Contents

1. Introduction, Aims and Objectives

This is the third document in a series recording the progress of the Embedded Systems Project, the aim of which is to construct an autonomous line following buggy that navigates around a track in the fastest time possible. This document will provide an overview of the main technical and managerial decisions made during the buggy's development so far and present a plan that will detail strategies to ensure success in the next stages of the project.

The technical choices have considered both the hardware and software that will be implemented in the construction of the buggy. The hardware decisions have centred on the characterisations of the sensor array and motors. The software decisions have focused on the overall software system design and control algorithms that will determine how the inputs and outputs interact. On the managerial side, important decisions were made related to assigning team roles, communication methods, record keeping and the team's approach making key choices. The plan for the project's future that will be presented in `the form of a Gantt chart alongside a health and safety risk assessment and budget plan for additional components that may be required.

To make the project more achievable, it was broken down into manageable tasks. This was done by using the functions required of the buggy in the technical demonstrations, as the short term aims which are discussed in the planning section. Another overarching aim of the project is for the buggy to move around the track in the fastest possible time, optimising the hardware and software components at each stage is integral to this. The project milestones and deliverables come in the form of three technical demonstrations and a final report. The technical demonstrations will be an opportunity to exhibit the function of the buggy, with the final one being a head-to-head time trial race with two attempts. The final report will summarise and reflect upon the project, discussing how the planning and organisation contributed to the outcome of the heats and final design of the buggy.

Fig. 1 showcases the buggy's CAD design, characterised by a two-tier structure enhancing agility through a compact footprint. Notably, heavier components are placed on opposing sides for optimal weight distribution. Furthermore, a dedicated cable management slit behind the battery pack ensures efficient organisation. Importantly, the PCB housing the line sensors is positioned beneath the bottom tier.

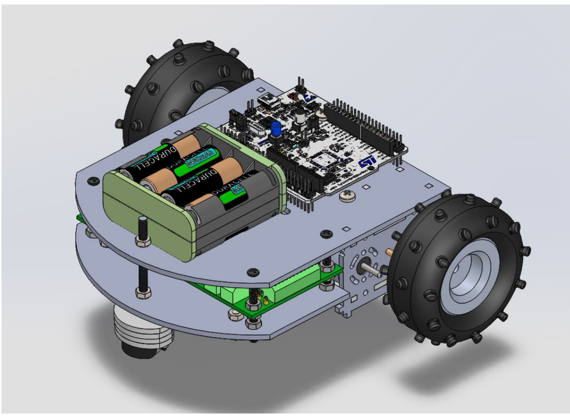


Fig. 1. CAD representation of the buggy

2. Technical Overview

This section will explore some of the more technical decisions made during the design process, how they relate to each other and why they will lead to a fast buggy.

2.1. Motor Characterisation

The main motor parameters found in the motor characterisation lab were the back EMF constant (K_e) and the torque constant (K_t) values which were found to be 0.0094 Vs/rad and 0.0074 Nm/A respectively [1]. They describe how much torque the motors can produce. Ideally, these values would be equal [2] however heating of the motor during testing and systematic measurement error caused them to differ. The torque constant was used to predict the maximum output of the motors, providing a basis on which to choose an appropriate gearbox. With the motor stalled, the maximum value the voltage was 3 V [1] at its maximum current of 1.4 A [2]. Graphing the voltage against the current of the stalled motor gave (1) where 2.2 Ω is the armature resistance and 0.14 V is the brush voltage [1]. The motor characterisation also made it possible to calculate a theoretical maximum speed for the buggy and so a minimum software response time, covered later in this section.

$$V = 2.2I + 0.14 \quad (1)$$

2.2. Sensor Characterisation

To select which sensor would be used in the buggy, the main characteristics of each sensor were compiled into a table [3]. After the different values were compared, the TCRT5000 photoemitter-detector pair was chosen for its relatively low current draw, daylight blocking filter, infrared light emission and matched emission/detection wavelengths [4]. By graphing a line-spread function and testing the sensor's current output at different heights, the optimum configuration was to run the LED at 13 mA and to hold the sensor at 15 mm over the track [3]. The 13 mA current provided enough power to the LED that the photodetector easily distinguished between the white and dark sections of the track [3]. Positioning the sensors at this height above the track would allow them to output different current values for the location of the line over a spread of 15 mm. This still outputs a significant difference between the light and dark sections of the track. With these chosen parameters, the current values will vary from 8 μA to 90 μA depending on the colour of the track [3]. This influenced the design of the sensor board as it provided data for how far apart the sensors should be and inspired the adjustable height chassis design.

2.3. Software System design

The buggy's software is responsible for controlling multiple hardware functions. Line sensors are important to get accurate positioning relative to the white line which will impact the buggy's trajectory and turns. When the buggy is on a slope, the software changes speed according to whether it ascends or descends based on the data from the encoder. The software is also designed to handle line inconsistencies and implements the Bluetooth Low-Energy signal which will initiate the 180° turn.

The software prioritises effective memory management to work under the constraints of the STM32 microcontroller. With only 512 kB flash memory and 96 kB SRAM [3], the system may crash if the code is not robust and cannot handle error meticulously. The software also has to make efficient use of the resources on the buggy to extend its battery life. The software's reaction time is rapid at only 12.78 μs [3] which improves stability of buggy during turns or when facing any line inconsistencies.

The complete system is illustrated in Fig. 2 [3].

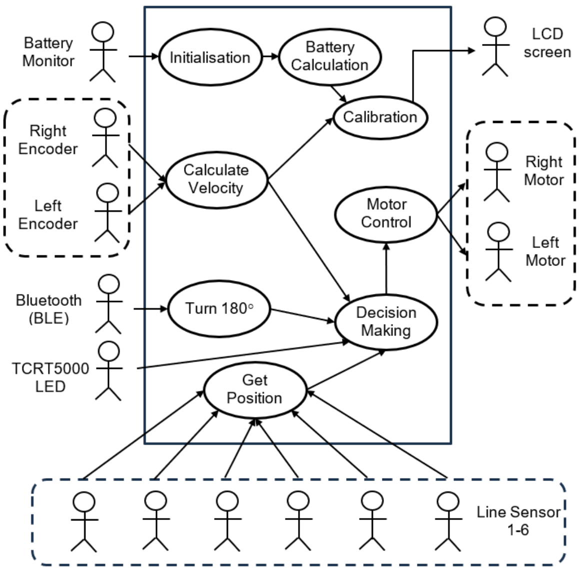


Fig. 2. Case diagram of buggy's software system [3]

2.4. Control Algorithms Selection

The Control Algorithms play an important role in steering the buggy along the white line. When the buggy runs off the line, the control algorithm needs to guide the buggy back to the centre. PID (Proportional-Integral-Derivative) control was selected for the algorithm due to its smoother operation as a result of how tightly it can follow the line.

At first, Bang-Bang control was considered due to its simplicity, high accuracy and economical memory usage. The logic is straightforward – when the buggy reaches a certain distance beyond the line, the controller instructs the buggy to turn by a set amount until the buggy overshoots the line on the other side. This, however, creates a serious disadvantage in that this would lead to the buggy oscillating across the line in a sawtooth manner, which could create a lot of vibrations, potentially leading to more problems (such as damage to the buggy and increased errors). Furthermore, the constant turning, and overshooting would slow down the buggy. Bang-Bang control was therefore abandoned in favour of PID control.

PID control uses a combination of proportional, integral, and derivative terms to firstly calculate an "error" of how far away from the centre line the buggy is, and then to reduce the error to zero. This process is continuous and results in the buggy closely following the white line. The proportional part of the algorithm generates output directly proportional to the instantaneous error, the integral term accumulates the error with a view to reducing the steady state error and the differential term considers the rate of change in the process and predicts future displacement behaviour, enhancing the response speed of the system [2]. However, the choice of the three coefficient values, K_p, K_i and K_d is crucial to the success of the PID control algorithm. The further from the optimum values these are, the worse the performance of the system and ultimately, the slower the buggy will be.

2.5. Chassis Design

The chassis, the project's very foundation, demands meticulous design for reliability, flexibility, and thoughtful material selection. Any shortcoming in these areas directly jeopardises the project success. Recognising this, material selection prioritised properties crucial for chassis performance and manufacturability. Acetyl emerged as the optimal choice due to its low density – minimising weight for agility – and minimal buckling under the anticipated component load (calculated as 0.445 mm in DR2 [3]), ensuring structural integrity. Notably, its ease of manufacturability facilitates efficient construction and modification, vital for iterative design and prototyping.

The presented chassis design in DR2 [3] prioritises agility, weight distribution, and flexibility. An agile buggy enables smoother and faster cornering, enhancing track performance and reducing software complexity. A 2-tier chassis structure (refer to Fig. 1) was therefore implemented, achieving:

- Compact and space-efficient hardware packaging, resulting in a narrower and shorter buggy compared to a conventional 1-tier design.
- Strategic motor and battery placement, countering front/back-heavy tendencies and minimising risk of tipping for improved stability.
- Optimised wheel placement, enabling 180° turns without track adjustments or reversing manoeuvres, enhancing agility and manoeuvrability.

The 2-tier chassis configuration grants flexibility in line sensor positioning relative to the ground. Both the chassis base and PCB offer independent height adjustments, enabling the selection of the line sensor height for maximised performance.

In conclusion, the chosen material and presented chassis design prioritise agility, stability, and sensor efficiency while considering ease of manufacture. This approach lays the foundation for a high-performance buggy with efficient track performance and simplified software development.

2.6. Winning features

This buggy integrates several innovative features to help it navigate the track expediently. These include an ingenious chassis design that places the entire bottom deck of the chassis on four, variable height bolts. This allows for a simple process to change the height of the sensors above the track, which facilities a quicker optimisation of the sensors. The chassis also has small format design that means it can do a 360° turn on the track without having to reverse, which gives a greater freedom in the turning of the buggy.

Another potentially winning feature is the combination of software design and sensors placement. Many components are common between teams and so the focus will be on integration between the hardware, the software, and the control algorithm. Not all the sensors on the buggy will be turned on all the time, this will reduce power consumption, and will also reduce crosstalk on the sensors which could result in unpredictable behaviour from the PID controller. The order in which sensors' LEDs will be flashed has also been carefully considered to ensure that there will always be one fresh reading from each side of the buggy, to ensure a rapid response time to a corner on the track.

3. Team Organisation

A project is nothing without the team behind it, and a team is nothing if not supported by processes and structures that encourage accountability, plurality of ideas and open communication. This section explores those mechanisms and explains how they will lead to the success of the project.

3.1. Roles and responsibilities

The established team structure fosters accountability by creating clear expectations for each role. However, ownership is not solely confined to individual positions. Tasks within each domain are actively distributed, ensuring consistent workload distribution across the team. Therefore, consider the roles as leadership positions guiding their respective areas, rather than solely responsible entities.

When assigning roles and delegating tasks, the strengths of individuals were carefully considered to leverage the full potential of each team member. This ensures optimal resource utilisation and a diverse spectrum of expertise within each domain, as shown in Table 1. Leadership roles are divided into Software, Hardware (encompassing chassis, motors, and sensors), and Control. These "departmental leads" manage work distribution within their area, effectively harnessing the combined expertise of their team members. As the project progresses to the execution stage, leads will continue to assign tasks within their departments, ensuring a fair and balanced workload allocation.

Table 1 Individual roles for the project

Person	Roles
Mustafa	Leader, Software Co-lead
James	Hardware Co-lead
Will	Administrator, Control Lead
Muhammad	Software Co-lead
Shuhan	Hardware Co-lead

For DR1 and DR2, each report section benefited from a dedicated lead and deputy duo. This dual leadership ensured comprehensiveness and clarity by incorporating two distinct perspectives on the content. Additionally, the team leader provided final feedback for every section, further enhancing quality. The section teams for both reports are detailed in Tables 2 and 3.

Table 2 DR1 task allocation

Sno	Section	Lead	Deputy
1	Introduction	Mustafa	Will
2	Motor Characterisation	James	Shuhan
3	Load Measurements	Muhammad	James
4	Gear Ratio Selection	Will	Shuhan
5	Summary and Conclusion	Mustafa	Will

Table 3 DR2 task allocation

Sno	Section	Lead	Deputy
1	Introduction	Mustafa	Muhammad
2	Software	Muhammad	Mustafa
3	Line Sensor Characterisation	James	Shuhan
4	Circuit Diagram for Proposed Line Sensors	Shuhan	James
5	Non-Line Sensors	Will	-
6	Control	Shuhan	Will
7	Hardware Overview (including Chassis Design)	Mustafa	Muhammad
8	Summary and Conclusion	Will	James

3.2. Communication

Communication is integral to ensuring the efforts of the team are greater than the sum of the individual team members. Generally, meetings were organised over WhatsApp (as shown in Fig. 3). If it was necessary to meet virtually, a discord server (also shown in Fig. 3) was employed for the voice call functionality. Additionally, all work was shared and collaborated on using Microsoft OneDrive and Office.

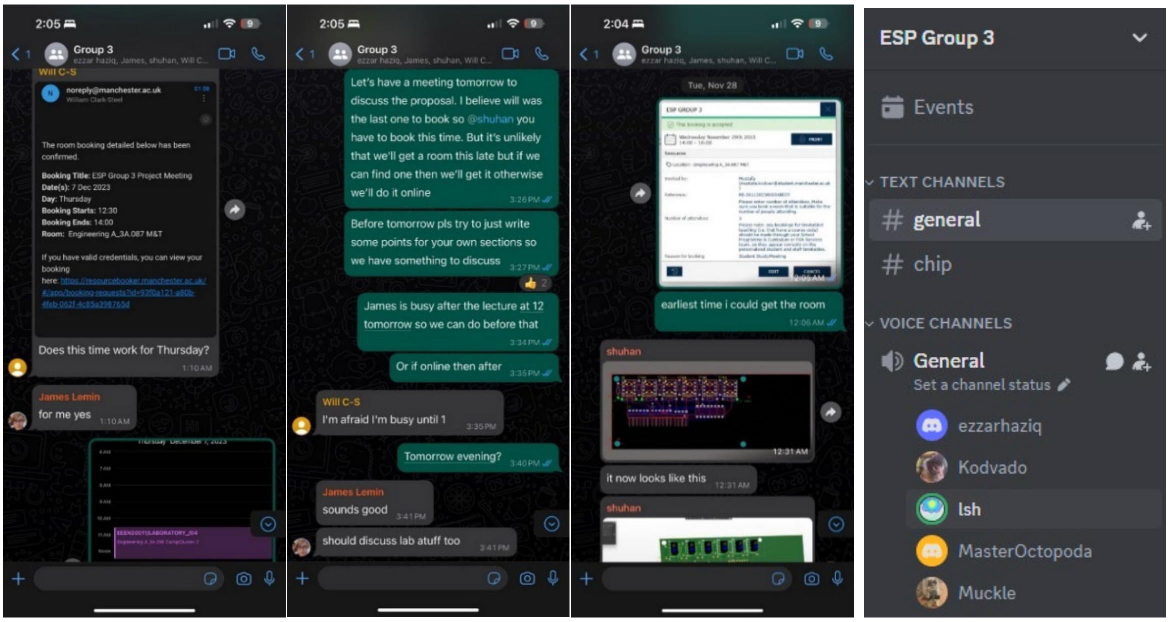


Fig. 3 Screenshots showing the organisation of group meetings and the evidence of a virtual meeting.

The shared folder boasted a highly organised and intuitive structure, exemplified in Fig. 4. Each folder was similar to this structure, featuring the internal versioning system depicted in the figure as well. This system employed natural numbers, with finalised documents marked "_Final." Iterations for revisions arose from team feedback on both clarity and content, leading to new numbered versions within the designated folder.

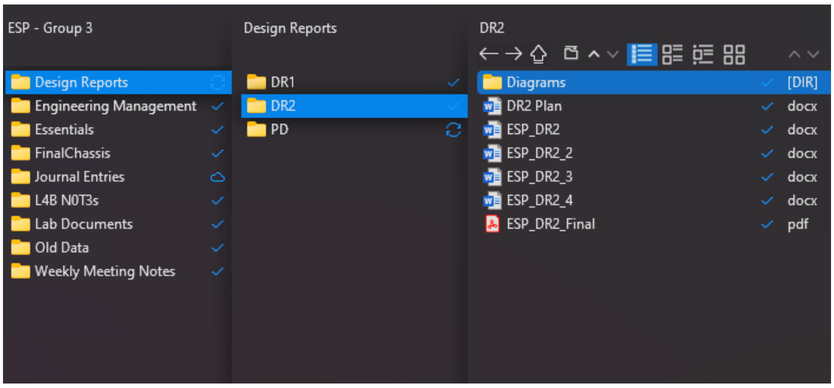


Fig. 4. Group 3 OneDrive Shared Folder

3.3. Meetings

Generally, the team meets once in person to decide the tasks for that week and then follows up with a discord call to track progress and discuss any areas of concern.

Team meetings fostered a culture of open discussion, actively encouraging everyone to contribute solutions to project challenges. Diverse approaches were welcomed and evaluated, with consensus sought through open dialogue and respectful debate. Similarly, when faced with disagreements, both parties were empowered to present their arguments, followed by a team vote to reach a fair and inclusive decision.

Overall, this collaborative system effectively strengthened team cohesion and kept everyone informed, fostering a transparent and engaging environment. This close integration demonstrably yielded high-quality design reports in the first semester. Notably, the system evolves alongside the team, continuously adapting and growing in effectiveness with each iteration. This iterative approach ensures an enduring fit for group dynamics and enhances project outcomes over time.

3.4. Learning Styles

In order to get the most out of the team members, the approach of the team was tailored to different learning styles of its members. To better understand what those styles were, the team looked at the roles referred to in [2]. By those definitions, Muhammad and William are “Pragmatists”. James, whose learning style is most accurately described as an “Activist” complements the others in lab settings which maintains a balance between quickly testing a solution to the problem and finding the right solution to the problem. This also means that time is not wasted on purely theoretical arguments and facilitates a faster testing process. On the other hand, Mustafa and Shuhan are more meticulous in their planning and problem-solving as a “Theorist” and a “Reflector” respectively, which is beneficial where the problems are a complex as they are able to consider other options while James keeps exploring practical solution. This diversity of learning styles benefits the team as it facilitates efficient problem solving as people’s strengths can be amplified, their weaknesses compensated, and the issues remedied.

4. Planning and budget

4.1. Planning and Gantt Chart

The Fig. 5 and Table 4 show the team project plan. The Gantt chart was used to help in understanding the sequence of activities and ensures that the team focus on the right tasks at the right time. Also, the Gantt chart identifies the major deliverables of the project, including the three technical demonstrations which assess many aspects of the buggy. A final report is also needed to summaries the whole year project development and group performance. When the project plan is updated, the Gantt chart will also be updated.

Table 4 Project plan with important deadlines [5]

Activity	Deadline
Proposal Document Present a comprehensive summary of design decisions made which includes aims and objectives, technical overview, team organisation, planning and budget.	Week 2 13:00 on 9th February 2024 (Friday)
Technical Demonstrations: TDA – Motor Control and Sensor Prototyping TDB – Line Sensing and Control TDC – Heats	 Week 5 Week 9 Week 11
Last chance for gearbox change	Week 7
Final PCB Submission	Week 8 13:00 (Friday)
Laser Cutting and Order Submission	Week 9 13:00 (Friday)
Final Report Produce a complete final report which includes executive summary, final system components summary, team organisation and planning, budget vs outturn, analysis of heats. This report will describe the entire racing system constructed to assess group performance.	Week 12 13:00 on 10th May 2024 (Friday)

To ensure that the project can proceeded smoothly, potential project delays and project risks must be considered. This includes managing dependencies and milestones; dependencies are connections between tasks that could impact each other. The Gantt chart plays an important role in controlling the executions of tasks sequentially, to avoid any unwanted delays due to earlier problems. Potential contingencies must be acknowledged and prepared when things go wrong, this has been mentioned in the risk assessment. Planning for contingencies can reduce or avoid unexpected delays. System integration (the process of combining different components into one whole system) and testing time (the duration allocated for technical testing to ensure the functionality of the system developed) are also important parts that need to be considered.

4.2. Cost of Buggy

Parts to purchase:

1. 1 LM741, 1 MHz Op Amp (£0.80)

2. 4 TCRT5000, Reflective Optical Sensor (£2.88)
3. 6 4 Way SIL Header, 2.54 mm pitch (£1.62)
4. Custom PCB (£12.36)

Buggy total cost = freely given components + components to purchase = £291.49

Table 5 Total cost of the buggy [5]

Manu. Part	Quantity	Cost per Component (£)	Total Cost (£)	Manu. Part	Quantity	Cost per Component (£)	Total Cost (£)
2N7000	1	0.23	0.23	**Mechanical Parts**			
Resistor	-	0.10	-	Chassis	1	42.00	42.00
Var. Resistor	-	0.12	-	Front Wheel	1	2.47	2.47
Red LED	1	0.45	0.45	Rubber Tyre	2	1.45	2.90
Green LED	1	0.48	0.48	Motor	2	3.92	7.84
Yellow LED	1	0.48	0.48	Gearbox Box	2	7.00	14.00
White LED	2	0.47	0.94	**Populated PCBs**			
Integrated Circuits				NUCLEO-F401RE	1	15.00	15.00
LM741	2	0.80	1.60	MBED-016.1	1	42.54	42.54
MCP6002	1	0.30	0.30	STM Breakout	1	10.00	10.00
MCP6004	1	0.41	0.41	Controller Board	1	30.00	30.00
LM339	1	2.41	2.41	**Unpopulated PCBs & IC Sockets & Headers**			
ULN2003	1	0.47	0.47	Jumper Cables	1 bag	4.19	4.19
LM311	1	0.66	0.66	8 Pin IC Base	3	0.56	1.68
Sensors				Sensor Mini PCBs	3	1.00	3.00
TCRT5000	6	0.72	4.32	4 Way SIL header	12	0.27	3.24
NSL-195M1	2	0.81	1.62	Custom PCB	1	12.36	12.36
KCL5685S	2	0.73	1.46	**Misc**			
SFH203P	2	0.89	1.78	Battery Holder	1	2.28	2.28
BPW17N	2	0.53	1.06	Batteries	8	2.00	16.00
AEAT-601BF06	2	21.40	42.80	Insulation Tape	1	2.56	2.56
HM-10	1	13.53	13.53	Cable Ties	3	0.09	0.27
				Stripboard	1	4.16	4.16

4.3. Risk Register

Table 6 Health and Safety Risk Register for the Project

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
Race	Sharp edges on buggy	May cause injury	People handling the buggy (5 people, 1 group)	Shave off the sharp edges, have first aid kit ready in case anyone gets injured	3	3	9	Y
Race	Overheating of buggy's motor	Causes fire	Everyone watching the race (250 people, 50 groups)	Stay attentive on the buggy while its working, have an evacuation plan and fire safety measures	5	1	5	Y
Race	Mechanical failures	Buggy fall off / hit on people close to the track	Everyone close to the race track (250 people, 50 groups)	Have a designated first aid station, trained medical personnel on-site	2	2	4	Y
Race	Code malfunctions	Buggy makes unusual movements off the track and will collide with spectators	Everyone close to the race track (250 people, 50 groups)	Have a spectators-safe area for everyone watching the race	3	2	6	Y

Assessment ID Number (E&EE_Initials_DATE_Number)**: ESP_2023-24_group 03** **Activity Location: Whitworth Hall**

				THIS RISK ASSESSMENT WILL BE SUBJECT TO A REVIEW NO LATER THAN: (MAX 12 MTHS)
MANAGER/SUPERVISOR	NAME: Emad Alsusa	SIGNED:	DATE: 9/2/2024	
Student:	NAME: Mustafa Kodvavi	SIGNED:	DATE: 9/2/2024	

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

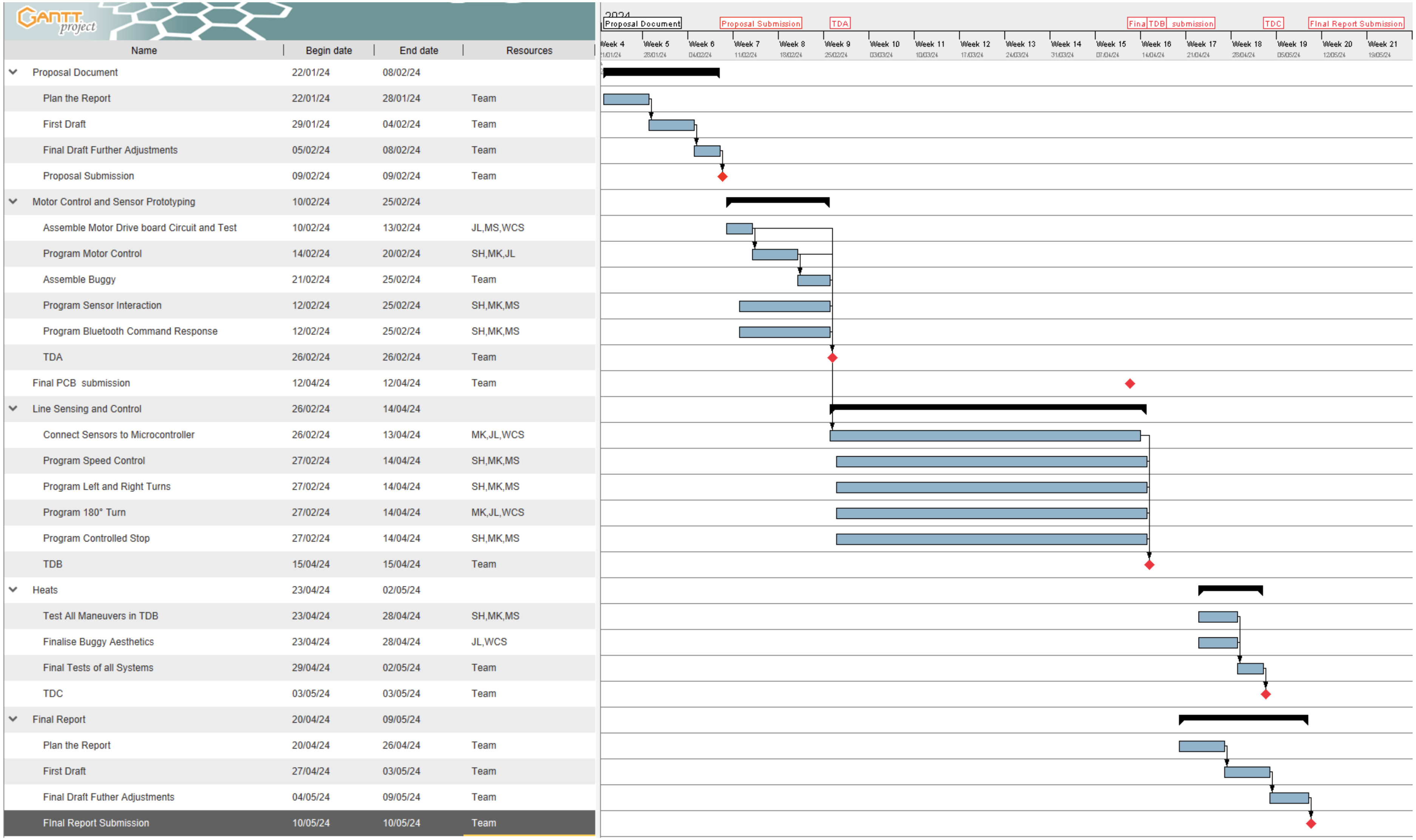
risk ratings **are classified as** ***low*** **(1 – 5),** ***medium*** **(6 – 9) and** ***high*** **(10 – 25)**

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

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



	Name	Begin date	End date	Resources
⌄	Proposal Document	22/01/24	08/02/24	
	Plan the Report	22/01/24	28/01/24	Team
	First Draft	29/01/24	04/02/24	Team
	Final Draft Further Adjustments	05/02/24	08/02/24	Team
	Proposal Submission	09/02/24	09/02/24	Team
⌄	Motor Control and Sensor Prototyping	10/02/24	25/02/24	
	Assemble Motor Drive board Circuit and Test	10/02/24	13/02/24	JL,MS,WCS
	Program Motor Control	14/02/24	20/02/24	SH,MK,JL
	Assemble Buggy	21/02/24	25/02/24	Team
	Program Sensor Interaction	12/02/24	25/02/24	SH,MK,MS
	Program Bluetooth Command Response	12/02/24	25/02/24	SH,MK,MS
	TDA	26/02/24	26/02/24	Team
	Final PCB submission	12/04/24	12/04/24	Team
⌄	Line Sensing and Control	26/02/24	14/04/24	
	Connect Sensors to Microcontroller	26/02/24	13/04/24	MK,JL,WCS
	Program Speed Control	27/02/24	14/04/24	SH,MK,MS
	Program Left and Right Turns	27/02/24	14/04/24	SH,MK,MS
	Program 180° Turn	27/02/24	14/04/24	MK,JL,WCS
	Program Controlled Stop	27/02/24	14/04/24	SH,MK,MS
	TDB	15/04/24	15/04/24	Team
⌄	Heats	23/04/24	02/05/24	
	Test All Maneuvers in TDB	23/04/24	28/04/24	SH,MK,MS
	Finalise Buggy Aesthetics	23/04/24	28/04/24	JL,WCS
	Final Tests of all Systems	29/04/24	02/05/24	Team
	TDC	03/05/24	03/05/24	Team
⌄	Final Report	20/04/24	09/05/24	
	Plan the Report	20/04/24	26/04/24	Team
	First Draft	27/04/24	03/05/24	Team
	Final Draft Futher Adjustments	04/05/24	09/05/24	Team
	Final Report Submission	10/05/24	10/05/24	Team

Fig. 5. Gantt Chart

5. Summary

This Proposal Document has discussed and presented the key decisions made during the planning stages of this project. The technical overview provided the main outcomes of hardware characterisation and software design. The motor constants K_e and K_t were discussed in terms of how they linked to the gearbox selection and the maximum speed of the buggy. The TCRT5000 was selected for the sensor array, its supplied current of 13 mA was calculated, and its positioning decided. During the software section of this report, the interactions between hardware and code were considered alongside the limitations of the microcontroller. The control algorithm being implemented is PID control as it is the method that causes the least oscillation around the white line. The buggy also implements several winning features such as the small chassis footprint, IR LED sequencing and adjustable height sensors.

The team organisation section presented how decisions were reached and how each team members' roles were allocated. It also described how the workload was divided based on the team's strengths and weaknesses. Furthermore, it provided evidence on group communication via WhatsApp and meetings that took place both in person and online via Discord. Microsoft OneDrive is used for file sharing, and report writing took place on a collaborative Microsoft Word document.

Project planning discussed the approach to the upcoming deliverables and set out the schedule for the remainder of the project in the form of a Gantt chart. In addition, a risk assessment was produced for the race day focused on health and safety. Lastly the full budget for the buggy components was calculated as £291.49.

6. References

[1] ESP Group 3, "Design Report 1," University of Manchester, Nov. 2023.

[2] University of Manchester, Embedded Systems Project EEEN21000 Technical

Handbook, 2023/24 ed

[3] ESP Group 3, "Design Report 2," University of Manchester, Dec. 2023.

[4] Vishay Semiconductors, "Reflective Optical Sensor with Transistor Output",TCRT5000 Datasheet, Rev. 1.7, 17-Aug-09

[5] University of Manchester, Embedded Systems Project EEEN21000 Procedures Handbook, Version 2023.1 (September 2023)