Project Initiation Document

Line Follower Robot

The Great Guys

2019

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Revision History

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Executive Summary

Project Initiation Document (PID) seeks to talk about the project goals, approach and methodology. It provides as a starting point for any project to help achieve the outcomes within the stipulated time. The PID outlines the major factors which will also contribute towards the project. The purpose of this project is to design and develop a line follower robot. The approach towards achieving this team project consists of implementing the basic fundamentals and principles of systems engineering. The project begins with identifying the objectives and transition towards system requirements, architectures, reviews, ending with the final report and fabricated product. Along the way, several milestones are laid out that define the various stages of the project. The major learning outcomes of this project are to be able to apply the ideas of systems engineering in tandem with the technical knowledge gained over our semesters to produce a product with real-life applications, in this case, line follower robot.

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Acronyms and Abbreviations

ANU	Australian National University
CoDR	Conceptual Design Review
Eng.	Engineering
FDR	Final Design Review
IR	Infrared Radiation
PID	Project Initiation Document
SRS	System Requirements Specification

Units of Measurement

The International System of Units (SI) is used in this project unless otherwise specified.

Table A: Units of Measurement

Measurement	Symbol	Description
Currency	$AUD	Australian dollar

1 Project Context

The aim of the project is to utilise the fundamentals of Systems Engineering and implement in a real-world application, in this case, building a line follower robot. Systems Engineering is one of the most important steps for the development of a project. It is highly versatile and is used across various fields such as software/IT, manufacturing, construction, computer science etc. The idea behind deploying systems engineering is that it helps to achieve a customer-centric product. The entire project is based around the needs and requirements of the customer/user, thus creating a satisfactory end result for both parties. Lastly, using systems engineering and the learning outcomes from various courses, we aim to design and develop a line follower robot.

1.1 Background

Systems Engineering has been part of the industry since the mid 20th century. Figure 1.1 depicts the process flow that is followed for the development and execution of a product/project. With the development of technology and needs through the years, it was important to establish new approaches towards delivering customer driven solutions. Hence, new strategies of systems engineering were born and have since been the backbone of most projects in the industry.

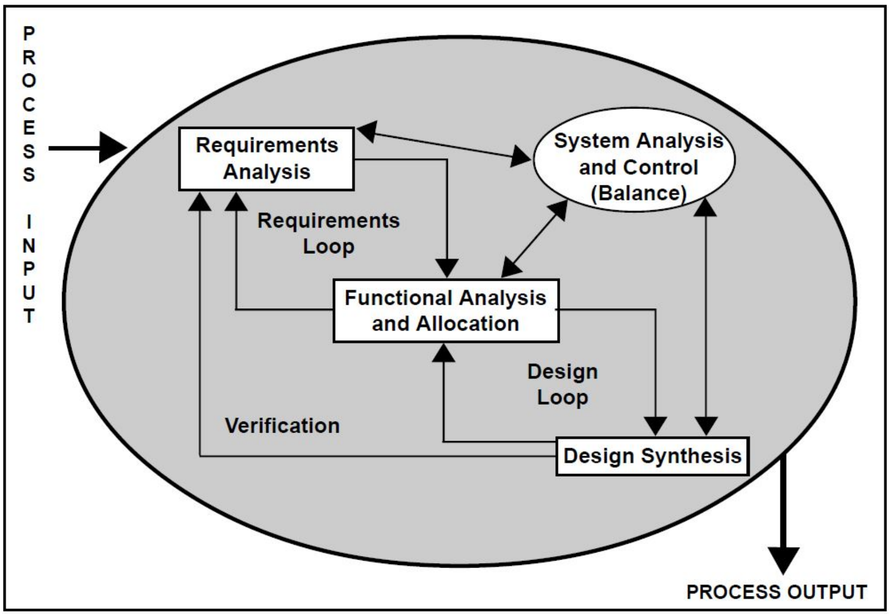


Figure 1.1: Systems Engineering cycle

The next part of the project involves robotics. Microprocessors, microcontrollers brought about the changes in automation and industry. They have been an integral part of building robots, computers and machines making human work easier. When we talk about the line follower robot in particular as shown in Figure 1.2, it started as a hobby project and later developed into bigger and advanced applications such as warehouse robots. The autonomous capability of this robot adds to the additional benefits it can offer. As seen in [1], the paper has dealt with the implementation of an autonomous line follower that uses IR sensors to detect the black lines over a white background or vice versa. Additionally, there have been similar papers published in this field with minor changes to design, but all follow the same basic principles. Few different ideas were used in [2], in order to achieve the line follower robot.

Thus, we can infer from previous work, the various design and approaches to be slightly different depending on the application but the end result remains the same. With the help of systems engineering, we aim to build a project which can meet our requirements and perform the intended tasks.

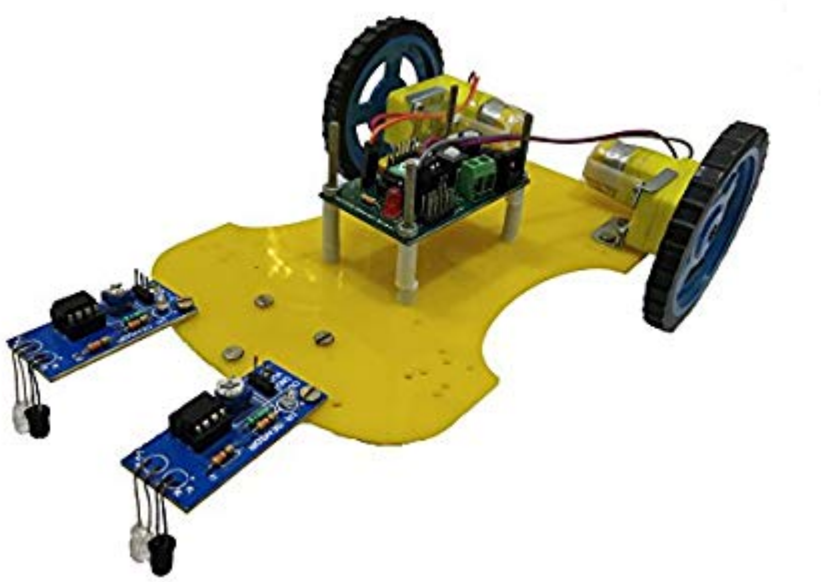


Figure 1.2: Line follower robot (Source: Google Images)

1.2 Business Needs and Requirements

The first step in systems engineering is to be able to define the problem as precisely as possible. As we progress, it is important what factors influence the project and how they influence it. Based on this information, we design our project requirements and needs. They are the most crucial step in the beginning stages of systems engineering. A well-defined project and its needs, will provide a solution which is as close to the intended purpose. Any project with the best requirements will produce better outcomes in the preliminary and final design phases. Often, this section of the project can get overlooked which leads to poor solutions and less customer driven product. For our project, the requirements are not as complex as in the industry but this exercise to define the needs helps us understand the project from the customer's perspective, in this case, our tutor and professor who expect a certain outcome. The fundamental requirements of this project are that the robot needs to follow a line on a background of a different colour autonomously. In doing so, the principles of systems engineering must be integrated into the project to obtain an understanding of the professional work environment.

1.3 Scope

As discussed earlier, the line follower robot started as a fun activity for hobbyists but has now transformed into different concepts. The integration of obstacle avoidance and using advanced sensors such as cameras to detect lines of any colour has been a major boost in this robot. Due to such technological advancements, the robot is being extensively used in industry all over the world. It has significantly improved the efficiency of most companies that are deploying such robots in their warehouses or factories.

1.4 Mission Statement

The objective of this project is to design and develop a line follower robot that can navigate autonomously over a black line on a white background (or vice versa) and integrating the fundamentals of systems engineering to achieve the final outcome successfully. The ability to work with a diverse team with different technical and non-technical backgrounds is one of the key learning outcomes from this project. Moreover, the aim is to work together as a unit and be able to present the solution within the given time constraints.

2 Stakeholders

Stakeholders are people who are involved and have influence on a project. In our project, we have identified several stakeholders and how much they could affect our project during the whole process.

2.1 List of Stakeholders

Generally, the influence that a stakeholder could have on a project could be determined by 2 elements, the power of stakeholders in project and their interest in the project, which will be shown in Table 2.1. The stakeholder list will be shown in Table 2.2

Table 2.1: Stakeholder requirement satisfaction strategy

		Power	
		Low	High
Interest	High	Keep informed	Manage closely
	Low	Monitor	Keep satisfied

Table 2.2: Stakeholder list

Name	Description	Interest	Power	Strategy
Project team	Our team is the core of this project, who will decide all design and document	High	High	Manage closely
Tutor Noushin Dolati Ilkhechi	Tutor who instruct and help us in this project, she will give necessary help in process	High	Medium	Keep informed
Professor Qinghua Qin	Course convener of this course, he will provide a place for us to discuss, provide instructions on this project and offer technical help.	Low	Low	Monitor

Name	Description	Interest	Power	Strategy
The Australian National University (ANU)	ANU determines the milestones and the document we need to submit and the deadline. It also provides us with the budget.	Low	High	Keep satisfied

2.2 Expectation Matrix

The stakeholder requirements are classified into engineering and project management. Stakeholder name will be expressed by abbreviation. The expectation matrix is shown in Table 2.3.

Table 2.3: Expectation matrix

Expectation	Priority	Category	Responsibility	Owner(s)
All required documents should be submitted on time	High	Project management	All team members	ANU
IR sensor should be used in this project	High	Engineering	Students who order materials	Tutor Noushin Dolati Ilkhechi
There should be regular meetings every week	High	Project management	All team members and Tutor Noushin	Professor Qinghua Qin
Team members should attend meetings.	Low	Project management	All team members	Project team
The cost of line follow robot should be in the budget limit	High	Engineering, Project management	Students who order materials	ANU, Project team
The line following robot should be able to follow the designed routine	High	Engineering	All team members	ANU, Professor Qinghua Qin

3 Design Need

3.1 Customer requirements

The constraints in a system are mainly composed of two parts: business constraints and design constraints. Business constraints mostly derived from the budget and deadlines of the project, and design constraints come from the system scale. Table 3.1 shows critical constraints in the project.

Table 3.1: Design constraints

Expectation	Priority	Category
Design constraints	C1	The robot can drive automatically without the need for human remote control
	C2	The robot is powered by battery
	C3	The robot can be installed with motors and sensors easily
	C4	The robot recognizes lines of black colour and moves with them.
Business Constraints	C5	The cost to establish the robot shall not exceed $AUD400.
	C6	The designing and construction period of the system shall not exceed 3 months.

3.2 Constraints

Customer requirements are the highest-level requirements in requirement hierarchy and are the basis for the analysis of detailed requirements such as system requirements and functional requirements. According to the constraints listed in Table 3.1, the customer requirements in the project are shown in Table 3.2.

Table 3.2: Customer requirements

Customer Requirement ID	Customer Requirement
CR1	The robot shall follow black line on a white background.
CR2	The robot shall be powered by batteries.

Customer Requirement ID	Customer Requirement
CR3	The robot shall calibrate the moving path by itself.
CR4	The robot shall be assembled by sensors, motors and other components.
CR5	The robot shall be easy to maintain.
CR6	The robot shall drive automatically and stably.
CR7	The robot shall be operated without remote control

3.3 Assumptions

Assumptions in this part aim to come up with some actual situations and try to give solving approaches based on imagining the robot is working in a real industry environment. Firstly, the robot requires a stable power system. Because of the automated driving system, the robot needs a battery system that can be continuously and stably powered to support normal operation. Secondly, the changes of light in the working environment may affect the recognition function of the robot's sensors. Therefore, the robot needs sensors with lower light sensitivity to reduce the impact of the working environment on work efficiency. Thirdly, the robot needs to overcome the influence of motor vibration on its structure in actual work. Since the robot has a complicated structure and is driven by a motor, the vibration generated by motors can affect the stability of the robot. To solve this problem, on the one hand, when designing the structure of the robot itself, it is necessary to carry out finite element analysis of the whole structure to ensure that the vibration does not affect the operation of the whole system. On the other hand, the control system can be used in the circuit to adjust the robot automatically. Fourthly, the robot can be urgently braked by the operator in an emergency or error. Since the control system of the robot is designed as the circuit, a bug will occur during debugging or actual use, which will cause the robot to deviate from the running trajectory. This problem can be handled by adding a braking function during the design of the control circuit. Finally, the robot needs to be easy to replace components and maintenance, which means that when designing the structure of the robot, the structure should be as simple as possible while ensuring work efficiency. Table 3.3 shows the assumptions and solutions illustrated above.

Table 3.3: Assumptions and solutions

Assumption	Solution
Stable power system	A continuous and stable battery system

Assumption	Solution
Light changing	Sensors with lower light sensitivity
Motor vibration	Finite element analysis and control system
Emergency or system error	Braking function in circuit
Easy to maintain	Simple structure

3.4 Operational Objectives

Since the customer requirements indicate the needs for the project and the requirements for the robot, the operational objectives can be obtained from these requirements. Table 3.4 illustrates the operational objectives of the project.

Table 3.4: Operational Objectives

Objective ID	*Operational Objective*
O1	Achieve autonomous driving
O2	Detect black path
O3	Assemble sensors and devices
O4	Overcome vibration
O5	Own a stable power system
O6	Easy to maintain
O7	Work in different light conditions

3.5 Operational Conditions

3.5.1 Environment

The line follower robot works in various places and therefore the environment has different impacts on the performance of the robot. The following conditions will be considered:

- Illumination: The illumination will influence the robot as IR sensors are sensitive to the illumination. Thus, this line follower robot requires a good quality of illumination environment.
- Temperature: Some electrical elements of the robot require the corresponding work temperature. The control board and others driver boards have temperature limitations.
- Road conditions: Because of structure, the robot needs to work in an even road, instead of rugged road, whatever in indoor or outdoor. And the following line should be clear for the robot to identify.

3.5.2 Scenarios

This robot majorly works in the industry field and since automatically travelling the predetermined route without the need for manual pilotage, the robot can complete the task that automatically transport goods or materials from the starting point to the destination, which can save more time and manpower. Since the visual line is to control the route that robot follows, the associated staff can adjust this line to adapt to different delivery tasks.

Besides that, this robot can work for the patrol inspections. In some electrical substation, for example, the working place is usually large and it is time consuming for workers to inspect all the facilities. Therefore, cameras can be mounted on the robot so that the worker can efficiently monitor the facilities in the station, rather than field trip.

4 Work Breakdown

This part illustrates how the developing timeline is managed in this project. Chapter 4.1 introduces the required deliverables of this project. Moreover, a more detailed work breakdown structure is demonstrated in Chapter 4.2. Lastly, to ensure all tasked will be solved in time, a Gantt chart is shown to clearly present the schedule in Chapter 4.3.

4.1 Deliverables

The deliverables of this project, including the documents and the demonstration, as well as their description and the deadline are shown in Table 4.1.

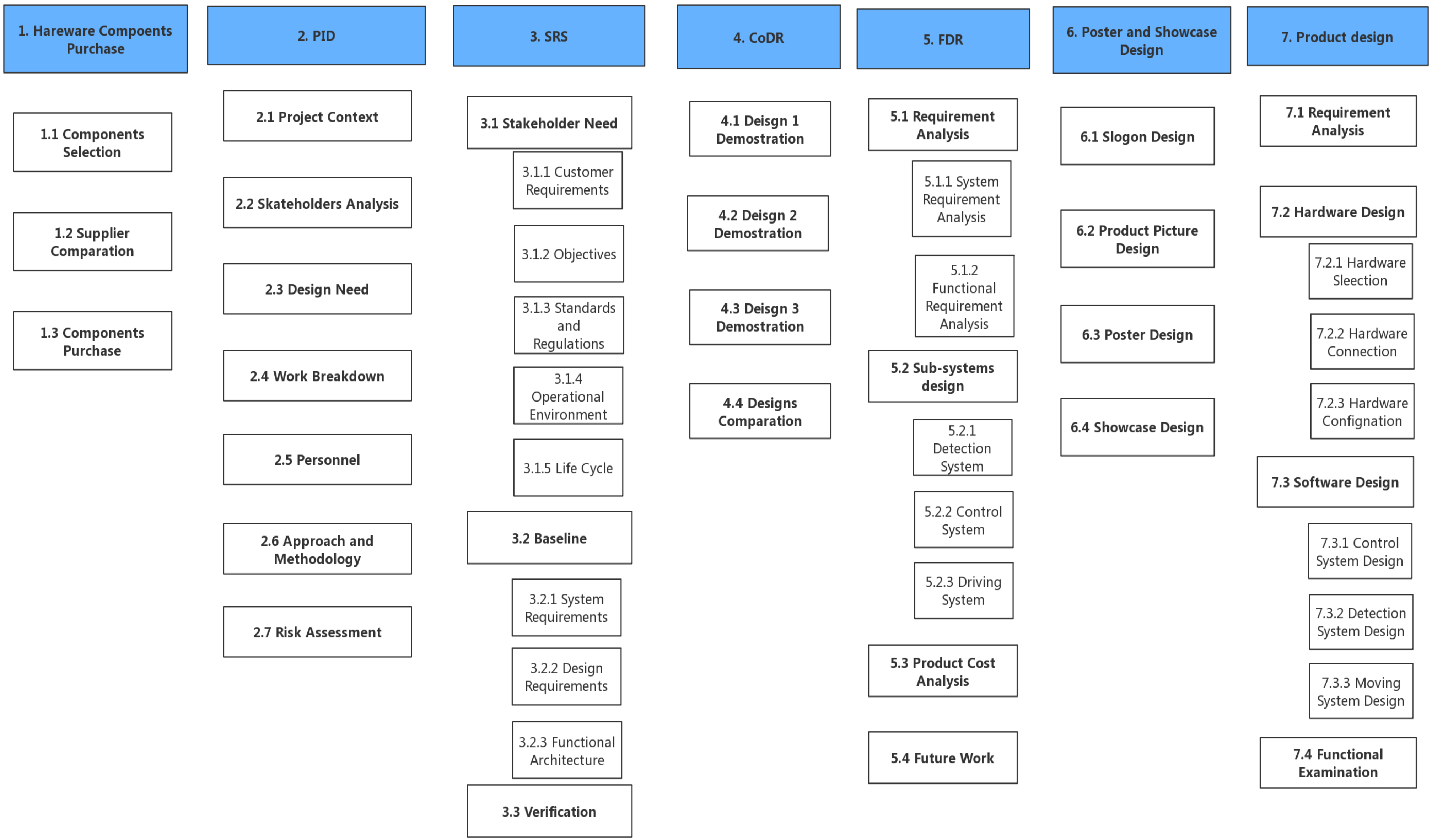
Table 4.1: Deliverables

Deliverables	Description	Deadline
PID (Project Initiation Document)	This document identifies the scope, requirements and the constraints of the project.	9 August
SRS (System Requirements Specification)	This document specifies the potential requirement of the project, including system requirements, customer requirements and functional requirements, etc.	23 August
CoDR (Conceptual Design Review)	This file presents different design paths to realize the project goal and examines how the primary designs fits the SRS. This file will be presented as PowerPoint slides.	26 August
FDR (Final Design Report)	FDR gives a comprehensive demonstration of design and technical details about the prototype.	18 October
Project poster and showcase document	This file provides the advertising posters.	20 October
Work portfolio package	This document illustrates how the portfolio constructed	22 October

4.2 Work Breakdown Structure

The layout of the work breakdown structure of this project is shown in Figure 4.1.

Figure 4.1: Working breakdown structure



4.3 Schedule

The schedule of this project is shown in Figure 4.2 using Gant chart.

Figure 4.2: Project schedule

ENGN8170 Engineering Project (2019 Sem2) Line Follower Robot		day	22-Jul	29-Jul	5-Aug	12-Aug	19-Aug	26-Aug	2-Sep	9-Sep	16-Sep	23-Sep	30-Sep	7-Oct	14-Oct
		Week	1	2	3	4	5	6	Teaching break	Teaching break	7	8	9	10	11
No.	Tasks														
1-1	First Lecture		→												
1-2	Group Forming		→												
2-1	Literature Review		→												
2-2	Hardware Selection		→	→											
2-3	PID			→	→										
2-4	Hardware Ordering			→	→										
3-1	SRS					→	→								
3-2	Hardware Design					→	→								
4-1	CoDR							→							
4-2	Software Design								→	→					
5-1	FDR										→				
6-1	Poster Design											→	→		
7-1	System Test													→	→
7-2	System Debugging													→	→

5 Personnel

In this project, the team members have different backgrounds as Table 5.1 shows. While all of us are currently doing Master of Engineering in Mechatronics in ANU, our engineering major in our bachelor's degree is diverse. For example, three members have Mechatronics background, other three have Electrical Engineering background, and two have Mechanical Engineering background.

Table 5.1: Team member composition

No.	Name	Current study (Master degree)	Background (Bachelor degree)
1	Rishab Jain	Mechatronics	Mechatronics
2	Zehao Xu	Mechatronics	Mechatronics
3	Chaohuo Wu	Mechatronics	Mechatronics
4	Yanjun Li	Mechatronics	Mechanical Eng.
5	Xiaochen Liu	Mechatronics	Electrical Eng.
6	Chaoyun Gong	Mechatronics	Telecommunication/Electrical Eng.
7	Hanwen Bi	Mechatronics	Mechanical Eng.
8	Masahito Takeuchi	Mechatronics	Electrical Eng.

5.1 Personnel Skills Matrix

To analyse the team's strengths and weaknesses, based on the analytics method for personnel skill [5], we collected the data of each knowledge score and skill score as shown in Figure 5.1 and Figure 5.2. Each knowledge and skill was given a score from 1 to 7 depending on the member's personal assessment of knowledge and skills. The detailed result of each person's score is shown in Appendix in Table B.

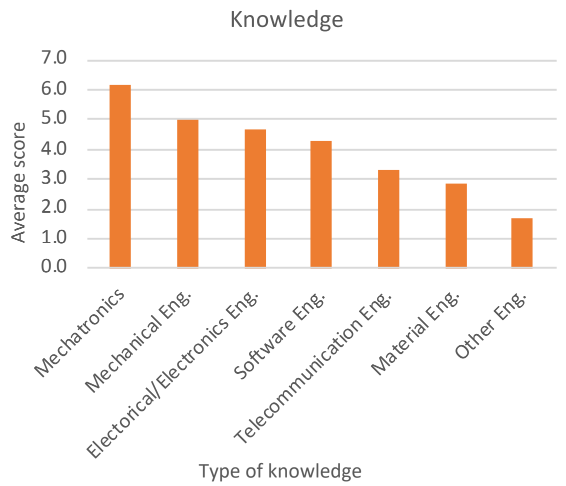


Figure 5.1: Knowledge score

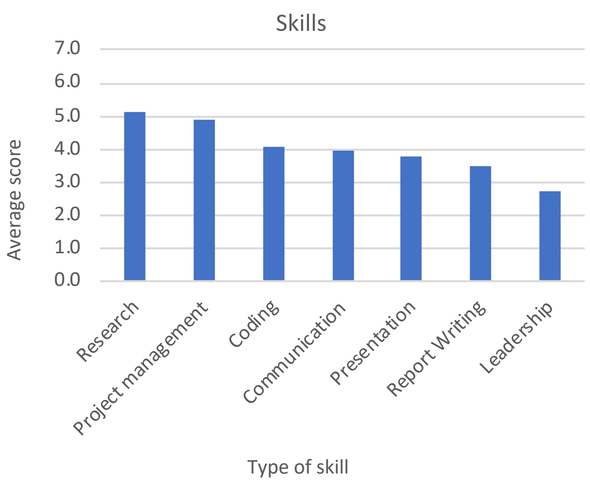


Figure 5.2: Skills score

5.1.1 Strengths

Figure.5.1. shows that our team is most knowledgeable in the fields of Mechatronics Engineering and Electrical Engineering. Furthermore, Figure 5.2 reveals that the team has strong skills in research and project management. These results can contribute positive effects on this project because our topic is based on Mechatronics field, and this course, ENGN8170, focuses more on research and project management side.

5.1.2 Weaknesses

Figure 5.2. shows that our team may have insufficient knowledge in the fields of Material Engineering and other Engineering, for example Biomedical Engineering. Figure 5.2. further shows the team's inadequate skills in report writing and leadership. To compensate these insufficient knowledge and skills, the team will seek guidance and help from experts in ANU and other institutions and maximise our research skills to gain more knowledge in those fields. Furthermore, to improve the abovementioned weak skills of the team, we should allocate sufficient time for report writing and have close communication with each other. On top of that, we should act positively and each should try to make contributions as much as possible to develop leadership skills [6]. In addition to that, self-awareness, challenging experience and the mind of support would be key factor to enhance leadership skills [7].

5.1.3 Coding skills

Looking at the detail of coding skills, it can be seen that we have good command in using Verilog, Matlab, Python and C, which are quite useful tools for an engineering project. In this project, C is mainly used for Arduino UNO [8] to integrate software and hardware.

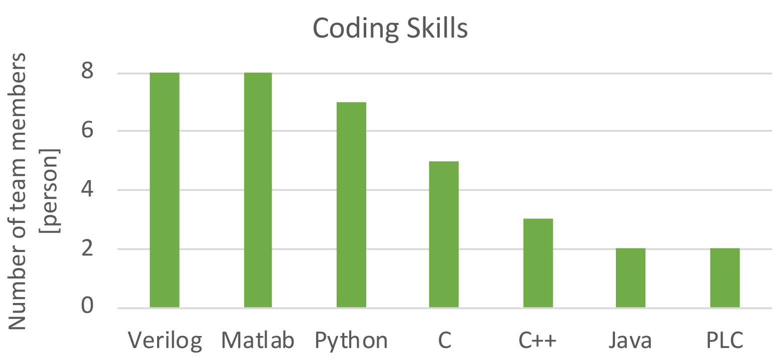


Figure 5.3: Coding Skills

6 Approach and Methodology

To achieve the goal of this project. Our group will use system engineering method to do the job step by step. Figure 6.1 shows the system life-cycle. Our design should follow the steps.

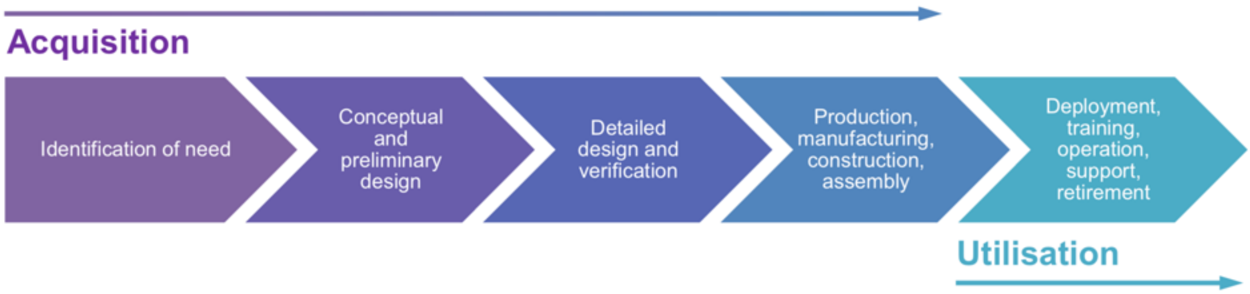


Figure 6.1: System life-cycle [3]

Firstly, our group need to define the needs of stakeholders and the technical requirements [4]. The stakeholders' need is a linear follower robot. This robot can follow a specific line by using its own navigation system automatically. The line will have different colour of the background and will be winding. This robot can be used in different areas for example to deliver goods or other things. For technical requirements, our group should design the shape and circuit for the robot to move. To implement the functions of robot, our group also need to write code and program for the robot based on the controller, sensors and motors. The components for writing codes includes AVR microcontroller, DC motors and IR sensors.

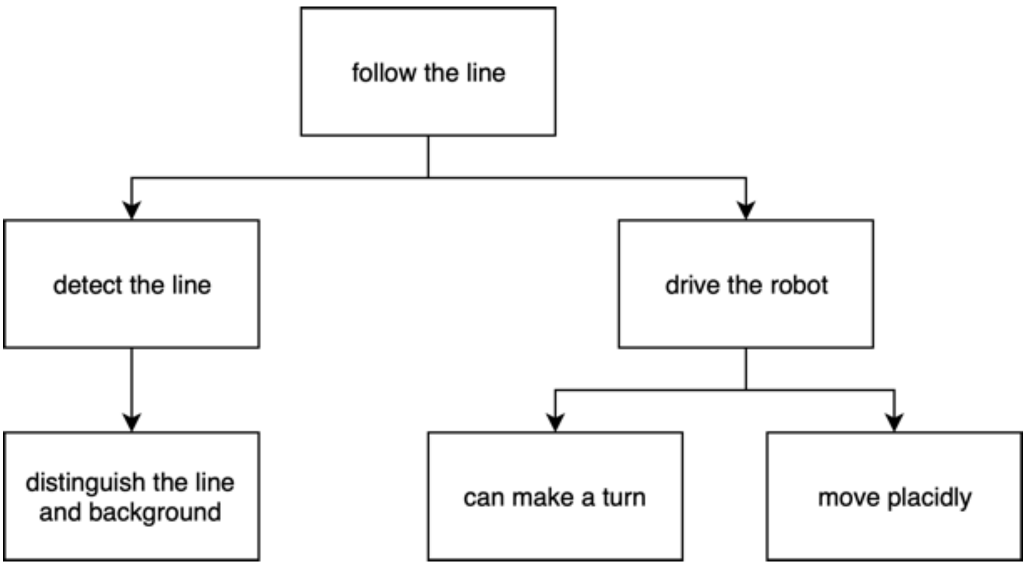


Figure 6.2: The function architecture

Secondly, our group will design the function architecture. Figure 6.2 has shown the function architecture of this project. The main function of our robot is to follow a specific line. It can include two sub-level functions, detect the line and drive the robot. The sub-level function of detecting the line is to distinguish the different colour between line and background. And driving the robot includes two functions, making a turn and moving placidly.

Thirdly, design physical architecture. Each design in physical architecture should support for the function architecture. The robot could be a car with three or four wheels and two or four motors. The IR sensors could be about five.

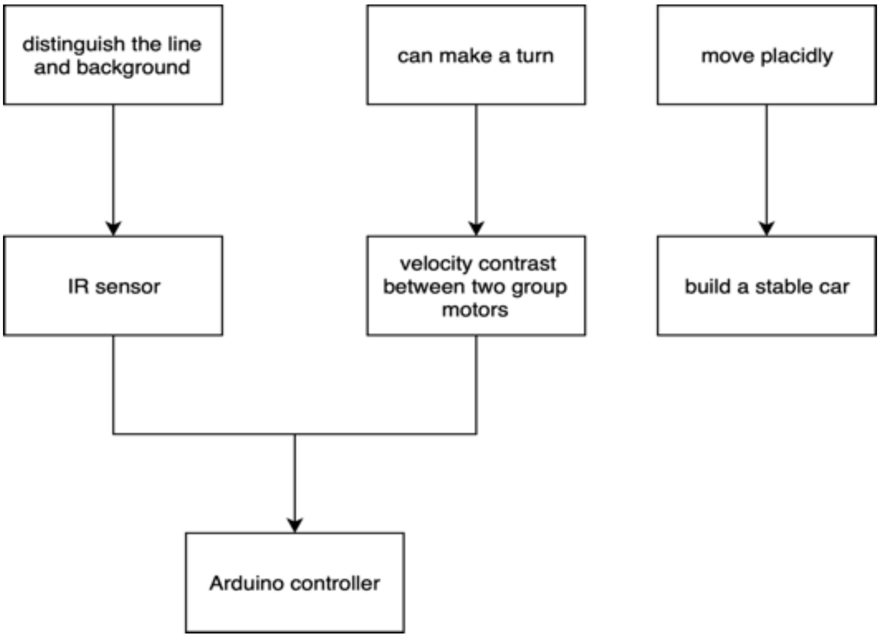


Figure 6.3: The physical design depended on functions

Figure 6.3 shows the physical architecture based on the function architecture. And finally, our group will apply an Arduino controller to control the whole system.

After that, detail design can be processed for the details of the robot.

Fourthly, our group will do integration and validation. To construct the whole robot and writing code to program the robot. Then, the completed robot will be tested several times in different ways for different functions. For example, changing the width and angle of corner to test the performance of robot.

7 Resources and Facilities

To make our project conducted smoothly and effectively, the following resources and facilities will be deployed in this project. We will purchase some hardware items using our budget given by ANU and will reuse some items that the team members already have.

7.1 Software

Table 7.1: Software lists

Software	Description
Doodle	Scheduling tool to set up the meeting schedule.
Google Docs	Online document management tool to share and upload each team member's progress.
Microsoft Office	Microsoft Office Packages such as Word, Excel and PowerPoint to report and organise materials.
C language	Basic programming language for Arduino.
Solid works	Software to model 3D CAD design.

7.2 Hardware

Table 7.2: Hardware lists

Hardware	Description
Arduino UNO	Open-source microcontroller board to integrate hardware and software
Wheels	To move a robot effectively.
Chassis	To load hardware components connecting each wheel.
Breadboard	To design electrical circuit for the creation of prototype or experiments.
Motor	To rotate wheels converting electrical energy into mechanical energy.
Motor driver	To control motor behaviour adjusting direction, speed or torque.
IR sensor	To detect line to follow composed by transmitter and receiver

Hardware	Description
Battery	To provide electricity for motors and Arduino UNO
Battery shield	To hold batteries not to fall down, keeping the balance of robot.
Tape	To test the function of line follower robot.
Jumper wire	To connect electrical signals each other on the breadboard.
Computer/Laptop	To do research, to program codes or to organise report materials.

7.3 Facilities

Table 7.3: Facility lists

Facility	Description
Ian Ross Design Studio	The Ian Ross Design Studio will be used to host regular team meetings. The room's teaching schedule will need to be consulted prior to selecting the regular meeting time.
Final year engineering computer labs	Team members will require access to the final year engineering computer labs to use software packages such as solid works, MATLAB, AnSYS, and Microsoft Office packages.
Hancock Library Study Room	It has a good space to have a meeting, has a big monitor, and is close to ANU Engineering building. Booking is required.
Students Commons in Kambri	Accessible space to discuss with a couple of members located in the central are in ANU. Non-booking is required.
ANU Maker Space	Laboratory space to create some components for a robot using 3D printer. Accessible to all ANU students and staffs.

8 Risk Assessment

The risk assessment is a vital strategy to help team members manage their projects appropriately [9]. In this section, the Risk Identification Matrix of project risks and product risks will be presented which shows the priority of different risks identified by their likelihood and consequence. Besides, a high-level risk description and analysis will be shown, which is a guideline of our risk management.

8.1 Risk Identification Matrix

Table 8.1: Risk Identification Matrix of Product Risks

		Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Almost Certain	Low	Medium	High	Extreme	Extreme
	Likely	Low	Medium	Medium	High	Extreme
	Possible	Low	Low	Medium	High	Extreme
	Unlikely	Low	Low	Medium	High	High
	Rare	Low	Low	Low	Medium	Medium

Table 8.2: Risk Identification Matrix of Project Risks

		Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Almost Certain	Low	Medium	High	Extreme	Extreme
	Likely	Low	Low	Medium	High	Extreme
	Possible	Low	Low	Medium	Medium	High
	Unlikely	Low	Low	Low	Medium	High
	Rare	Low	Low	Low	Medium	Medium

8.2 Risk Register

Table 8.3: Risk Register

Risk No.	Risk Description	Likelihood	Consequence	Priority	Mitigation strategy	Risk after mitigation
Product Risk						
R1	Components are not arrival in time	Likely	Moderate	Medium	Make purchases early and avoid oversea purchases.	Low
R2	Components are broken during assembling or test	Possible	Major	High	Order spare parts.	Low
R3	Forget ordering some components	Unlikely	Major	High	Make a clear list of components to order	Nil
R4	The line follower robot cannot follow the line correctly in some conditions	Rare	Catastrophic	Medium	Design a powerful control algorithm and test it in multiple conditions.	Low
R5	Components do not match each other while assembling	Unlikely	Major	High	Consider the type and size of components while design	Nil
R6	The final product does not meet customer requirements	Unlikely	Catastrophic	High	Make a clear record of all customer requirements. Talk to customers regularly and update the change of customer requirements in time.	Low

R7	Order wrong components	Unlikely	Major	High	One group member order components and two or three group members double check the order.	Nil
Project Risk						
R8	Over budget	Unlikely	Moderate	Low	Make a clear budget plan and check it before order components.	Nil
R9	Team members cannot finish their parts on time	Possible	Moderate	Medium	Make clear and fair work arrangement. Each group member has a schedule	Low
R10	Group members are injured during assembling and test stage	Unlikely	Major	Medium	Follow the safety requirements while assembling and testing.	Low
R11	Group member dispute	Possible	Moderate	Medium	Respect all group members and listen to their suggestions. Team leader moderate the dispute immediately when it happens.	Low
R12	Lack of communication to the stakeholder	Rare	Moderate	Low	Arrange regular meeting with stakeholders every week	Nil
R13	Fail to follow the project plan	Possible	Major	Medium	Make a clear reasonable, and detailed plan and time schedule. Use project management tools to manage and track each step.	Low

References

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Appendix

1. The detail scores of team member knowledges and skills mentioned in Chapter 5: Personnel.

Table B: Detail scores of knowledge and skills

			Knowledges							Skills						
No.	Name	Background (Bachelor)	Mechatronics	Mechanical Eng.	Electorical/Electronics Eng.	Software Eng.	Telecommunication Eng.	Material Eng.	Other Eng.	Research	Project management	Coding	Communication	Presentation	Report Writing	Leadership
1	Rishab Jain	Mechatronics	7	6	5	3	2	4	1	7	5	2	6	3.5	3.5	1
2	Zehao Xu	Mechatronics	6	6	3.5	3.5	6	1.5	1.5	7	3.5	1.5	6	5	3.5	1.5
3	Chaohuo Wu	Mechatronics	7	5	4	6	3	2	1	7	5	6	1	3	3	3
4	Yanjun Li	Mechanical Eng.	6	7	4.5	4.5	2.5	2.5	1	7	6	1	3.5	3.5	3.5	3.5
5	Xiaochen Liu	Electrical Eng.	6	3	5	7	4	1	2	3	5.5	7	1	3	5.5	3
6	Chaoyun Gong	Telecommunication/Electrical Eng.	5	5	5	2	3	7	1	2	5	7	5	5	2	2
7	Hanwen Bi	Mechanical Eng.	6	7	4	4	2	3	2	7	5	6	2	3	3	2
8	Masahito Takeuchi	Electrical Eng.	6.5	1	6.5	4	4	2	4	1	4	2	7	4	4	6
		Average	6.2	5.0	4.7	4.3	3.3	2.9	1.7	5.1	4.9	4.1	3.9	3.8	3.5	2.8