The University of Manchester

Department of Electrical and Electronic Engineering

Embedded Systems Project 2020-21

FINAL REPORT #1

Group Number: 28

Group members:	ID Number	I confirm that this is the group's own work.
Seyonne Leslie-Dalley	10627531	☒
Samuel Prescott	10718137	☒
Nikoleta Nikolova	10625009	☒
Sei Yeu Chew	10631672	☒
Muaz Faisal Rafiq	10624805	☒
Cheng Chen	10730684	☒

Tutor: Dr Subhasish Charkraborty

Date: 18/05/2022

Contents

1. Executive Summary

This report identifies the success of the group specifically in terms of the buggy's performance in the heat and the progress of the group's collaboration throughout the whole project.

Team Organisation and Planning

Throughout the entirety of the Embedded Systems project, the group's collaboration skills such as time-management and communication skills have majorly improved. This improvement is evidenced by the marks given for Design Report 1: 66/100 in the first semester, to the marks given for the Proposal Report: 94/100. However, as the deadlines became more technical and less report-based the achievements of the groups also decreased due to a lack of planning and therefore lack of equality in the work split between the members. (e.g. got 55 for TD1 and 17 for TD3).

The team worked sufficiently well as a group. However, there was a clear lack of consistency in the reliability of some of the members and thus the quality of the group's achievements was affected.

Future improvements that could have been implemented were more online meetings for more executive time management and the split of the workload on a basis of individual strengths.

Final System Components

The main components used in the final buggy that were chosen and designed by the group were:

- Gearbox 2: as the perfect trade-off with torque and speed
- TCRT5000 Sensor: the most effective choice and gave a wide range of values
- A unique sensor PCB board with 6 TCRT5000 sensors with a separation distance of 20 mm and a Darlington Array: allowed for a larger coverage of the track
- Implementation of Sensor PID for line-following
- Implementation of Motor PID for speed control

Out of all the components, the control algorithms were the most important and successful as they were essentially what allowed the buggy to fulfil its main purpose - to follow a line, and therefore achieve to some degree the majority of the Embedded Systems Project deliverables.

Budget vs Outturn

The group out of a £40 budget only spent a total of £9, therefore financially the buggy was a success as it stayed well within the allocated budget.
By totalling the cost of every aspect of the buggy including freely-given parts the buggy came to a total cost of £324.92. Therefore, a suitable retail price would be anything in excess of £502.38 (50% more) in order to cover the parts costs, labour costs, and machining costs. Therefore, the retail price would be ~ £549.99.

Analysis of Heats

In the heats, the buggy failed to qualify to get a time as it couldn't complete the assessment track in one full run in either of the two tries it had. However, the buggy managed to get a score of 70/100 on the third try where it was able to complete the individual sections of the track. The main problem with the buggy in the heats was the failure of the speed control which meant that the buggy struggled to get up the hill without additional guidance. Another big issue was the chassis design as it pushed the sensors down causing there to be unexpected results in the sensor values and therefore minimised the accuracy of the line following code. Some very successful aspects of the buggy were the sensor PCB and the line-following code as they successfully performed the large majority of the time. The buggy in terms of the heats performed as initially expected and although it didn't complete the track in one full run it did manage to complete each individual aspect of the track (navigate bends, navigate up and down a hill, navigate a line end and a turnaround signal). Therefore, marking this as the main success criteria for this chapter, the buggy was a success.

2. Introduction

The Final Report aims to evaluate the group's progression in the embedded systems project throughout the success of buggy and also the collaboration and team-working skills developed by the team.

The buggy's success will be evaluated by analysing the components which made up the buggy and identifying if and why any changes were made on a software and mechanical level.

There will be further analysis of the progress of the buggy in the heats and through each technical demonstration. As stated in the [2] the buggy should be able to follow a white line on a black track provided by the university, move up a ramp with an 18-degree incline, turn around and come to a controlled stop at the end of the track through a Bluetooth signal sent from a group member at any point of time; this will make up the main points of the success criteria.

The report will assess how the team worked together and adhered to the predetermined aims and deadlines which were detailed in Design Report 2 [4] and how the group progressed in their communication and team-working skills throughout the entirety of the Embedded Systems Project.

Arguably most importantly the success of the project will be evaluated by comparing the expenditure to the set budget. A retail price for the buggy will also be calculated and critically analysed.

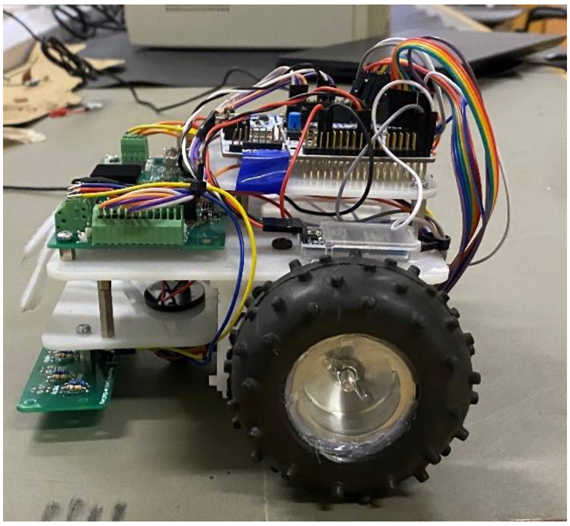

Figure 1: Image of Final Buggy

3. Team organisation and Planning

During the first semester, the most significant part of this module was the submission of both the design report 1 and 2. From the beginning of the semester, the focus was placed on the Motor characterization lab, analysing the results from this lab in order to calculate the minimum torque required for the buggy to overcome 18 degrees slope and to select an appropriate gearbox that meets the minimum torque that the buggy needs without relinquishing too much of the speed and then write the first design report using the collected information.

The objectives from the start of the Line Sensors Lab until the end of the first semester, have been building various sensors, examining different characteristics of those sensors such as optimum operation distance, dark current, how far to place the sensors from one another taking into account the occurring cross-talk, background illumination, the number of sensors needed in order the buggy to have good coverage, and also writing Design Report 2 and developing a chassis design.

During the first 2 weeks of the second semester, the team's focus was on writing a Proposal Report. The rest of the second semester was dedicated to the four technical demonstrations, the elaboration of a PCB, and the delivery of the Final Report.

Even though the proposal report and the final report were part of the second semester's assessments, the objectives as shown, have become more technically orientated during the second semester, instead of being more focused on making design decisions and writing reports as they were in the first term.

Because of this significant change in the objectives, the team needed to organise more in-person meetings during the second semester, in order for the software team to perform physical tests on the buggy and improve the code. Also, the Easter Break was between the second and the third technical demonstration which resulted in the team not having all of its resources available as usual because most of the team members went home during the break. This translated into the team starting to work on the third technical demonstration just after the second one has finished, meeting consistently throughout the week before the break, and continuing to work on it just after the end of the Easter break.

Discuss any changes to your Gantt chart during the project.

The Gantt chart for the whole project is shown in figure 2 below and contains all the deliverables and objectives for the project.

As the project has progressed, the Gantt chart has undergone multiple revisions as the project plan has changed and evolved. Since the version included in the proposal report, the major adjustments were in response to changes in the buggy development teams. All the mechanical aspects of the buggy had been completed after the second technical demonstration, so the hardware team was split: Seyonne joined the software team, and Zach joined the electronics team. The third and fourth hardware tasks were removed, as they were no longer needed. Not long after the second technical demonstration, the PCB, sensors, and wiring were fully completed as well, resulting in the third electronics task being cut short, and the fourth task being removed entirely. A milestone to indicate the completion of the PCB was added, and the electronics team began work on the final report. This was represented with the new task called “Final Report Preparation”, which was worked on by Muaz, Zach, and Caesar. This was then linked to the final report itself, which was also extended by a week since the group began working on it earlier than it was originally predicted. The final technical demonstration was simplified to just the software task. Everyone had also been properly assigned to their respective sections of the final report, as this wasn’t known at the start of the semester.

Another change was that everything around and after Easter had to be shifted by 1 week, as the dates given in the procedures handbook were wrong. The exact dates for the technical demonstrations were added, as they weren’t originally known, and they were changed from tasks into milestones. The length of the Blackboard quiz was increased by one day to account for the 24-hour window to complete it. Finally, all the tasks had been changed to accurately represent their state of completion.

Did everything go to plan, and were all deliverables achieved?

During the first report, the tasks were not delegated with the workload difficulty in mind, forcing a few of the members to work nonstop until the night before the due date. Therefore, things got out of hand when the team was working on its very first task which resulted in getting not a so good mark of 66% for the first design report. However, the group took into account those mistakes and split the workload for the next reports more evenly, had more meetings every week, and checked progress much more frequently. Those ideas turned out to be really effective as the next reports were completed a substantial amount of time before the actual deadline and exceptional grades of 83% and 94% for Design Report 2 and Proposal Report respectively have been achieved.

Regarding the technical demonstrations, the team faced a serious issue during the first one. This included having problems with the batteries of the buggy. Even though

all of the software has been developed and tested successfully, the batteries had less than 50% charge during the assessment which translated into the buggy changing its direction too slowly, so it couldn't draw out a square shape as it successfully demonstrated before the assessment. This resulted in a mark of 55% being awarded which was not what the team was aiming for.
Everything went to plan during the second technical demonstration as the team scored 100%. However, things got out of control in terms of the third demonstration. That was due to poor team organisation and bad judgment because the group did not work on the tasks set for this demonstration during the Easter break thinking that working before and after the break will be enough. Yet getting only 17% on the third technical assessment proved the time needed to finish those tasks was miscalculated by the team. And finally, everything went as planned for the final demonstration as the group knew the buggy can perform all the required tasks separately. The team got a grade of 70% from its third attempt as the buggy successfully fulfilled all the set requirements individually.

Were there any difficulties within the group and how were these resolved?

As it has been mentioned before, in the beginning, the workload was not being split evenly causing a lot of stress and feelings of unfairness and unappreciation amongst some of the members. However, those issues were brought up and taken more seriously, so the work was split more equally for the next assignments, and also more meetings were organised which allowed the team to check progress more often. This approach gave the team members who were more deadline-driven the ability to do the required work for each meeting rather than just the main deadline. Also, after the completion of the first design report, the group discussed how each member worked as an individual to better understand how the team should approach tasks and deadlines. The regular meetings ensured every team member was thoroughly familiarised with the particular task and the assigned work, enabling the group to work more closely, ask questions and help each other. Finding the team's weak spots improved communication and organisation significantly, and therefore made it easier for everyone to adjust, be productive and perform at their best.

How might have your teamwork improved if you were to do the project again?

Throughout the project, the team's organisation has improved considerably. However, we only started becoming efficient as a group during the second technical demonstration. If we were to repeat the project, we would have held more virtual meetings, due to meeting up in person usually not including all group members. Therefore, having more online meetings would result in better and more effective time management. Moreover, we would split the work across all members using a strategy that is more oriented towards the individual strengths of every member. Implementing all of those strategies, now that we know each other better, would result in the team working more efficiently, doing more quality work, and splitting the workload fairly and evenly.

Name	Begin date	End date	Resources	Coordinator
Motors Pre-Lab Work	04/10/2021	11/10/2021	Muaz,Zach,Caesar	
Motors Lab	12/10/2021	12/10/2021	Muaz,Zach,Caesar	
Design Report 1	25/10/2021	04/11/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Introduction	25/10/2021	02/11/2021	Seyonne,Nikoleta	
Motor Characterisation	25/10/2021	02/11/2021	Sam,Muaz,Zach	
Load Measurements	25/10/2021	02/11/2021	Seyonne,Nikoleta,Caesar	
Gear Ratio Selection	25/10/2021	02/11/2021	Sam,Muaz,Caesar	
Conclusion	25/10/2021	02/11/2021	Zach	Zach
Finalisation	03/11/2021	04/11/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
DR1 Submission	05/11/2021	05/11/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Sensors Pre-Lab Work	11/10/2021	25/10/2021	Sam,Seyonne,Nikoleta	
Sensors Lab	26/10/2021	09/11/2021	Sam,Seyonne,Nikoleta	
GANTT Chart & Risk Assessment	08/11/2021	11/11/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Project Plan Submission	12/11/2021	12/11/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Design Report 2	15/11/2021	02/12/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Introduction	15/11/2021	26/11/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	Zach
Software	15/11/2021	26/11/2021	Sam,Seyonne,Nikoleta	Nikoleta
Line Sensor Characterisation	15/11/2021	26/11/2021	Sam,Seyonne,Nikoleta	Sam
Circuit Diagram	15/11/2021	26/11/2021	Seyonne	Seyonne
Non Line-Sensors	15/11/2021	26/11/2021	Sam,Nikoleta	Sam
Control	15/11/2021	26/11/2021	Muaz,Zach,Caesar	Muaz
Hardware Overview	15/11/2021	26/11/2021	Muaz,Caesar	Caesar
Summary	15/11/2021	26/11/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	Zach
Finalisation	29/11/2021	02/12/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
DR2 Submission	03/12/2021	03/12/2021	Sam	Sam
CAD Drop-in	19/11/2021	19/11/2021	Zach,Caesar	Caesar
Blackboard Quiz	07/12/2021	08/12/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Peer Review	06/12/2021	09/12/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Peer Review Submission	10/12/2021	10/12/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Return Sensors Rig	17/12/2021	17/12/2021	Seyonne	Seyonne
Proposal Report Preparation	13/12/2021	17/12/2021	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Proposal Report	07/02/2022	17/02/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Introduction	07/02/2022	10/02/2022	Zach,Caesar	Caesar
Technical Overview	07/02/2022	10/02/2022	Seyonne,Nikoleta,Muaz	Seyonne, Nikoleta
Team Organisation	07/02/2022	10/02/2022	Sam,Nikoleta,Zach	Nikoleta, Zach
Planning & Budget	07/02/2022	10/02/2022	Sam,Seyonne,Muaz	Sam, Muaz
Summary	07/02/2022	10/02/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	Caesar
Draft	11/02/2022	11/02/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Finalisation	11/02/2022	17/02/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Proposal Submission	18/02/2022	18/02/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Buggy Development	15/02/2022	09/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Pickup Buggy Parts	15/02/2022	15/02/2022	Nikoleta	Nikoleta
TD1 Development	15/02/2022	28/02/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
TD1 Hardware	15/02/2022	28/02/2022	Seyonne,Zach	Seyonne
TD1 Software	15/02/2022	28/02/2022	Sam,Nikoleta	Sam
TD1 Electronics	15/02/2022	28/02/2022	Muaz,Caesar	Muaz
TD1 - Motor Control	01/03/2022	01/03/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
TD2 Development	02/03/2022	21/03/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
TD2 Hardware	02/03/2022	21/03/2022	Seyonne,Zach	Seyonne
TD2 Software	02/03/2022	21/03/2022	Sam,Nikoleta	Sam
TD2 Electronics	02/03/2022	21/03/2022	Muaz,Caesar	Muaz
TD2 - Sensors	22/03/2022	22/03/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
TD3 Development	23/03/2022	25/04/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
TD3 Software	23/03/2022	25/04/2022	Sam,Seyonne,Nikoleta	Sam
TD3 Electronics	23/03/2022	28/03/2022	Muaz,Zach,Caesar	Muaz
PCB Complete	29/03/2022	29/03/2022	Muaz,Zach,Caesar	Muaz
TD3 - Control & Steering	26/04/2022	26/04/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
TD4 Software	26/04/2022	09/05/2022	Sam,Seyonne,Nikoleta	Sam
TD4 - Heats	10/05/2022	10/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Gearbox Change Deadline	22/03/2022	22/03/2022	Seyonne,Zach	Seyonne
PCB Submission Deadline	01/04/2022	01/04/2022	Muaz,Zach,Caesar	Muaz
Laser-Cutting & Order Submission Deadline	29/04/2022	29/04/2022	Seyonne,Zach	Seyonne
Blackboard Quiz	03/05/2022	04/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Peer Review Form	09/05/2022	12/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Peer Review Submission	13/05/2022	13/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Return Buggy Parts	19/05/2022	19/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Final Report Preparation	29/03/2022	29/04/2022	Muaz,Zach,Caesar	
Final Report	02/05/2022	19/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Introduction & Summary	02/05/2022	17/05/2022	Seyonne,Zach	
Components Summary	02/05/2022	17/05/2022	Nikoleta,Muaz	
Organisation & Planning	02/05/2022	17/05/2022	Sam,Zach	
Budget vs Outturn	02/05/2022	17/05/2022	Muaz,Caesar	
Heats Analysis	10/05/2022	17/05/2022	Seyonne,Nikoleta	
Finalisation	18/05/2022	19/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	
Final Report Submission	20/05/2022	20/05/2022	Sam,Seyonne,Nikoleta,Muaz,Zach,Caesar	

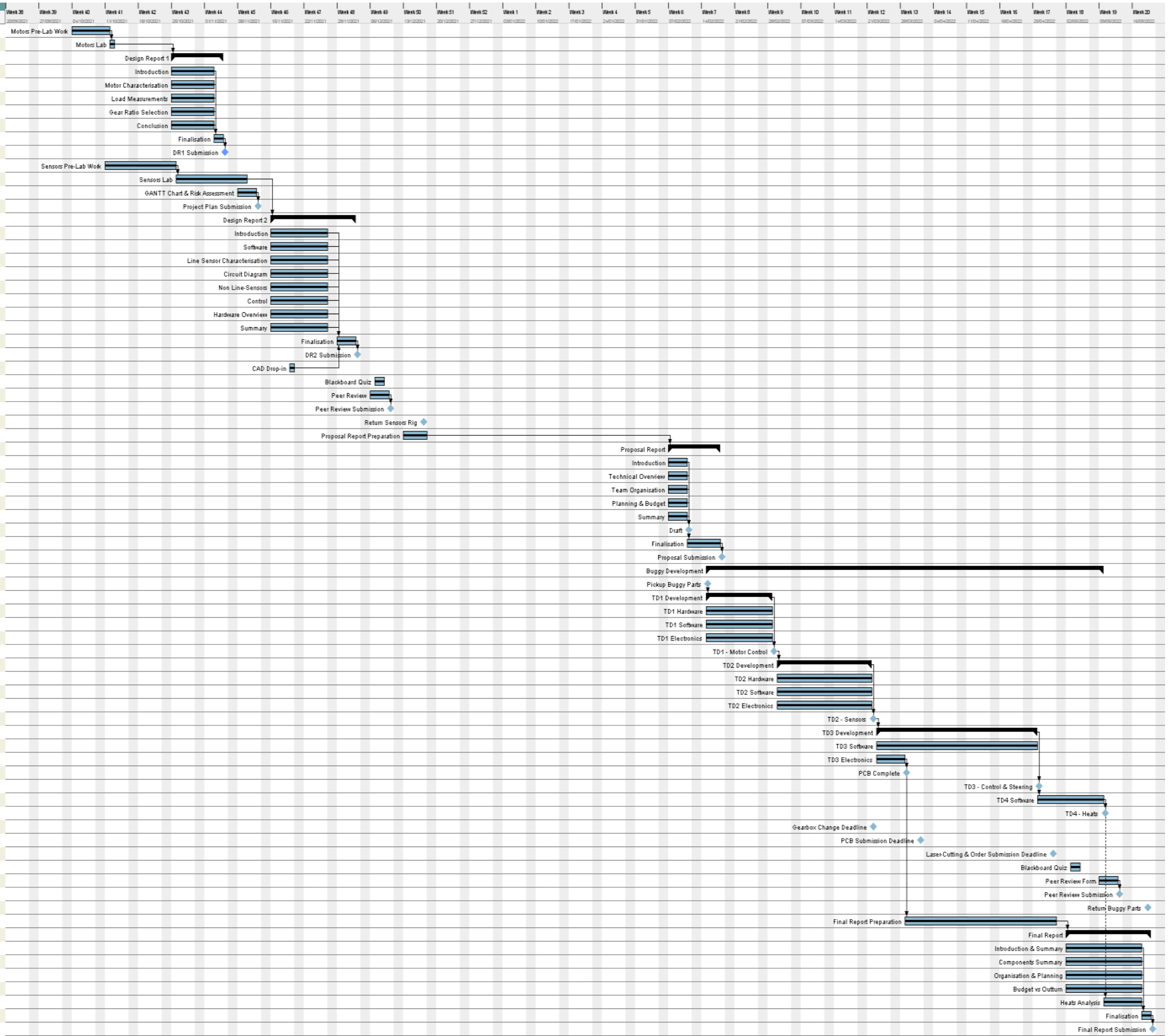

__Figure 2 : Gantt Chart__

4. Final System Components Summary

Mechanical components

The mechanical components comprise of 3 main components which are the motors, the gearbox, and the encoders. The motors provided by the university are identical throughout the entire cohort. It was apparent that the motors alone did not provide enough torque in order for the buggy to make its way up a ramp. It was calculated that the maximum output torque that the motors can provide is 0.000856 Nm (as shown in [3] while the minimum torque needed for the buggy would be 0.115 Nm. Hence, 3 different gearbox combinations were given to be tested and selected according to each group's needs. From calculations using equations provided in the Technical Handbook, it was observed that the required gear ratio for the buggy is 9.71%. Gear ratios of Gearbox 2 and Gearbox 3 both are ideal choices as they each have a gear ratio of 10.84% and 13.55% respectively. Ultimately, Gearbox 2 was selected as it did not sacrifice as much speed in comparison to Gearbox 3. The chosen gearbox was tested when the buggy was assembled giving very good results, so a decision Gearbox 2 was an appropriate choice was reached, which lead to no changes needed in terms of the gearbox. Regarding the encoders, every motor was connected to an encoder. Those encoders were able to measure and display the current speed of the wheels. Moreover, with the means of those, the motors' speed was controlled and kept constant, so the buggy doesn't speed up or slow down when it meets a slope.

Electronic components

The electronic components of this project primarily consist of line sensors and PCB. The TCRT5000 sensors were the sensors chosen for the buggy as they had properties that allowed for the most optimum performance. Lowest dark current and least affected by ambient light are the factors that need to be considered when choosing the best line sensors as both of these factors are sources of noise. The TCRT5000 proves to be the most effective sensor as it has a dark current voltage of 0.1 mV,[4] the smallest across all the options. It also has a built-in daylight blocking filter that keeps it from being affected much by visible light. With regards to the arrangement of the sensors, a total of 6 sensors in a straight line adjacent to each other was implemented to allow greater coverage. A distance of approximately 20 mm between sensors was applied as it not only provided the control algorithm with more readings but also reduced cross-talk between sensors which lessen the issues when developing the software. The sensors have been soldered onto the PCB which has been placed 5 mm off the track as sensitivity is at its peak at that point. For the PCB, it is worth mentioning that a number of headers – Digital input header, Analogue output header and Power header – are utilized to reduce the number of wires and ultimately save space on the PCB. Resistors with values of 390 Ω and 10k

Ω were chosen for the PCB on the basis of choosing an optimal current to power the LEDs. Therefore, the PCB worked very well enabling the buggy to navigate the white line accurately and competently.

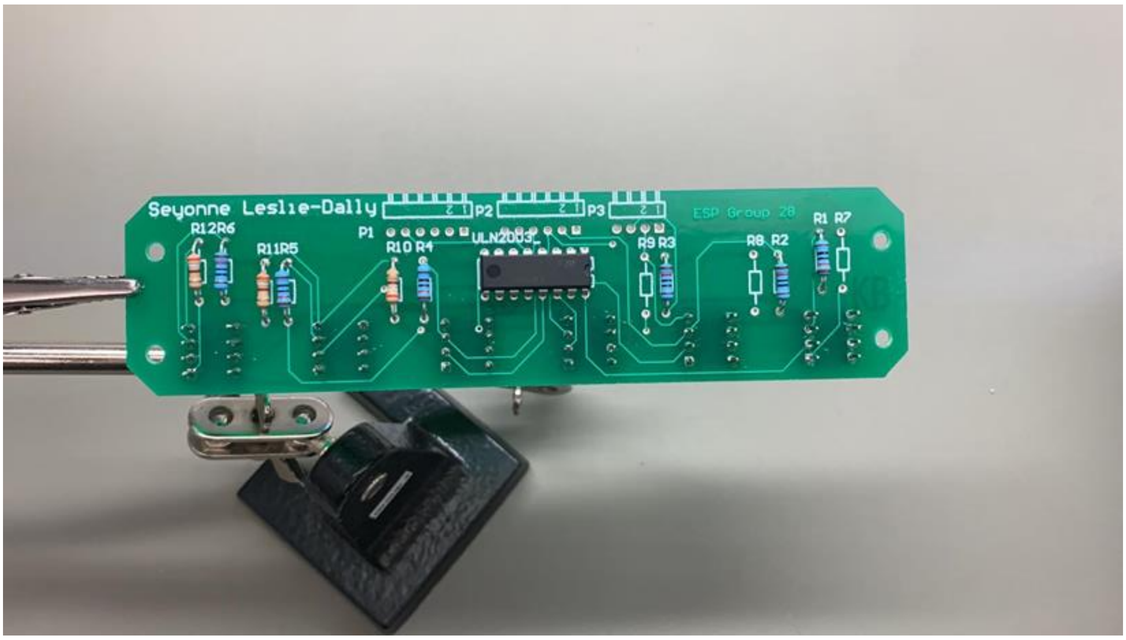

Figure 3: Image of Group 28 sensor board

Control components

Developing a control algorithm was an essential part of the implementation of the buggy as having this enabled the buggy to adjust the speed of the wheels depending on the values gotten from the encoders and regulate its direction based on the registered values from the line sensors. The control algorithm was implemented using 2 different PID controls for the sensors and the motors separately. Proportional-Integral-Derivative control system was chosen because it allowed the buggy to move around more smoothly due to the damping provided by the derivative term, it stayed directly above the line due to the integral term and had overall good control variability.

The speed/direction of the wheels was controlled by utilising the motor driver board. The wheels are powered by individual motors that will use PWM signals as inputs to control the speed while the direction is dictated by the H-bridge. To control the motors a unipolar mode has been implemented to reduce the switching losses, so a direction had to be also specified.

Software components

The first major part of the system is a Sensor Array Class which includes functions to turn the LEDs on, to turn the LEDs off, to read the value of a single sensor, to read the values of all 6 sensors, to read the position of the line, for the buggy to start to follow the line again after it turns around following a Bluetooth signal. The function dedicated to determining the position of the line takes every sensor's value with a different weight. This is implemented by multiplying the values of the sensors by different numbers from 0 to 600 with an increment of 100. This allows us to have a precise location of the white line regarding the position of the sensors.

Another crucial part is a sensor PID class, which includes a function to calculate the control signal using the PID equation. A motor class has also been developed which consists of functions to set the PWM period, to set direction of the wheels, to set the output duty-cycle, to adjust the speed of the right motor, to adjust the speed of the left motor, to stop the motor.

An additional major part that has been put in is a motor PID class which includes a function to calculate the control signal using the PID equation. Other main functions are those to set up the motors, to read the speed from the encoders, and to adjust the motors' speed based on the error of the line position compared to the offset. The offset in our case is the middle between the 3rd and the 4th sensor, which can be calculated to be 250 from the equation that determines the line’s position, which is described above.

Other crucial parts of the software are functions to set up a Bluetooth signal, also to detach the sensor ticker and the motor ticker when a Bluetooth signal is received, and to attach the tickers again, so the buggy could start following the line again after the turn around motion is performed.

5. Budget Vs. Outturn

In [5] the budget and total expenses for purchasing materials were calculated and after getting the materials, the team successfully assembled the buggy and completed the technical demonstration 4. In this section of the final report, the group will show the planned budget and outturn of the buggy. In addition, an expected price for selling the buggy will be provided.

Table 1: Budget: components that are proposed to purchase and contingency

Section	Component	Units	Cost
Sensors	TCRT5000	12	£ 4.32
Unpopulated PCBs	Sensor mini PCBs	3	£ 3.00
	8 Pin IC Base	3	£ 1.68
Total	£ 9.00		

As shown in Table 1 above the group only spent a total of £9 out of their £40 budget, and thus were able to successfully adhere to their budget.

Table 2: Total cost: true parts of entire buggy

Section	Component	Units	Cost
Mechanical parts	Chassis	1	£ 42.00
	Front wheel	1	£ 2.47
	Rubber tire	2	£ 2.90
	Motor	2	£ 7.84
	Gearbox	2	£ 14.00
Sensors	TCRT5000	12	£ 4.32
	AEAT-601BF06	2	£ 42.80
	HM-10	1	£ 13.53
Integrated Circuits	ULN2003	1	£ 0.47
Populated PCB	NUCLEO-F401RE	2	£ 15.00
	MBED-016.1	1	£ 42.54
	STM breakout	1	£ 10.00
	I/O board	1	£ 30.00
	Controller Board	1	£ 30.00
Unpopulated PCBs & IC Sockets & Headers	Jumper Cables	1 bag	£ 4.19
	4 Way SIL Header	1	£ 0.27
	Sensor mini PCBs	6	£ 6.00
	8 Pin IC Base	6	£ 3.36
	Unpopulated PCB	1	£ 5.96

Miscellaneous	Battery Holder	1	£ 2.28
	Batteries	8	£ 16.00
	Insulated Tape	1	£ 2.56
	Cable Ties	3	£ 0.27
	Stripboard	1	£ 4.16
Others	Resistors	20	£ 2.00
Total cost	£ 324.24		

Table 2 shows the total cost of the group's buggy and including freely provided parts. The prices were taken from [1]. The PCB broke before technical demonstration 2 so it was changed to a stripboard and completed TD2. After TD2, six new TCRT5000 sensors were used to make a new PCB which cost £ 4.32.

<u>Retail Price</u>

Before answering this question, a market survey is needed to investigate the market price of the car and analyse a reasonable retail price. From the commercial point of view, the buggy is quite valuable as it has autonomous line-following compatibility, so therefore it can be widely used in the education industry. It can not only be used to enhance students' interest in learning electronic and electrical engineering and broaden the scope of knowledge but also provide models and references for students who are learning to make this type of buggy.

In addition, because of the high production cost and the long production time, the demand for the buggy is very high. In the field of economy, it is extremely important to consider the production and labour costs. The cost of each component of the buggy can be seen in Table 2 above with a total of £324.24. In order to calculate an accurate retail price several factors need to be assessed: total buggy cost, labour costs, machining costs, and finally a suitable profit margin. Furthermore, the type of production line needs to be considered e.g. if it will be considered as a batch or bespoke item. Therefore, taking this into consideration a good retail price would be £549.99

6. Analysis of Heats

<u>How did you prepare for the heats? Evidence of testing?</u>

The heats were held on Tuesday the 10th of May 2022, and in order for the buggy to qualify and get a time result, it had to complete the required track in one go and had two chances in order to achieve this. The track consisted of a left-turn bend, a right-hand bend, and then had to go uphill of a hill with a maximum incline of 18 degrees and then via a Bluetooth signal it had to successfully navigate back down the hill, follow both bends and then stop within 20 cm of the end of the white line [1].

Firstly, in preparation for the heats, the track which was put up in A16 in Sackville Street Building was repeatedly used over the Easter Break and constantly in the run up to the heat days in order to test and tune the buggy code which consisted of a separate sensor and motor PID. In particular, numerous tests were made on this track using different firmware as adjusting the parameters of the motors PID control because the buggy was speeding up too much when going down the slope.

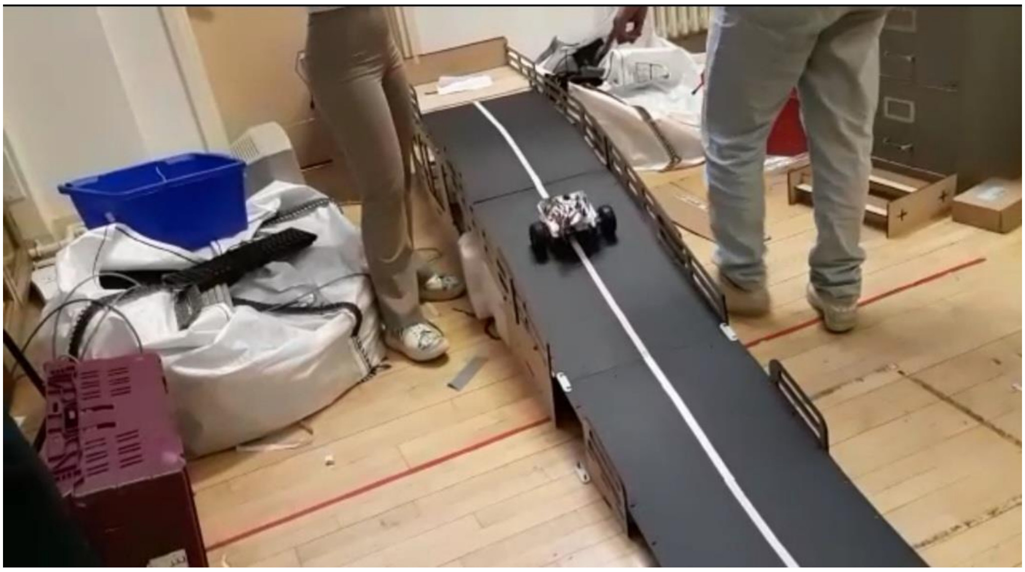

Figure 4: Buggy on A16 ramp

A track was also made at Seyonne’s home in order to test the buggy on the weekends and times when A16 was unavailable. This homemade track was very helpful in the preparation for the heats as it allowed the buggy to be tuned to follow the white line in a calmer setting because the week before the heats the track in A16 was very busy due to all groups making use of it. This often meant waiting in a long queue to make a test, so this resulted in a big waste of time.

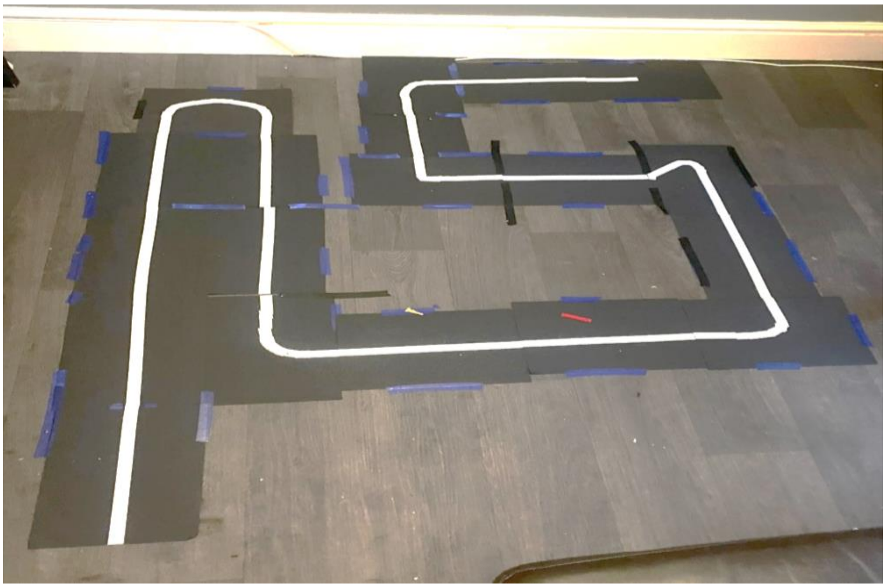

Figure 5: Homemade Track

Other preparation used for the heats involved the coding team consistently meeting out-of-hours to test and write code together.

<u>How did the buggy perform in the heats?</u>

On the buggy's first attempt at the track, it didn't complete any section at all as it drove off the white line. This was very peculiar and unexpected as not long before that the buggy had actually completed the track in A16. Therefore, in this heat, the buggy scored 0/100.

Due to this problem, the people who have developed the code (Nikoleta and Seyonne) rushed downstairs to A16 and tested various codes, and finally uploaded the code that was implemented on the buggy when it had successfully completed the track in A16 that morning. They also rechecked all the wires and tightened the wheel nuts in order to minimise and reduce any unknown effects and outcomes the buggy could have for the second attempt.

On heat two the buggy successfully completed the straight line, the left-bend, and the right-bend, however when it approached the incline it couldn't get up the hill. This was an issue that had repeatedly occurred before when the battery was too low, or the wheels slipped so the sensors went off the line and the buggy then thought the track had finished, so it had stopped. For that run of the track, the buggy scored 30 out of 100.

Due to the failure of the buggy to complete the track in one full go Group 28's buggy didn't qualify for the final race. However, the team was allowed a third attempt to test every section individually. On this try, no code was changed as it has already been tested that the buggy could complete each section separately using this code. On this run, the buggy scored the maximum points it could - 70/100.

What were the most successful features of your buggy?

Overall, in terms of successful aspects of the buggy, the PCB created and designed by the electronics team was one of the best bits of the buggy. This is because as explained in [4], the sensors were separated by 20 mm which meant they had a good overall spread, and the buggy had the ability to visualise the line quite well. This seemed to be an issue with other buggies whose sensors were too close together so couldn't navigate the track at their highest potential if they had a wider PCB.

Another very successful aspect of the buggy would be the code to turn the buggy around. When it was finally fine-tuned it was very successful and worked 100% all the time. The code for this involved the buggy stopping when it gets the Bluetooth signal, and then starting a rotation where it detaches the motor and sensor PID tickers. After a specific wait time, it would reattach these PIDs which means it would be able to sense the line and start following it again successfully

What were the worst features of your buggy?

The buggy could have implemented a better sensor PID control as several times it did struggle to get up the initial incline of the hill as it would lose the line. However, this could have been improved if the code for the buggy had started earlier. This problem could have been solved by developing code that allowed the buggy to identify between the end of the track and just the loss of line. This would have prevented the problem that occurred during the 2nd heat attempt when the buggy lost the line. This could have been done by making the buggy remember its last position and then implementing this error in order to get back on the track.

Moreover, the PID motor control hadn't been properly tuned so the buggy would speed up too much when going down the slope. It was partially fixed by increasing the sample time and tuning the coefficients. When the buggy was stopped too close to the start of the slope for the Bluetooth turnaround the time it had to adjust its position relative to the white line was too little, so the drifts it made were too sharp and result in the buggy losing the line. When the Bluetooth turn was made closer to the wall and further away from the start point of the slope, the buggy had enough time to align itself with the white line and implement the PID motor control properly. These tests brought to the team's attention that the buggy moving down the slope was depending too much on the manual control which is not a reliable approach.

A big issue with the buggy was also the chassis design as this was firstly redesigned multiple times and the battery box was positioned directly where the sensor board was placed. Therefore, if the sensor board wasn't tightened off enough the weight of the battery box would weigh down and push down the sensor board and therefore the sensors would be too close to the track. This meant that the sensors would start reading lower signals than expected and would result in the buggy failing to follow the line. This also caused an issue when the buggy tried to go up the hill as at the start of the incline the buggy's sensors would be too close to the track causing the buggy to think the line had stopped.

Overall, the performance of the buggy was adequate in the heats as it didn't manage to qualify for a time but did manage to complete each individual section of the track as per the specification in [1].

7. References

[1] *Embedded Systems Project Procedures Handbook,* 2021.1. University of Manchester

[2] *Embedded Systems Project Technical Handbook,* 2021.1 University of Manchester

[3] ESP Group 28 “Design Report 1 – Motor Characterisation”, November 2021.

[4] ESP Group 28 “Design Report 2 - Technical Characterisation”, December 2021.

[5] ESP Group 28 “Proposal Report”, February 2021.