The University of Manchester

Department of Electrical and Electronic Engineering

Embedded Systems Project 2020-21

Proposal Document

Title: Overview of the project

Group Number: 1

Group members:	ID Number	I confirm that this is the group's own work.
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Date: 18/02/2021

Contents

Introduction

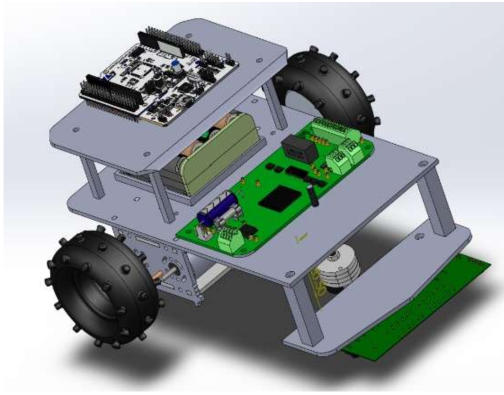


Figure 1 Solidworks CAD design of the final buggy construction

The purpose of this project is to build a buggy that can be programmed to follow a white line of width 17 mm [1]. This will be achieved by designing the chassis (as seen in figure 1) and using the TCRT5000 line sensor.

This document highlights the decisions taken in order to make the buggy work, as well as the rationale behind the decisions made. This was achieved by going through multiple labs and calculations, to obtain the optimal components to be used. This document also details the steps undertaken to work as a team to complete the given tasks, including communication and collaborative working. Finally, this report details the project plan, the main deliverables, and deadlines (a brief summary is given below). The components used and their relative prices are specified to assess the budget of the project.

Figure 1 shows the final construction of the buggy, it is shown to have multiple layers. The top layer contains the microcontroller for easy access. The middle part contains the battery pack, with a battery pack holder, in addition to the motor drive board. Finally, the bottom part of the chassis holds the line sensor PCB to the correct height away from the ground.

Approaching deadlines:

- 22nd of March: Motor control demonstration. [2]
- 12th of April: Sensors demonstration [2]
- 19th of April: Demonstration on the control/steering of the buggy. [2]
- 26th of April: Buggy completion and testing date. [2]
- 14th of May: Final report to be submitted. [2]

Technical Overview

The motor provides the buggy with the driving force required to move forward. It is what drives the gears and the rubber wheels, affording enough driving force to move the buggy across a flat surface and up an inclined slope. The required force and torque to move the buggy was found by first determining K_T and K_E. This was determined by plotting T versus I and E versus ω for the motor while running and using equations 1 and 2 [3]:

$$T = K_T I \tag{1}$$

where K_T is the motor torque constant

$$E = K_E \omega \tag{2}$$

where K_E is the motor back EMF constant

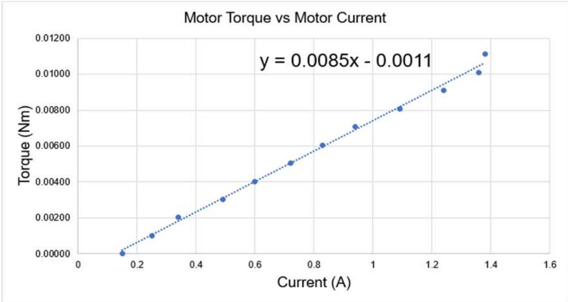


Figure 2 - Relationship between motor torque and motor current while the motor is running [3]

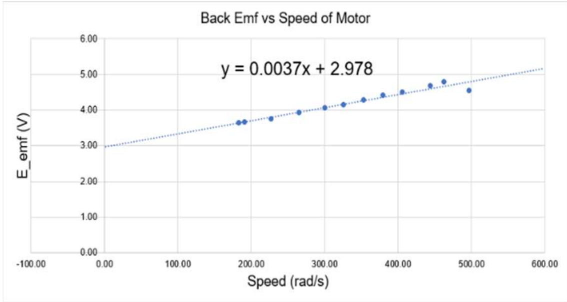


Figure 3 - Relationship between motor back emf and motor speed while the motor is running [3]

From the gradient of figure 2, the value of K_T was found to be 0.0085 NmA^{-1}, and similarly from the gradient of figure 3, K_E was found to be 0.0037 NmA^{-1}. Theoretically, these values should be the same, but differed due to experimental error [3].

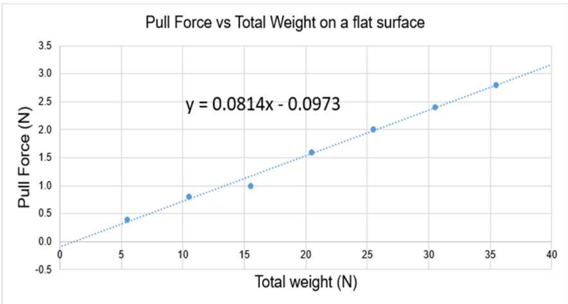


Figure 4 – Relationship between the pull force on a flat surface with the total weight of the buggy

Next, the value of F_{Pull} , the force required to move the buggy, was calculated. The total minimum force required by the buggy to ascend the slope was calculated using the equation 3 [3]:

$$F = mg \sin\theta + c_f mg \cos\theta \tag{3}$$

Then, the torque required was calculated using the equation [3]:

$$T = F_{pull} r \tag{4}$$

where r is the radius of the wheel/motor shaft.

c_f was determined by finding the gradient of figure 4, giving a value of 0.0814. The mass of the buggy was estimated by the following sum to be:

m = 70 g (MC board) + 38 g (breakout board) + 53 g (motor drive board) + 265 g (battery pack) + 2(133 g + 95 g) (motors and wheels) + 119 g (castor wheel) + 30 g (ball castor) +560 g (test chassis) = 1591 g = 1.591 kg [3].

Then, F_{Pull} to move the buggy on a flat surface was calculated [3]:

$$F_{pull} \geq (0.0814 \times 1.591 \times 9.8) = 1.27 \text{ N}$$

From there, the force required to move the buggy up an inclined plane of 18˚ was calculated [3]:

$$F = (1.591 \times 9.81)\left((8.14 \times 10^{-2} \cos 18) + (8.14 \times 10^{-2} \sin 18)\right) = 6.03 \text{ N}$$

Therefore, the force required on each wheel will be 3.015 N, as there are two wheels. Finally, taking the wheel radius to be 40 mm, the torque required to move the buggy from stationary on a flat surface per wheel was calculated [3]:

$$T = Fr = 40\times10^{-3}\times 1.27 = 0.0508 \text{ Nm}$$

The torque required to move the buggy from stationary up the slope per wheel was calculated [3]:

$$T = Fr = 40\times10^{-3}\times 6.03 = 0.2412 \text{ Nm}$$

The purpose of the software is to control the motion of the buggy. After the buggy is turned on, it will enter a sleep state until a white line is detected by the line sensors [4]. After the line is detected, the motors will turn on and the buggy will move at a predetermined speed [4]. When a turn is detected, the motors will move with different driving forces to redirect the buggy [4]. When the buggy reaches a slope, the motor current will increase, to increase the speed and allow the buggy to ascend the slope, and when the buggy is descending, the speed will be appropriately altered [4]. When the buggy reaches the end of the line, a Bluetooth signal will be sent to it to make it turn it and go back to the start [4]. At the end of the track, the motors will brake, and the buggy will come to a stop within 20 cm of the line [4]. The buggy will remain stationary unless a white line is detected by the line sensors, or a Bluetooth signal is detected [4]. The software section of Design Report 2 contains the case description and the object specification of the software.

The line sensor that will be used in the buggy is the TCRT5000. This sensor was chosen as it contains a phototransistor and an emitter together in a small package, which allows us to add multiple sensors into the chassis [4]. Also, the emitter and phototransistor were designed to be used together, which means there will be no compatibility issues [4]. Furthermore, the phototransistor is coated, which blocks out any background light outside the IR range, allowing us to only detect the reflected light from the emitter [4]. Finally, the emitter and phototransistor are separated by a block between them, which stops the light going directly from the emitter to the phototransistor [4].

To control the velocity of the wheels, a set control algorithm is required that reads the signals coming from the line sensor and executes alterations to the direction and speed of wheels [4].

In step control, sensor measurements are made between -1 and 1 (left or right of line)[4], which leads the buggy to zigzag across the white line. Using a dead zone with step control will increase the stability and reduce this zigzag affect, however this is unsuitable for a lap with a bend in it because, when the curvature radius is too small, the sensors will not receive information quickly enough.[4]

Using PID (potential-integral-differential) control uses the same range of sensor measurements as step control, but each value of the sensor measurements represents a different value of u(t), leading to much less deviation of the white line [4]. An integral part of the control is to overcome the offset from the line caused by steady state offset, and the differential control is added to improve smoothness of the algorithm. All this together describes the equation for the control algorithm [4]:

$$u(t_k) = \left[K_p e(t_k)\right] + \left[u_i(t_k - 1) + K_i e(t_k) T_s\right] + \left[K_d \frac{e(t_k) - e(t_{k-1})}{T_s}\right] \quad (5)$$

The chassis is split into four layers (as seen in figure X):

- The main chassis,
- The top chassis,
- The bottom chassis, and,
- The battery pack holder

The main chassis is the largest part of the buggy, connecting all other layers. The Top chassis holds the microcontroller, allowing the buggy to be shorter for easier manoeuvring around a turn. The bottom chassis holds the line sensors at their functioning distance from the ground (2.5mm), allowing the sensors to pick up the white line. The battery pack holder attaches the battery pack to the main chassis [4].

Stress analysis shows that the maximum deflection for the main chassis is at 1.132 mm and 0.01339 mm for the bottom chassis[4]. The other layers are fixed from all four sides so the deflection is negligible. Acetyl (the material of choice for the chassis) has a relatively low density, among other parameters such as Young's modulus and Flexural strength, which is why stress analysis showed low deflections.

The rear wheels are at the back of the buggy to push back the centre of gravity, improving control of the buggy. The front wheel to balance this on the floor is a light, small castor ball centralised and placed behind the line sensors, so that the sensors can track the line before motion.[4]

The multi-layer chassis is more likely to be compact compared to other chassis. This gives the buggy an edge as its turning speed will be faster and the stress will be more spread across layers, making it sturdier. Also, designing the buggy into layers makes it more compact so it is easier to control. In addition, we added a battery pack holder to the base of the main chassis; A light, simple design to lock into place the battery pack holder without the need for Velcro or tape.

As well as this, the addition of two extra sensors should improve information collected by microcontroller and thus improve stability. Wall sensors on either side of the chassis allow the buggy to measure the distance between itself and the walls, ensuring we can centralise our buggy on the track and ensure the chance of collision is minimised.[4] Finally, an ultrasound sensor implemented on the buggy will give additional control and manoeuvrability around obstacles.

Team Organisation

In the group, the assessments are divided into 3 parts for 2 team members to work on, and everyone could choose what they wanted to work on, hence the team worked efficiently and flexibly. In order to finish the project on time, everyone must finish their own parts before the deadline which has been decided on in the meeting. At this point all 6 members meet up and look at all the relevant parts done by each pair. This allows for checking of the work multiple times by different people.

To keep the responsibility for every student the same, the group assigns the tasks according to the proportion of marks in order to share the workload evenly.

The distribution of assignment is entirely voluntary, and every member tries their best to help other members once they finish their own parts, which helps the group finish the work on time. After the task is reassigned, the group usually sets a deadline which is at least one week earlier than the deadline on blackboard. Hence, the team has plenty of time to make final adjustments and checks to ensure that they get the most marks.

In addition to the tasks, there are a few formal roles assigned for team organisation, so that the project runs smoothly. There is a project manager, which ensures that the project runs smoothly and that all of the tasks are done on time. There is the secretary that takes note of any actions taken in the meetings and conclusions for future meetings. There is also, the journal writer, that takes the notes written by the secretary and notes down what everyone has done individually that week and writes a journal post on blackboard with the following information. Finally, there is the finance manager, which takes care of all of the costs and budgets and is responsible for the ordering of the parts.

There is a shared folder to upload work, and every group member can edit any file on this shared folder. The shared folder also shows the submitting time and name of the member. The blackboard journals contain a record of the work for each week, as well as a list that shows each individual member's work done that week.

Most of the communication happens via WhatsApp. Furthermore, the team has multiple online meetings each week via zoom.

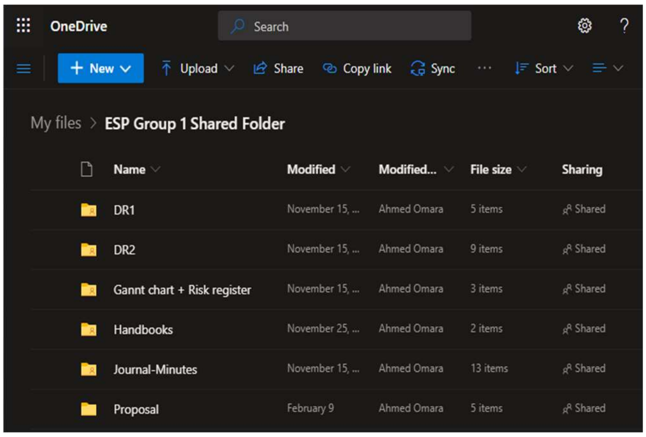


Figure 5 The shared space for any files involved in the course of the project

When making decisions, everyone will talk about their own mindset and give suggestions. Everyone was happy when making decisions finished. meetings are held online; the quantity and quality of communication spent in online meetings is much greater than messaging in a group chat (The WhatsApp group can be seen in figure 6).

When receiving a new project, each member reads the given information carefully and notes down some key points. In meeting, the group presents their ideas and provides their input, from which the work is split up in different ways depending on the number of tasks and the difficulty of the task, such that the work is split up evenly. The modes of work used, include:

- Group Work
- Individual Work
- Working in a pair

When each member finishes their part of the work, the subgroup/whole group will combine their efforts to improve each other's parts. Reading the report together online makes the finding and correction of errors easier, which improved the quality of the report, as everyone partook in providing suggestions for improvement. This allowed for the work to be proofread multiple times.

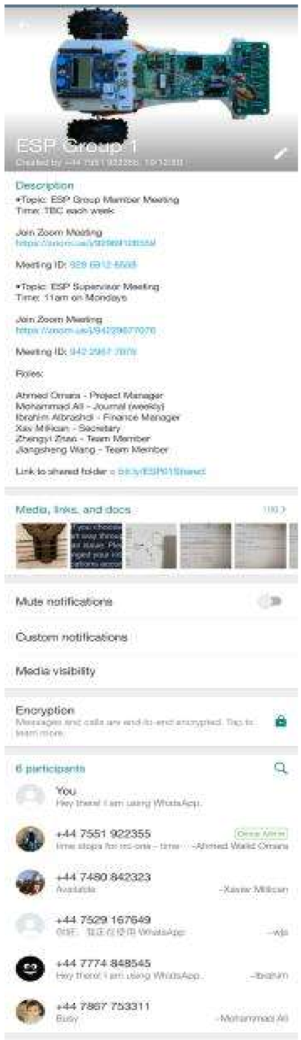


Figure 6 WhatsApp group for the team

Often, the group set a deadline in the meeting, by which members should finish the draft before the final deadline, making the plan simple and clear. In the group, the sense of responsibility was strong, and everyone had their tasks completed on time, so everyone was always doing something for the group.

Individual work is very different from group work. The quantity of work involved for this project is huge, so the efficiency of group work is very important. Firstly, communication is a key point, so the group had meetings at least twice a week via zoom (the meeting link can be seen in figure 7) and always kept in touch via WhatsApp. Secondly, timing was also a key point, because if one person couldn't finish their work on time, then that would have wasted a lot of time for other members and the deliverable would be delayed, and hence the group could potentially miss the deadline or work would be incomplete. Finally, assistance is key; when someone encountered any problems, everyone was available to give a helping hand, so that the workload could be effectively covered, and the quality of work is increased.

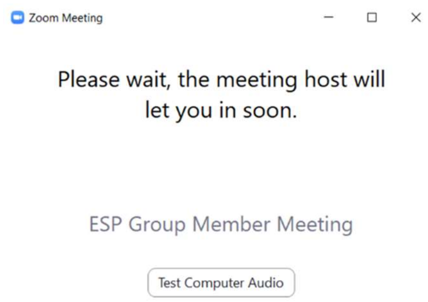


Figure 7 Zoom meeting

Each member of the group has a different learning style and will go around completing their work in alternative ways. To accommodate this, the group promotes freedom of selection of tasks and a loose timetable of when to work, as long as deadlines (internal or external) are met.

Planning and Budget

The key deliverables in this project involve, four technical demonstration (the deadlines for these deliverables are mentioned in the introduction) and one final report. In the technical demonstrations, the aim is to demonstrate that a certain part of the hardware and software is working at a given time [1]. Each technical demonstration depends on the earlier technical demonstration, so it is imperative to pass the earlier technical demonstrations to move on with the project [1]. The Gantt chart displayed in figure 7 displays all the deliverables and the required deadlines, illustrating the dependencies and the resources required for each task. If any of these deliverables are not met on time, then the contingency would be to try to work on it later and plan for the next technical demonstration [1]. If the previous technical demonstration cannot be completed before the upcoming technical demonstration, then plans should be made to focus on the upcoming technical demonstration and come back to the missed work later. The system should be tested multiple times before the technical demonstrations and should be integrated beforehand.

The 1st technical demonstration involves the motor control. The aim of this technical demonstration is to establish the relevant registers on the microcontroller and use them to adjust the duty cycle of the PWM outputs of a test input in order to alter the speed of the motors and hence measure the speed of the motors using the encoders [1]. Another aim of this technical demonstration is to be able to change the bridge control mode of the motors; this is in order to observe the output voltages in unipolar mode compared to bipolar mode. The final part of this technical demonstration involves showing that the motors can drive the buggy in the given path [1]. This technical demonstration depends on the software development lab for developing the code of the motor control [1]. This should involve one team member in the software lab, another team member for designing the hardware and assembly, and another team member for testing, finetuning and review [1].

The 2nd technical demonstration involves the sensors [1]. This is to ensure that the sensors on the buggy (not including the wheel encoders) are working in the intended way [1]. At this stage, the sensors should be fitted into a completed array, even if they are not fitted onto the buggy yet. In this technical demonstration it is required that the correct signals be received and displayed in the correct format (e.g., a graphical representation). At this stage, the circuit schematics, board layout and wiring diagrams should be completed and brought into the demonstration [1]. At this stage it is necessary to demonstrate the Bluetooth communication between a mobile phone and the buggy [1]. It is necessary to explain what will happen in case of changes in the track or ambient light and how the buggy will respond in such cases [1]. This depends on the 1st technical demonstration and as such should be completed after. This also depends on the software and circuit development labs for designing the sensor circuits and writing code for controlling the sensors. This should involve one team member in the software lab, another team member for the circuit development lab, another team member for designing the hardware and assembly, and another team member for testing, finetuning and review [1].

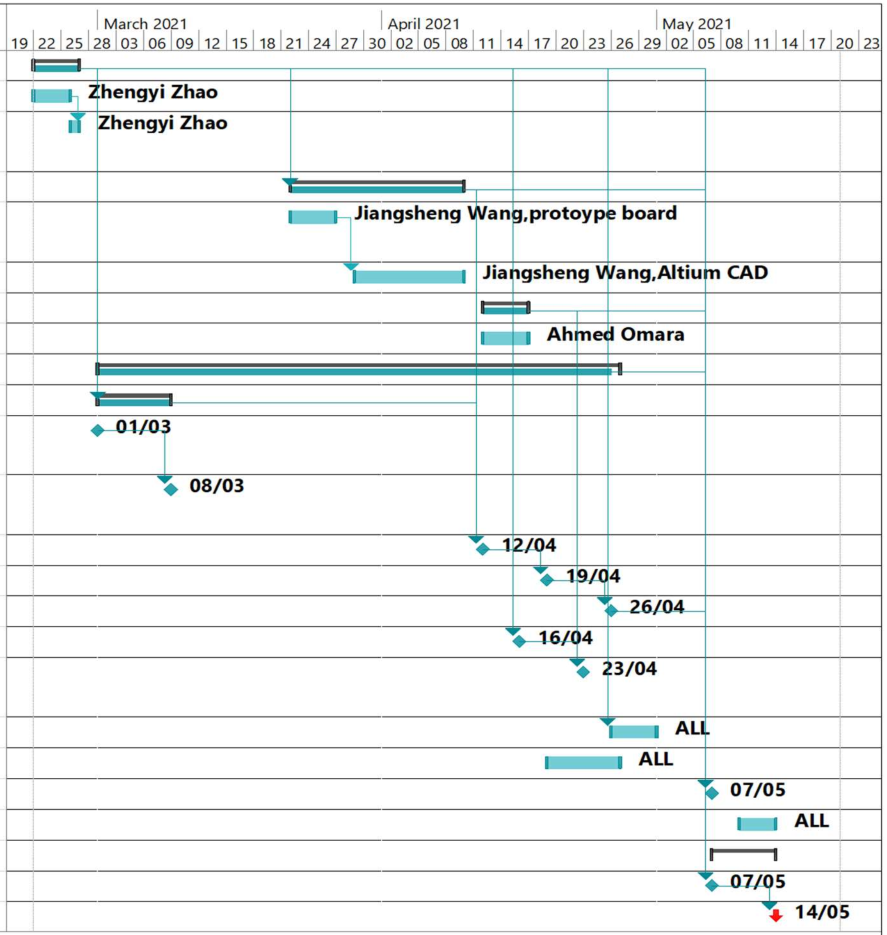
The 3rd technical demonstration involves the steering of the buggy. At this stage, the buggy should be fully assembled, and the sensors should be fully operational. In this technical demonstration it is required to demonstrate that the buggy can follow a small track containing a white line on a flat surface [1]. This track may have, line breaks, inclines, or curves. The circuit diagrams should be present, and the operation of speed control should be shown during the demonstration. The buggy should be able to make a 180° turn and return to the beginning [1]. At the end of the track, the buggy should be able to stop within 30 cm of the white line. This depends on the first 2 technical demonstrations and as such should be completed after the first 2 technical demonstrations. This also depends on the software development Lab for programming the control mechanism for the steering of the buggy. This should involve one team member in the software lab, another team member for designing the hardware and assembly, and another team member for testing, finetuning and review.

The 4th and final technical demonstration involves demonstrating that the buggy is fully functional and follows the intended track. Marks will be awarded for each section, where bonus marks will be awarded if the buggy finishes in the fastest time [1]. Other than the turn point, the buggy should be able to operate autonomously and only require a Bluetooth signal when it reaches the end of the track. This is the final technical demonstration and as such depends on all of the previous technical demonstrations [1]. This also depends on all hardware and software management and finetuning that should have occurred after the 3rd technical demonstration. This should involve one team member in the software lab, another team member for the circuit development lab, another team member for designing the hardware and assembly, and another team member for testing, finetuning and review.

The final deliverable after the technical demonstrations is the final report [1]. This involves the full planning and execution the project, including the components used, team organisation and planning, the costs, and an analysis of the technical demonstrations. This should be completed after the technical demonstrations; however, each part of the report may be started after each technical demonstration. This depends on all of the deliverables that have come before this, including all of the technical demonstrations and all previous reports. This should involve all team members and should ideally work in parallel to the technical demonstrations and should be completed afterwards.

Besides the technical demonstrations and the final report, there are a few deadlines that should be met. These include the deadline for changing the gearbox ratio and the deadline for this is any time before the 2nd technical demonstration. The 2nd deadline involves, the final PCB submission, which should be submitted before noon Friday of week 8 [2]. The 3rd deadline is the laser cutting submission of the chassis, which should be submitted by noon Friday of week 9 [2]. After all of the technical demonstrations have been completed, the parts for the buggy should be returned before noon Thursday Week 12 [2].

ID	Task Name	Duration	Start	Finish
1	**Software development lab**	**5 days**	**Mon 22/02/21**	**Fri 26/02/21**
2	Write code from flowchart	4 days	Mon 22/02/21	Thu 25/02/21
3	test that program functions as intended	1 day	Fri 26/02/21	Fri 26/02/21
4	**Circuit development lab**	**15 days?**	**Mon 22/03/21**	**Fri 09/04/21**
5	Design circuit on protype board and test that circuit works	5 days	Mon 22/03/21	Fri 26/03/21
6	Design circuit on a PCB	10 days	Mon 29/03/21	Fri 09/04/21
7	**Hardware development lab**	**5 days**	**Mon 12/04/21**	**Fri 16/04/21**
8	build chassis from CAD design	5 days	Mon 12/04/21	Fri 16/04/21
9	**Technical demonstrations**	**41 days**	**Mon 01/03/21**	**Mon 26/04/21**
10	**TD1 - Motor Control**	**6 days**	**Mon 01/03/21**	**Mon 08/03/21**
11	Demonstrate motor control in lab	0 days	Mon 01/03/21	Mon 01/03/21
12	Last chance to change gearbox ratio	0 days	Mon 08/03/21	Mon 08/03/21
13	TD2 - Sensors	0 days	Mon 12/04/21	Mon 12/04/21
14	TD3 - Control/Steering	0 days	Mon 19/04/21	Mon 19/04/21
15	TD4 - Heats/Race	0 days	Mon 26/04/21	Mon 26/04/21
16	Final PCB Submission (@12pm)	0 days	Fri 16/04/21	Fri 16/04/21
17	Laser cutting and order submission (@12pm)	0 days	Fri 23/04/21	Fri 23/04/21
18	Blackboard quiz	5 days	Mon 26/04/21	Fri 30/04/21
19	Submit text for prizes	6 days	Mon 19/04/21	Mon 26/04/21
20	Peer review form deadline (@1pm)	0 days	Fri 07/05/21	Fri 07/05/21
21	Return the parts of the buggy	4 days	Mon 10/05/21	Thu 13/05/21
22	**Final report**	**5 days**	**Fri 07/05/21**	**Fri 14/05/21**
23	Final report draft deadline	0 days	Fri 07/05/21	Fri 07/05/21
24	Final report deadline	0 days	Fri 14/05/21	Fri 14/05/21



Project: EEEN21000 Embedded Systems Project
Date: Wed 17/02/21

Task	Manual Task	Start-only
Split	Duration-only	Finish-only
Milestone	Manual Summary Rollup	Deadline
Summary	Manual Summary	Progress

Page 1

Figure 7 A Gantt Chart Detailing the tasks to be done and their timeframe

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Risk Assessment

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
Final race	Water damaging the circuit	Buggy catching fire	Student and staff near the buggy	Have no liquids near the electronics	2	3	6	Y
Final race	Overload motor with high current, causing motor to overheat	Buggy catching fire	Student and staff near the buggy	Limit the current to the motor	2	2	4	Y
Final race	Buggy getting out of the track	Buggy collides with other buggies and people.	People near the track of the race	Keeping a safe distance away from the track.	2	4	8	Y

Assessment ID Number: E&EE_IB_15/02/2021_10513452 **Activity Location:** University of Manchester

				THIS RISK ASSESSMENT WILL BE SUBJECT TO A REVIEW NO LATER THAN: (MAX 12 MTHS)
MANAGER/SUPERVISOR	NAME: Emad Alsusa	SIGNED:	DATE: 15/02/2021	14/02/2022
Student:	NAME: Ibrahim Al Brashdi	SIGNED: Ibrahim	DATE: 15/02/2021	14/02/2022

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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?	N
ARE SUBSTANCES THAT ARE HAZARDOUS TO HEALTH USED?	N	ARE THE EMPLOYEES REQUIRED TO WORK ALONE	N
IS THERE MANUAL HANDLING INVOLVED?	N	DOES THE ACTIVITY INVOLVE DRIVING	N
IS PPE WORN OR REQUIRED TO BE WORN?	N	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)**

SEVERITY

LIKELIHOOD	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

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

A budget for two Ultrasonic sensors and four additional Reflective Optical Sensors will be needed, costing each £3.04 and £0.72 respectively. Another £10 are added for the budget in case of a failure of any circuit component, so a budget of £18.96 is needed.

Part	Quantity	Cost Each (£)	Total cost (£)
Leaded resistors	**12**	**0.10**	**1.20**
Red LED	**1**	**0.45**	**0.45**
7 Element Darlington	**1**	**0.47**	**0.47**
Reflective Optical Sensor	**6**	**0.72**	**4.32**
Broadcom encoders	**2**	**21.4**	**42.80**
Bluetooth Module	**1**	**13.53**	**13.53**
Chassis	**1**	**42.00**	**42.00**
Front Wheel	**1**	**2.47**	**2.47**
Rubber Tyre	**2**	**1.45**	**2.90**
Motor A	**2**	**3.92**	**7.84**
Gearbox Box	**2**	**7.00**	**14.00**
STM32F401RE Nucleo Board	**1**	**15.00**	**15.00**
Mbed Application Shield	**1**	**42.54**	**42.54**
STM32 Break out board	**1**	**10.00**	**10.00**
I/O board	**1**	**30.00**	**30.00**
Controller Board	**1**	**30.00**	**30.00**
Jumper Cables	**1**	**4.19**	**4.19**
Sensor Mini PCBs	**3**	**1.00**	**3.00**
Battery Holder	**1**	**2.28**	**2.28**
Batteries	**8**	**2.00**	**16.00**
Insulation Tape	**1**	**2.56**	**2.56**
Cable Ties	**3**	**0.09**	**0.27**
Stripboard	**1**	**4.16**	**4.16**
Ultrasonic Sensor	**2**	**3.04**	**6.08**
Total buggy cost	**£ 298.06**		

Table 1 – Cost of buggy parts [1]

Table 1 shows the cost of each part within the buggy, in total the buggy is going cost £298.06.

Summary

In conclusion, this document is a short overview of each section researched and the method behind how the group has been planned and organised.

The driving force required to move the buggy on a flat surface is 1.27 N, while the torque is 0.0508 Nm. For a slope, the driving force required is 6.03 N and the torque is 0.2412 Nm. The buggy will be programmed in a way that will allow it to follow a white line using the TCRT5000 line sensor and adjust the speed and direction accordingly.

The control algorithm of choice is PID, as it allows for less deviation from the white line. The chassis consists of 4 layers, which makes the buggy more compact as well as spread the stress across the layers. This also allows us to make the bottom layer 2.5 mm from the ground, which is the optimal distance for the TCRT5000 line sensor.

The group consists of 6 members and is split internally into 3 subgroups. This allows us to split the work evenly, allowing more than 1 person to work on each section. The group communicates through a WhatsApp group chat, and meetings are conducted on zoom each week.

A Gantt chart was created that includes all the key deliverables and deadlines, including 4 technical demonstrations and a final report. Alongside the Gantt chart, a risk assessment was created in order to detail potential risks and measures to counteract them. The total cost of the buggy will be £298.06, and a list of all the components and their price is available above. The additional budget required in order to buy the extra required components is £18.96.

The Knowledge and understanding of each technical section relating to designing the buggy has been developed and expanded by every group member, whilst also ensuring not being over budget. This will allow us to create a buggy that functions as intended.

References

[1] L. Marsh. Procedures Handbook. (2020 Winter). EEEN21000 Embedded Systems Project. University of Manchester. United Kingdom

[2] L. Marsh. Procedures Handbook. (2019 Winter). EEEN21000 Embedded Systems Project. University of Manchester. United Kingdom

[3] A. Omara, M. Ali, I. Albrashdi, Z. Zhao, X. Millican, J. Wang. "Design Report 1". University of Manchester. Manchester. UK. 2020

[4] A. Omara, M. Ali, I. Albrashdi, Z. Zhao, X. Millican, J. Wang. "Design Report 2". University of Manchester. Manchester. UK. 2020