltages could be measured between the low and high voltage and as a result at this height the sensor has maximum sensitivity, which will be useful for the processing of the measurements by the microcontroller. Also, data from the experiments demonstrated that the voltage increase was more visible when using a 10 kΩ output resistor in series with the phototransistor and in-between values are available as well. Hence, a 10 kΩ output resistor will be used.

The configuration of the sensors was decided depending on how the irregularities of the track will be dealt with. A straight array of 5 TCRT5000 sensors will be placed at the front of the buggy collecting data for the position of the line (Figure 4). This configuration will ensure that the buggy does not drift away from the line as the outermost sensors can detect a sharp corner or turn and will also be able to deal with line breaks as the sensors will cover a wide range of the track. Finally, the integrated daylight blocking filter of the sensor will deal with the ambient light of the room and the change in the reflectivity of the white line so that these irregularities will not influence the measurements.

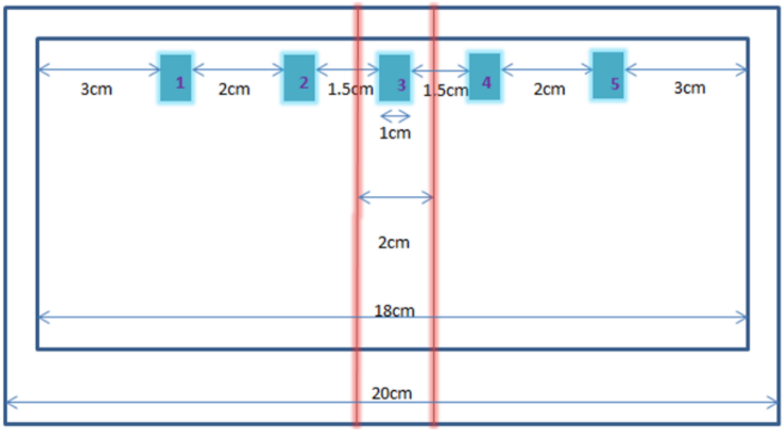



Figure 4: Sensors Geometry

Other sensors are also used which measure useful quantities or show the orientation of the buggy. First, a speed sensor uses a quadrature encoder to measure the speed and direction of the gearbox. Additionally, a battery monitor uses a Dallas Integrated Circuit to measure the voltage and the accumulated current of the battery. Also, a current sensor uses an isolating circuit on the motor drive board to measure the current sent to each motor and a Low-Energy Bluetooth module operating in 2.4 GHz will be used to aid the turnaround of the buggy when it reaches the end of the track. Finally, an additional tilt sensor will be used, which is more thoroughly discussed in the “Winning Features” section.

All the mentioned sensors give valuable quantities to the microcontroller which processes the input data and outputs actions depending on the software design of the system.

### 2.3. Software System Design

The software of the system will be designed to monitor the position of the buggy by analysing the data from the sensors and controlling its steering by changing the speed of the wheels.

At first, the constraints of the embedded system software need to be considered. These concern the memory, timing and cost. The memory limitation will not hinder progress because the available memory of 512 KB of flash and 96 KB of SRAM can store a big programme. In terms of timing, when deciding which algorithm to use it is important to bear in mind that the motors should react fast enough to turns or sharp corners. Also, the £40 budget limits the purchase of the additional features to maximise the system’s functionality. However, this amount is enough for the order of components for the buggy.

The implementation of software is based on the operation of the microcontroller getting signals from the various sensors (TCRT5000, speed sensor, battery sensor, Bluetooth, current sensor and tilt sensor) and controlling the two motors with different functions.

The main function of the code monitors the values measured from the leftmost and rightmost sensors and adjusts the current sent to the motors. Multiple functions will be written corresponding to many different use cases. As an example, Stop, GoSlower, ConstantSpeed, ReadSpeed, CalculateVelocity are functions which will be involved in the system's software. Other functions in the code responding to changes include refinding the line, steering in turns or sharp corners, stopping, overcoming a hill/step, dealing with a Bluetooth signal etc. Finally, the objects involved in the code will be: Motor, TCRT5000, Bluetooth, Control Algorithm, Speed Sensor, Velocity, Battery.

The software will hence adjust the speed of the motors by monitoring it with the quadrature encoders and comparing it with the required value. The appropriate control algorithm will give a better adjustment of the speed.

## 2.4. Control Algorithm Section

The selection for the controller depends on the type of sensor and the configuration of the sensors on the buggy. The configuration of 5 sensors in a straight array will allow the outermost sensors to output voltage levels from which the system understands where the line is relatively to its position.

The Proportional Controller is found to be the most suitable option to control the speed and direction of the wheels. This controller fits perfectly with the configuration of the sensors as it will be comparing the sensors' output with the reference value and will output the appropriate power difference in the two motors so that steering is effective. A Proportional Controller provides a good control of the speed by controlling the proportionality gain Kp. However, there are issues arising as well. The steady state offset is not eliminated completely which means that the buggy will not be directly above the line. This will not affect the buggy's performance significantly as the gain will be appropriately set so that the deviation from the line will be insignificant. Hence, the controller will be able to provide rapid corrections and responses.

The control algorithm is also defined. It reads the output value from the sensors and adjusts the steering depending on the values of Kp and the error. More specifically:

```
set value of Kp, offset, Tp;
//Kp is proportionality constant
//offset is the average voltage value across the sensors
//Tp is the power of each motor when error=0
start loop forever
VoltageValueLeft = read left line sensors;
VoltageValueRight = read right line sensors;
VoltageValue = average of all sensors outputs in a single sample
Error = VoltageValue - offset;
Turn = Kp*Error;
Power1 = Tp + Turn;
Power2 = Tp - Turn;
If VoltageValueLeft > VoltageValueRight
then Power1 -> RightMotor,
    Power2 -> LeftMotor;
If VoltageValueLeft < VoltageValueRight
then Power1 -> LeftMotor,
 Power2 -> RightMotor;
end loop forever;
```

The sensors are multiplexed to the same ADC on the STM32 microcontroller and will be sampled one after another with a total sampling time of 5 μs. That means that each sensor will be sampled for 1 μs. This is a rate that the selected microcontroller can keep up with [1]. Using this control algorithm the provided motors will be controlled.

## 2.5. Motor Characterisation

The motors used in the buggy are now fully characterised, after the necessary measurements have been carried out. They will be operated at 5 V and maximum 1.4 A due to overheating. Some important quantities like the armature resistance (1.893 Ω) and the brush voltage (0.0042 V) were extracted and contributed in deriving the two constants for the motor $K_E$ (0.0076) and $K_T$ (0.0084) with a small error included due to measurement readings. These constants are helpful to find the value of current needed to go up the maximum slope or to set a particular speed on flat surface.

Furthermore, the input torque of 0.012 Nm is not enough to drive the buggy up the maximum slope. Therefore, a gearbox is needed to provide the required torque of 0.1428 Nm. Appropriate calculations showed that the gear ratio needed corresponds to the gear ratio of **Gearbox 3** (output/input ratio = 18.75). Hence, this is the selected gearbox.

The current will be adjusted in the transition from the flat surface to the ramp and vice versa so that the torque needs are fulfilled. In the flat surface the current will be adjusted to approximately 0.4 A which will result in a calculated maximum speed of 1.8602 m/s. On the ramp, the current will be approximately 1.2 A which will give a maximum speed of 0.8615 m/s.

In conclusion, the motors are critical for the successful movement of the buggy however additional, innovative features will be added which will contribute to its agility.

## 2.6. Winning Features

Firstly, it is important for the buggy to realise when it is moving in a flat surface or on a ramp. This can be achieved using two tilt sensors one for the uphill and one for the downhill.

Each sensor consists of a mercury switch. When the terrain changes a small amount of the liquid mercury connects the metal electrodes allowing current to pass through. The effect of this will be the adjustment of the current, hence increase in torque on the ramp, and increased speed on the flat surface. The sensors will interface with the microcontroller using a digital input pin.

All the above are combined and placed together on the chassis of the buggy.

## 2.7. Chassis Design

The chassis of the buggy is a single layer of Acetyl with dimensions that adapt with the specifications of the track. The shape of the chassis is a rectangle with a semicircle front end. That way the components and wires on the buggy can be adjusted without getting cut on a sharp edge. The width of the chassis is 14 cm considering the track specifications and its length is about 23 cm. All components are attached on the base with screws. Figure 5 shows the chassis and its dimensions.

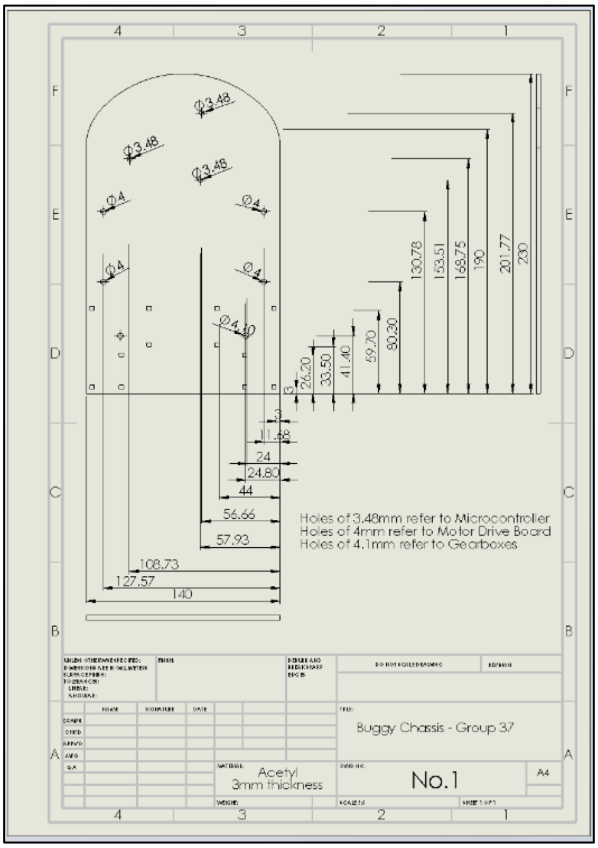



Figure 5: 2D Chassis Drawing

Its thickness is decided to be 3 mm as it will reduce the weight and therefore increase the speed. The robustness of the design was examined by carrying out the stress analysis on SolidWorks with the expected load. The load that the base is subject to is 491 g, which includes the battery pack (265 g), the motor drive board (53 g), the microcontroller (35 g), its breakout board (38 g) and wiring (100 g). An insignificant deflection of 0.1 mm and a small value of stress were found, which ensures that the chassis is not likely to significantly bend or break during the race.

Different materials were evaluated to choose the best option. After thorough analysis, Acetyl was decided to be the best to use as it is easily accessible and cheap. Also, it will be the lightest material to use for the same volume of chassis. Furthermore, Acetyl is easy and common to laser-cut.

A further discussion on the design reveals that the drivetrain of the buggy is rear-wheel drive which will make steering more efficient and will also improve acceleration and braking of the buggy. As a final point, it is worth noting that the wheels will have the same distance from the centre of the chassis so that steering is smooth in both right and left direction and the distance between them will be as small as possible to make steering faster.

## 2.8. Summary

As a conclusion, all the parts on the buggy are now known and their functionality is completely analysed. The effective communication between them will ensure a successful and competitive performance around the track. At this point, a clear image of the system is shaped. The successful cooperation of the team will guarantee the implementation of all the above features.

# 3. Team Organisation

## 3.1. Roles and Responsibilities

The roles and responsibilities of the group were set out in the first meeting. These roles were important to set out quickly, so everyone knew their part within the project group. The roles were picked out depending on what members felt most comfortable doing, this approach has also been used when splitting off technical tasks for the design reports. These roles and responsibilities have been a key part of the team's organisation and have kept the group in line and focussed throughout the first 12 weeks of the project.

Alkinoos - Meeting Organiser

Fed - Journal Writer

Kai - Minute Keeper

Ruoning - Helper

Elvis - Helper

## 3.2. Communications

As soon as the groups were announced, a One Drive folder was set up titled "Embedded Systems Project Group 37" and shared with the entire group (Figure 6). This folder has been integral to the success of the team as all of the documents required to complete tasks such as data sheets and section drafts for the report are shared. It has been an easy way to keep tabs on progress as well as quickly sharing documents that can be accessed. For example, it has been very useful when submitting the individual contribution entries for the weekly journal.

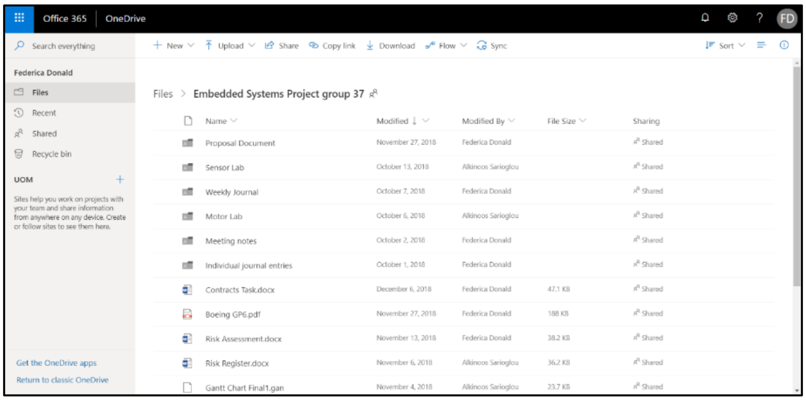



Figure 6: One Drive Folder

Additionally, a Facebook messenger group chat was created where quick burst of information and decisions can be made straight away. This method of contact was used as a last-minute review before submissions where all members have to confirm that they agree with what will be submitted after the final changes have been made. Where deadlines have been set over a longer period of time, the chat has also proved useful to send reminders as seen in Figure 7 where reminders have been sent out. This has helped the group stay on top of the many deadlines that have been required to meet since the start of the year.

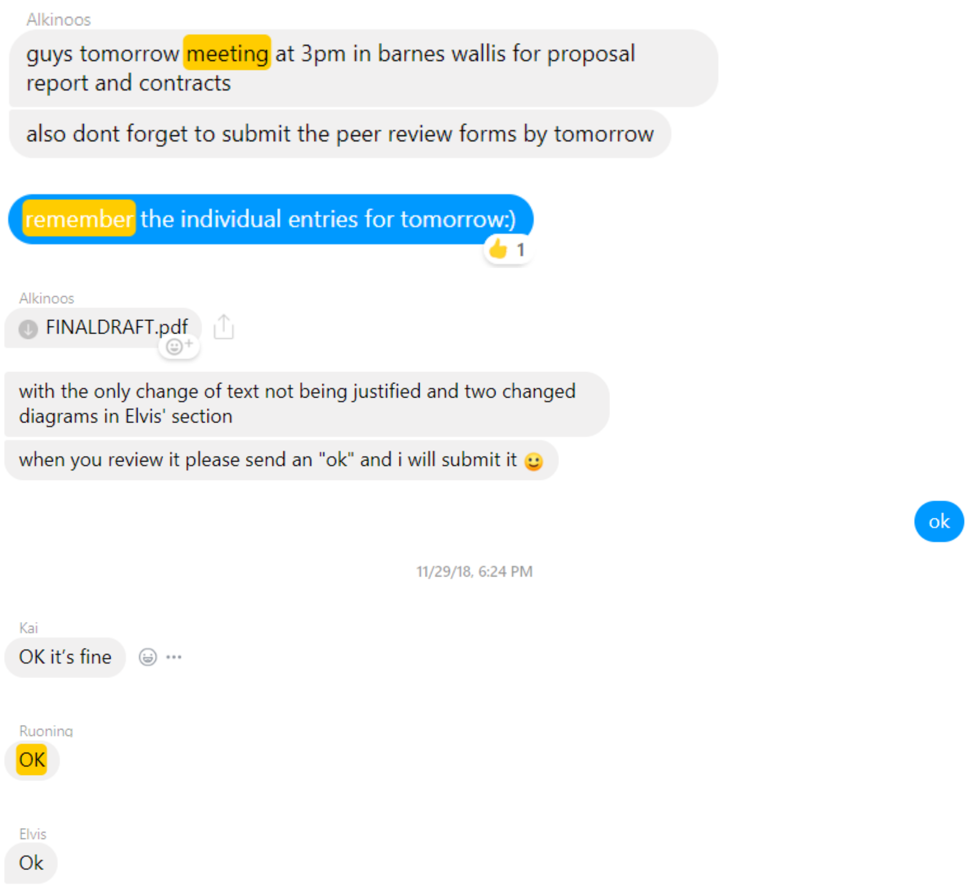



Figure 7: Online Communication

The weekly journal is the main source of evidence of meetings as one was created every week covering the progress and next steps discussed in the week. However, the Facebook group chat has also been used to keep record of the meetings, so everyone instantly knows what they need to be doing in the week. Everyone had to submit an individual journal entry by 4pm on the Sunday to their individual weekly journal folder. The person responsible for the weekly journal then edited that week's journal with everyone's entry and uploaded the journal to both Blackboard and OneDrive. The format for the journal stayed consistent throughout the weeks as a base template was used. The sections: Action items from last week, Project status, Individual student contributions and other issues were talked about within the weekly journal report to cover what was said during the weekly meetings.

| | |
|---|---|
| Week 3 | Motor lab complete. Everyone has been allocated their part in the design report to write. First bullet point version of our individual sections due in the folder Sunday 14th.<br><br>Participants of sensor lab are researching all the prelab work (data sheets, circuit diagrams to be fully prepared for Wednesday 17th. (further lab prep to be done as a group on Monday 15th afternoon) |
| Week 5 | Motor lab report draft has been written and submitted. On way to produce the full report by the end of week 6. Fed is going to read over and try cut down the 14 pages to become 10.<br>2 more sensors have been tested and ready to prepare the comparisons of the sensors to pick the best version. |
| Week 9 | Completed a first official draft of the DR2 report. Finalisation and proof reading to be done in week 10. |

Table 1: Example Weekly Journals for 3 weeks

## 3.3. Meetings and Decision Making

Meetings occur on average twice a week. This varies depending on the workload for that week. For example, when an assignment was given from engineering management or an important report deadline was coming up the group would meet more frequently in order to meet the deadlines. Usually, the meetings occur at the start and end of the week, so tasks can be given out at the start and people have enough time to complete them to a high standard before reconvening at the end of the week to assess what has been done and the next progress steps. All decision making has been done diplomatically to make sure the entire group agrees with what needs to be done and when for. By setting realistic time goals we have ensured that our quality of work is high. During our meetings the group discusses, previous deadlines, deadlines needing to be met by the next meeting and a general discussion of everyone's progress regarding their individual tasks.

## 3.4. Reflection on Success

The team organisation has seemed to be successful as all deadlines have been met on time and to a high standard where everyone has contributed to whatever task was being completed that week. Everyone knows what they have to do for the next meeting due to the Facebook chat being used to remind people about important tasks. This has been one of the main reasons for our group meeting deadlines and working consistently. As everyone met their own personal deadlines the group kept progressing with work without being held back by someone. The OneDrive folder has proved to be incredibly useful during the final group editing meetings for DR1 and DR2 as we can all preview the document at the same time and see markings people were making at once.

The workload has been shared out depending on who feels most comfortable doing which tasks. During the first meeting before a major task is started, everyone is asked which part they want to contribute to. Normally, this will depend on the technical aspects of that section and whether a person feels they can manage the workload and use their knowledge of the subject to complete it. This is believed to be the most diplomatic way of separating out tasks to ensure people are not doing something they do not want to do, which in turn could cause friction in the group. In an effort to spread workload as evenly as possible the roles of assistant leaders were delegated at the same time. These positions were used as helpers to sections and where needed they would contribute their own knowledge to the task.

Within semester 2 we are planning on sectioning tasks to people depending on what they feel they can aid the group best in. As some people prefer or understand better certain aspects of the project, when ordering the tasks in the Gantt Chart we considered these traits to allocate resources. For example, Alkinoos and Elvis having prepared the CAD submission and having an interest in the mechanical aspect of the project, the assembly and soldering will be their main focus. Whilst Federica, Kai and Ruoning, having spent time on the coding and control algorithms, will have the software as their main focus.

There are 4 learning styles we were asked to look at and review each of them to find which position we believed we fit into best. The four styles can be summarised as the Activist, Reflector, Theorist and Pragmatist. The activists "involve themselves fully and without bias in new experiences." [2] The reflectors "like to stand back to ponder experiences and observe them from many different perspectives to think about it thoroughly before coming to a conclusion.” [2] The theorists “adapt and integrate observations into complex but logically sound theories. They think problems through in a vertical, step-by-step logical way.” [2] The pragmatists “are keen on trying out ideas, theories and techniques to see if they work in practice.” [2] In our group we adopted all 4 learning styles between us.

Alkinoos - Reflector

Federica - Pragmatist

Elvis - Activist

Ruoning - Theorist

Kai - Pragmatist

# 4. Planning and Budget

## 4.1. Gantt Chart

According to the timetable of Semester 2, the Gantt Chart is created, as shown in Figure 8.

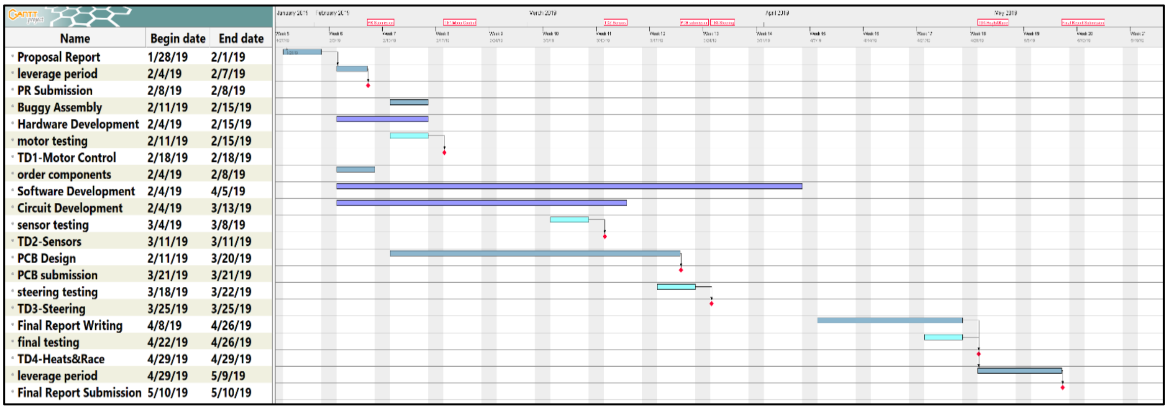



Figure 8: Gantt Chart

The arrows in the Gantt chart indicate dependencies: the submission of proposal and final reports depends on writing and editing the drafts. To guarantee the success of submission, a leverage period is set to avoid last-minute problems. Buggy construction depends on the hardware, software and circuit development which will be taking place throughout the first weeks of the semester. This process will hopefully lead to the full buggy integration. The success of technical demonstrations will be guaranteed by practicing and testing hardware and software in the lab sessions at least one week before each technical demonstration. Additionally, two of the group members are responsible for each part, based on their skills, to ensure the completion of the tasks.

## 4.2. Risk Assessment

The possible risks on the Race Day are shown in Table 2. For example, if the buggy is carried improperly, it would fall down and some components may be destroyed. Also, if batteries or the tilt sensors start leaking, people are exposed to toxic substances. Furthermore, if people touch the buggy immediately after the buggy stops running, their hands may get burned due to the overheating of the motors. Finally, if people don’t take care while walking, they may stumble on tracks or equipment on the floor. By listing these risks the necessary control measures will be taken to ensure that everyone stays safe during that day.

MANCHESTER 1824

The University of Manchester

| WORK ACTIVITY/ WORKPLACE (WHAT PART OF THE ACTIVITY POSES RISK OF INJURY OR ILLNESS) | HAZARD (S) (SOMETHING THAT COULD CAUSE HARM, ILLNESS OR INJURY) | LIKELY CONSEQUENCES (WHAT WOULD BE THE RESULT OF THE HAZARD) | WHO OR WHAT IS AT RISK (INCLUDE NUMBERS AND GROUPS) | EXISTING CONTROL MEASURES IN USE (WHAT PROTECTS PEOPLE FROM THESE HAZARDS) | WITH EXISTING CONTROLS | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | SEVERITY | LIKELIHOOD | RISK RATING | RISK ACCEPTABLE |
| Carrying the buggy | Buggy falling down | Hit people's feet | Group members | Take care when carrying the buggy | 4 | 3 | 12 | Y |
| Batteries on the buggy | Battery leaking | People exposed to toxic substances | Everyone | Check batteries frequently and wash hands after use | 5 | 1 | 5 | Y |
| Touching the buggy immediately after running | Heat | Hands could get burned | Group members | Touch buggy only when it cools down | 4 | 2 | 8 | Y |
| Tilt Sensor | Mercury in the tilt sensor | Mercury leakage | Everyone | Check it frequently and take care | 5 | 1 | 5 | Y |
| Track or equipment on the floor | People stumble | Physical injuries | Everyone | Make special warnings on the ground | 3 | 1 | 3 | Y |

**Assessment ID Number** (E&EE_Initials_DATE_Number)........................................................ **Activity Location:**......................................................................

| | | | | |
|---|---|---|---|---|
| | | | | THIS RISK ASSESSMENT WILL BE SUBJECT TO A REVIEW NO LATER THAN: (MAX 12 MTHS) |
| MANAGER/SUPERVISOR | NAME: Emad Alsusa | SIGNED: Emad Alsusa | DATE: Feb. 4th 2019 | |
| Student: | NAME: Alkinoos, Elvis, Federica, Kai, Ruoning | SIGNED: Alkinoos, Elvis, Federica, Kai, Ruoning | DATE: Feb. 4th 2019 | |

Version 5, Revision 0.4 *(5th October, 2009)* 1 of 2

MANCHESTER 1824

The University of Manchester

**IF THE ANSWERS TO ANY OF THE QUESTIONS BELOW IS YES THEN ADDITIONAL SPECIFIC RISK ASSESSMENTS MAY BE REQUIRED.**

| | | | |
|---|---|---|---|
| IS THERE A RISK OF FIRE? | Y | DOES THE ACTIVITY REQUIRE ANY HOME WORKING? | Y |
| ARE SUBSTANCES THAT ARE HAZARDOUS TO HEALTH USED? | Y | ARE THE EMPLOYEES REQUIRED TO WORK ALONE | N |
| IS THERE MANUAL HANDLING INVOLVED? | Y | DOES THE ACTIVITY INVOLVE DRIVING | N |
| IS PPE WORN OR REQUIRED TO BE WORN? | Y | DOES THE ACTIVITY REQUIRE WORK AT HEIGHT | N |
| ARE DISPLAY SCREENS USED? | N | DOES THE ACTIVITY INVOLVE FOREIGN TRAVEL | N |
| IS THERE A SIGNIFICANT RISK TO YOUNG PERSONS? | N | IS THERE A SIGNIFICANT RISK TO NEW / PREGNANT MOTHERS? | N |

***Severity value*** **= potential consequence of an incident/injury**

| | | |
|---|---|---|
| 5 | Very High | Death / permanent incapacity / widespread loss |
| 4 | High | Major Injury (Reportable Category) / Severe Incapacity / Serious Loss |
| 3 | Moderate | Injury / illness of 3 days or more absence (reportable category) / Moderate loss |
| 2 | Slight | Minor injury / illness – immediate First Aid only / slight loss |
| 1 | Negligible | No injury or trivial injury / illness / loss |

***Likelihood value*** **= what is the potential of an incident or injury occurring**

| | |
|---|---|
| 5 | Almost certain to occur |
| 4 | Likely to occur |
| 3 | Quite possible to occur |
| 2 | Possible in current situation |
| 1 | Not likely to occur |

***risk rating = severity value × likelihood value***

***risk ratings*** **are classified as *low* (1 – 5), *medium* (6 – 9) and *high* (10 – 25)**

**Risk Classification and Actions:**

| Rating | Classification | Action |
|---|---|---|
| 1 – 5 | Low | Tolerable risk - Monitor and Manage |
| 6 – 9 | Medium | Review and introduce additional controls to mitigate to "As Low As Reasonably Practicable" (ALARP) |
| 10 – 25 | High | Stop work immediately and introduce further control measures |

| LIKELIHOOD \ SEVERITY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | Low | Low | Low | Low | Low |
| 2 | Low | Low | Medium | Medium | High |
| 3 | Low | Medium | Medium | High | High |
| 4 | Low | Medium | High | High | High |
| 5 | Low | High | High | High | High |

Version 5, Revision 0.4 *(5th October, 2009)* 2 of 2

Table 2: Risk Assessment for Race Day

## 4.3. Budget

The components that need to be purchased are shown in Table 3. Since the buggy needs 5 TCRT5000 sensors but the freely-issued ones are only two, 3 additional sensors need to be purchased. The same stands for the small PCBs. Two tilt sensors are needed to measure the angle of the heap with two additional ones for back-up.

| Item | Quantity | Cost ( £ ) |
|---|---|---|
| TCRT5000 | 3 | 1.92 |
| Sensor mini PCBs | 2 | 2 |
| Tilt sensors | 4 | 9.6 |
| | | Total: 13.52 |

Table 3: Items to purchase

## 4.4. Total Cost

In the following table the total cost of all the components used is calculated. For the PCB Fabrication a quote was obtained by PCB Train and also an approximate cost for the manufacturing of the chassis was extracted.

| Item | Quantity | Cost( £ ) |
|---|---|---|
| resistors | 12 | 1.2 |
| TCRT5000 | 5 | 3.2 |
| HM-10 Bluetooth Module | 1 | 16.36 |
| Chassis | 1 | 42 |
| Front wheel | 1 | 2.5 |
| Rubber Tyre | 2 | 2.9 |
| Motor B | 2 | 14.22 |
| Gearbox box | 2 | 14 |
| NUCLEO-F401RE | 1 | 15 |
| MBED-016.1 | 1 | 33.09 |
| STM breakout board | 1 | 10 |
| Controller Board | 1 | 30 |
| Sensor mini PCBS | 5 | 5 |
| Battery holder | 1 | 3.5 |
| Batteries | 8 | 16 |
| Insulation tape | 1 | 2 |
| Cable ties | 3 | 0.6 |
| stripboard | 1 | 3.5 |
| Tilt sensor | 2 | 4.8 |
| PCB Fabrication [3] | 1 | 49.1 |
| Chassis Fabrication [4] | 1 | 27.8 |
| | | Total: 296.77 |

Table 4: Total Cost of components and buggy

# 5. References


[1] ST Life Augmented. (2015, Jan). *STM32F401xD – xE*. Available: https://www.st.com/resource/en/datasheet/stm32f401re.pdf , p. 107, [Accessed: 05- Feb- 2019]

[2] "Honey and Mumford — University of Leicester", Www2.le.ac.uk, 2018. [Online]. Available: https://www2.le.ac.uk/departments/doctoralcollege/training/eresources/teaching/theories/honey-mumford , [Accessed: 16- Dec- 2018]

[3] PCB Train. Available: https://www.pcbtrain.co.uk/quote-order , [Accessed: 05- Feb- 2019]

[4] Available: https://www.bearingboys.co.uk/Acetal-/Acetal-Sheet-500mm-x-500mm-x-3mm-NaturalWhite-37837-p , [Accessed: 05- Feb- 2019]