DESN1000

Redback Autonomous Car

Term 3

Preliminary Design Report

Date of Submission: 23-10-2023

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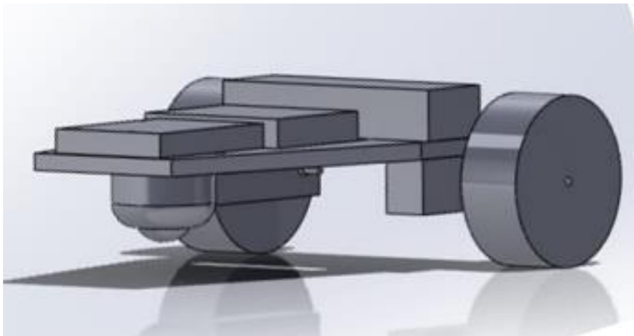
EXECUTIVE SUMMARY

Autonomous cars are driverless vehicles equipped with numerous components that enable them to navigate without human intervention. These cars can transform transportation safety by reducing human-induced errors and accidents, in turn saving lives as well as money.

To scale down this immensely technologically complex concept, the team will brainstorm ideas to make an innovative, Lane-Following autonomous robot. The miniature car must safely complete a predetermined track as quickly as possible while satisfying all objectives and constraints regarding its size, weight, cost incurred during production and overall aesthetics.

The proposed design for the challenge is a battery-powered robot constructed using acrylic sheets for both the base and body due to its high strength, low cost, and wide availability.

The robot will use infrared (IR) sensors to analyse its surroundings. These sensor modules emit infrared radiation to detect obstacles and other entities around them and do not require a bright light source to illuminate the path. Thus, they can sense objects even in the dim or complete absence of light, making their usage more efficient in all conditions.



Furthermore, the car will have two wheels with motors on the rear and a marble ball in the front to drive its movement. Incorporating three wheels into the vehicle's design introduces an additional advantage by enhancing its manoeuvrability, as the marble ball has a greater degree of freedom and allows more agile turning and better handling. It will also simplify the project's mechanical, electrical, and computing aspects by eliminating the necessity for a conventional steering mechanism.

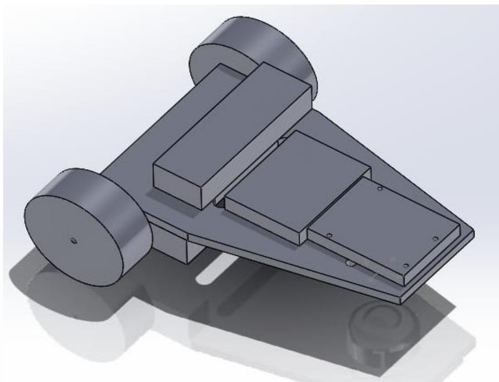


Figure 1(a) & 1(b): Concept design sketches

CONTRIBUTION STATEMENT

Ayusha Priyadarshani	-Worked on the Executive Summary, Contribution Statement, and Introduction -Edited the Design Proposal Report and EDP presentation video -Working on the computing aspects of the project -Wrote code for motor controller -Team Leader -Organised and participated in team meetings
Shayyan Sarlak	-Collaborated with Cameron and Junjie and worked on Concept Evaluation, Prototype Development and Project Plan -Working on the electrical aspects of the project -Made final circuit design -Team Leader -Organised and participated in team meetings
Oyindamola Taiwo-Olowa	-Worked on the Problem Definition and Conclusion -Made design sketches on SolidWorks -Working on the mechanical aspects of the project -Participated in group meetings
Cameron Newman	-Collaborated with Shayyan and Junjie and worked on Concept Evaluation, Prototype Development and Project Plan -Made design sketches on SolidWorks -Made assembly drawings of robot -Working on the mechanical aspects of the project -Participated in group meetings -Logged meeting minutes
Junjie Liang	-Collaborated with Cameron and Shayyan and worked on Concept Evaluation, Prototype Development and Project Plan -Working on the computing aspects of the project -Participated in group meetings
Driyarkara Ariel Brahmantyo	-Worked on Concept Generation -Working in the electrical stream -Participated in group meetings

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INTRODUCTION

Autonomous cars are machines of the future that have the potential to reshape the landscape of transportation. They use a combination of technologies to navigate and make decisions without human intervention. These cars will be able to communicate with each other in real-time, finding the most convenient and efficient path for the passenger.

Although the advancement in this field has not been as progressive as expected, consultancies predict that autonomous driving and advanced driver-assistance systems could generate between $300 billion and $400 billion in the passenger car market by 2035 [1].

The growing interest in this sector is due to the numerous advantages these vehicles bring. Road safety will increase as 94% of serious crashes are due to human behaviour [2]. Thus, higher levels of autonomy can potentially reduce dangerous driver behaviours, including accidents due to intoxicated, distracted, and impaired driving. However, one of the most significant benefits of self-driving cars is the independence they can provide to people who cannot drive. Senior citizens and people with disabilities will no longer need to rely on others for transportation and will be able to regain some, however small it may be, control over their lives.

Despite this, these automobiles must overcome several challenges in order to take over the world. Self-driving cars are a vision belonging to a perfect world that needs tremendous technological increment to be implemented in the real world. Crashes due to unpredictable human behaviour and system failures can be life-threatening. Passengers may be vulnerable to information abuse due to location sharing, which can jeopardise their safety and privacy. In addition, a much more sophisticated infrastructure will be demanded to introduce this concept effectively, leading to a steep increase in maintenance costs of cars, roads, and bridges.

The project at hand requires us to scale this idea down to a much smaller and simpler car. It should be capable of going around a given track as quickly as possible by making its own decisions without needing any assistance. The design should be safe, reliable, and aesthetically pleasing, while the car should not weigh more than 500g, and the dimensions should not exceed 250x200x250mm.

PROBLEM DEFINITION

Importance of Problem Definition

Problem definition is the first step in Clive Dym's six step engineering design process detailed in "Engineering Design: A Project-Based Introduction". It forms the basis for providing a solution to a given problem. This is typically done by drawing up a statement which fully outlines the objectives (features and behaviours the design should exhibit), constraints (limits or restrictions on the design's objectives), functions (specific things the design is expected to do) and means (ways to achieve said functions) of a proposed solution [3].

A revised problem statement is essential for building up the team charter- an agreement between the team and the client regarding what the project is to do. It allows the team to state more precisely and concretely what the client wants and needs. This makes it an effective communication tool, especially for clients with limited knowledge on the project topic and design process [3].

Clarification of the client's requirements

To get a clear understanding of what the client requires, it is important to define or frame the design problem clearly by extracting the various requirements. This helps in the emergence of a successful design solution.

Table 1: Justification of the team's requirement matrix

ID	Description	rationale	verification method
1	the system should weigh under 0.5kg	A specification of the 'RRR – Project Brief' document provided by the client	weighted by a kitchen scale <500g
2	the system should cost less than $100	A specification of the 'RRR – Project Brief' document provided by the client (price)	record purchase history estimated based on market price
3	the system should not exceed dimension 250mm*200mm*250mm	A specification of the 'RRR – Project Brief' document provided by the client (size)	measured using a meauring tape
3	the system should be able to navigate around the track	Project Brief' document provided by the client which is to design a (no contoller)	the system should complete one of our custom track
4	the system should be able to navigate within the bounded track	A specification of the 'RRR – Project Brief' document provided by the client (safe/not touch line)	the system should complete the custom track testing without touching the track lines
5	The system should be able to operate and complete multiply times	-As the system undergoes multiple rounds of testings and competition, it should be able to retain it's peak performance and intented function	should be about to complete 8/10 consecutive trial succesfully
6	The system should be asthetical minded	the system should be visually appealing to draw interest and to indicate it's completeness and quality.	has an exterior, contain colors and approved by all team members
7	the system should be innovative	To system should reflect the use of new designs and not common nuances	design meets it criteria, with additional features
8	the system will achieve time in group expectation	Project Brief document provided by the client. (fast)	complete testing track in under 60 second

Revised Problem Statement

In addition to the initial requirement clarification, it is important to formalise all the information gathered by drafting a revised problem statement that reflects a fuller understanding of the design process.

Project brief**:** Design and construct an autonomous lane-following robot that can safely complete a predetermined track as quickly as possible, while adhering to specified cost, weight, and size constraints, with an innovative and aesthetic design.

Given the client's instructions and constraints, a concise statement was put together that fully outlines everything needed to know about the design topic and proposed solution.

Problem statement**:** In response to the challenge of transportation safety, and in collaboration with Redback Racing, the project challenges each team to design an autonomous vehicle that can reliably traverse the preset racetrack at a high performance (fastest time). With a given budget of $100, a weight and size constraint of 500g and respectively, the vehicle is to safely traverse the track while remaining within the lanes. In addition, the vehicle should be an innovative and aesthetically pleasing to the observer.

CONCEPT GENERATION

Each member was to draw a design, where each member must include sketches, the advantages and disadvantages, and additional ideas of the design. This preliminary design report will show two members’ designs.

Design 1

Details of each component in the design: The vehicle base forms the central body, housing all other parts. The battery serves as the primary power source for the vehicle. Wheels with motors drive its movement. An Arduino, an open-source electronic platform, simplifies the process of reading inputs from sensors, like light detection, and translating them into outputs. The innovative marble ball replaces traditional motors with wheels, streamlining the circuitry for simplicity while still allowing for precise control. Additionally, the vehicle features a Pixicam sensor, responsible for detecting track lines and capable of identifying multiple colours, aiding in accurate navigation.

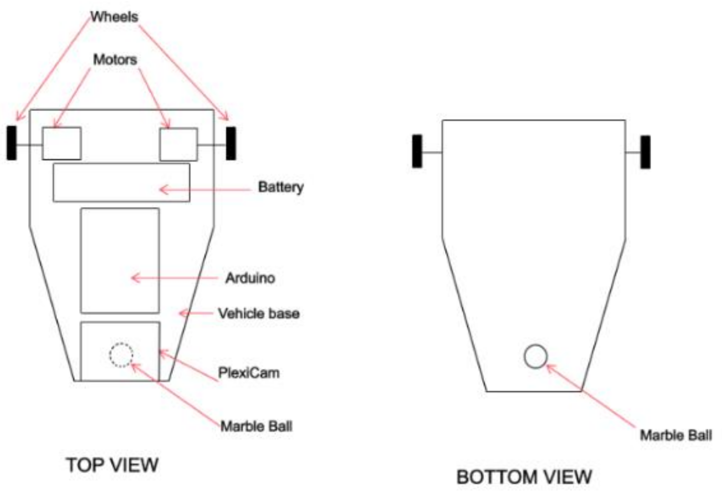


Figure 2: Design 1 sketch

Advantages: Firstly, the marble ball offers a significant advantage by simplifying the mechanical aspects of the vehicle, as it eliminates the necessity for a conventional steering mechanism. To add, the use of two motors in the vehicle’s system brings advantages to the coding aspect of the project, as the coding becomes more straightforward and efficient in comparison to more complex configurations. Secondly, the use of a symmetrical layout in the vehicle’s design provides a practical advantage by establishing a centred centre of mass and maintaining stability during the vehicle’s operation. Lastly, incorporating three wheels into the vehicle’s design introduced an additional advantage by enhancing its manoeuvrability, as it allows more agile turning and better handling.

Disadvantages: Firstly, the use of two motors may exceed budgetary constraints and add to the overall mass of the vehicle. Additionally, the three-wheeled configuration can present challenges when it comes to crafting an aesthetically pleasing body. Furthermore, the vehicle might be slightly heavier at the rear, affecting its balance and performance. Lastly, the three-wheel setup tends to be less stable compared to other configurations.

Additional ideas: Firstly, the incorporation of two fake front wheels, primarily for aesthetic purposes. Another innovative approach could involve making the vehicle’s body separable from the chassis, allowing for more convenient maintenance and customization in the future.

Design 2

Details of each component on the vehicle: The wooden base forms the structural foundation, housing and supporting all other elements. The battery serves as the power source, propelling the vehicle. Wheels with motors are responsible for the vehicle's movement. Light sensors play a critical role in detecting changes in light and converting them into electrical energy. A linear actuator transforms the motor's rotational motion into linear movements, facilitating push and pull actions. A plexiglass board adds an additional layer or vertical dimension to the design, supported by the stands. The Arduino, an open-source electronic platform, streamlines the process of reading sensor inputs and translating them into outputs, like activating motorized wheels movement.

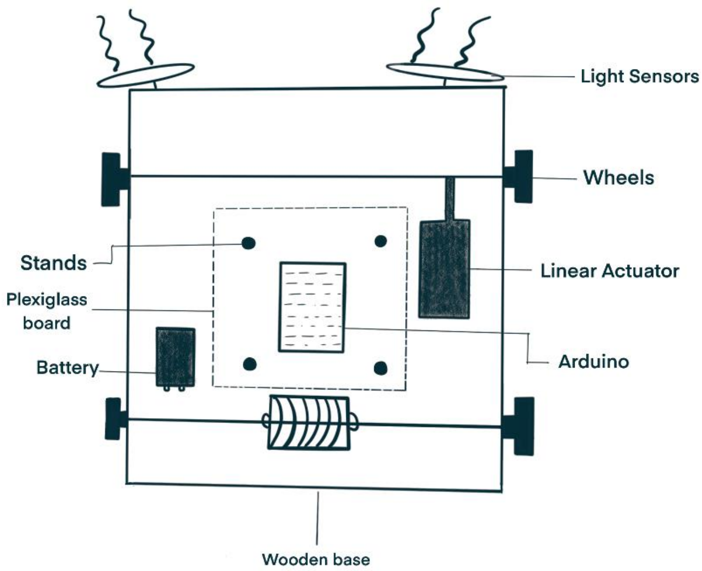


Figure 3: Design 2 sketch

Advantages: Firstly, the inclusion of four wheels provides a wider and more stable base, enhancing the vehicle's balance and overall stability. Additionally, the use of an Arduino to control the motor and actuator ensures safe and reliable breaking and precise turning, contributing to the vehicle's operational safety. The straightforward chassis design streamlines the assembly process, reducing the time required for construction. Furthermore, the two-story structure allows for the vehicle's dimensions, both in length and width, to comfortably comply with regulations.

Disadvantages: Firstly, it is slightly more costly and heavier than a three-wheeled alternative, which may affect budget constraints and overall weight. The inclusion of stands, plexiglass board, and linear actuator can contribute to increased weight compared to other designs, potentially impacting the vehicle's agility. Moreover, if the linear actuator is soldered, it may limit the degree of rotation available for steering, potentially reducing the vehicle's manoeuvrability and turning capabilities.

Additional ideas: First, connecting the linear actuator with a hinge could enable more substantial and flexible steering, eliminating concerns about solder connections snapping during operation. Expanding the placement of light sensors around the car can provide redundancy and ensure it remains within the lane, enhancing its precision. Moreover, the square-shaped base offers an ideal canvas for easily adding an aesthetically pleasing body to the vehicle, allowing for creative customization and design options.

CONCEPT EVALUATION

Table 2: Pairwise comparison chart of problem statement values.

	Durability	Price	Low maintenance	Aesthetics	Reliability	Efficacy	Ease of construction	Simplicity	Weight	Score	Rank
Durablity		1	1	1	0	0	1	1	0	5	4th
Price	0		1	1	0	0	1	1	0	3	5th
Low maintenance	0	0		1	0	0	1	1	0	3	5th
Aesthetics	0	0	0		0	0	0	0	0	0	8th
Reliability	1	1	1	1		0	1	1	1	7	2nd
Efficacy	1	1	1	1	1		1	1	1	8	1st
Ease of construction	0	0	0	1	0	0		1	0	2	6th
Simplicity	0	0	0	1	0	0	0		0	1	7th
Weight	1	1	1	1	0	0	1	1		6	3rd

The motivations behind the rankings in Table 2 are derived from the priorities outlined in the problem statement. It is axiomatic that the device's ability to complete the task it is designed for is ranked first in importance and thus, is followed by efficiency. It is of utmost importance to ensure the design specifications are fulfilled. Thus, follows weight and durability, respectively.

Durability has its importance through its attributes to safety, price of rebuilding, and reliability of the product. However, weight is prioritised due to the design constraints. This is, as failure to comply will result in a failure of the task. Although the price and size aspects are straight forward metrics, this is not the case for the weight of the vehicle. This is because it is mandated less than 500 grams, which includes all electrical components, as well as the wheels and chassis of the device. Careful consideration was made into the density and strength of different materials, as well as the weight and size of items ordered online.

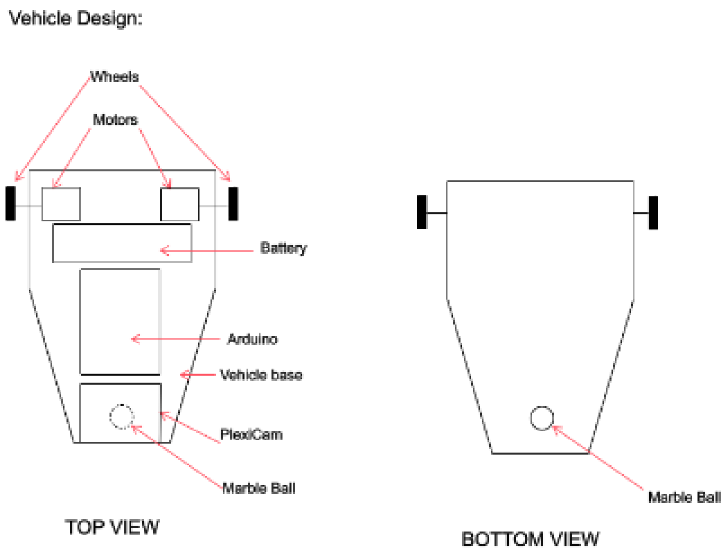
The ensuing considerations were the price, ease of maintenance and ease of construction. The importance of price was valued with similar rationale to the weight of the device, yet ultimately is not as great of a concern as the chassis is cheap to construct, and many of the electrical components were provided.

Ease of construction and maintenance were critical points in design evaluation. However, this is not deemed as paramount as other categories. This is due to the fact that difficulty in construction mainly stems from the initial research into how to construct the device. This includes, but is not limited to, the proper setup for the Arduino, the correct materials to use and the code created to control the device.

When analysing these features, it is apparent that once their methods are discovered and outlined, recreating each of the designs (whether for large or smaller scale manufacturing processes) is simple. Furthermore, the fact that each design was structurally sound, and there were minimal components that needed prolonged support, ease of maintenance was ranked lower on the list.

Finally, the two least important metrics of our design were simplicity and aesthetics, as these did not determine our device's ability to complete its task cheaply and reliably, but rather were further metrics that were used to differentiate good from great designs. Furthermore, they were features that could easily be tended to after an initial concept was created.

There were two designs considered for our project, and these were:



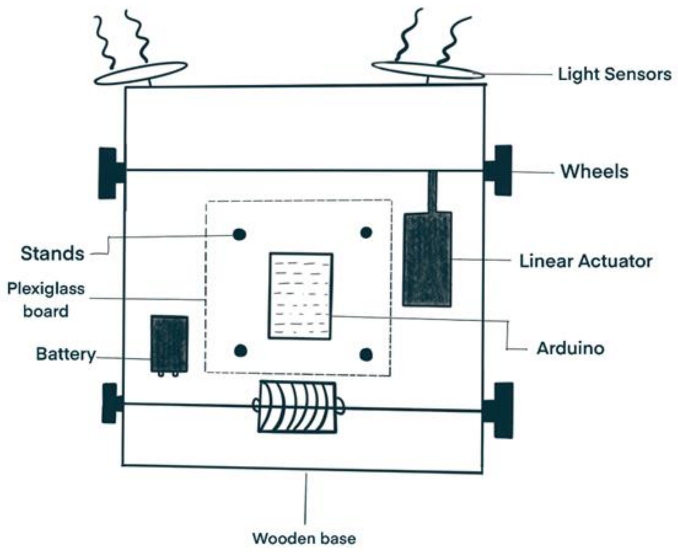


Figure 4: Concept sketch 1

Figure 5: Concept sketch 2

The main disparities between the two designs came in 1. Method of steering and locomotion, 2. How the device was going to be autonomous, and 3. The stability/dimensions of the device.

Design 2 uses infrared sensors to analyse their surroundings while Design 1 uses a pixicam. While both methods are completely valid, there are slight differences in using Infrared radiation in comparison to visible light cameras as sensors to create an autonomous vehicle. Firstly, the pixicam costs the entire $100 allocated to build the vehicle, which is ten times more than the infrared sensors, making IR more realistic. Secondly, there are differences in the nature of the two forms of light and their computational needs that favour IR sensors. The wavelength range of IR radiation is 780nm - 1mm, while visible light's is only 380-700 nm, meaning pixicam allows for a much smaller margin of error than IR. In conjunction with this, visible light sensors do not work as well under non optimal lighting conditions, as cameras require light to come from the object which only works if there is a sufficiently bright light source near it. Contrarily, IR can sense objects in the absence of light, making it more effective in all conditions. As a result, as IR sensors are more reliable and cost-effective, our team decided on them on our device [4].

Design 1 uses two wheels on the rear of the device, each with their own motor that allows for computer-controlled motor biassing to steer. In comparison, design 2 uses a linear actuator connected to the axle that can push or pull on one side to create rotation, thus steering. Considering the price of a linear actuator is at minimum 2-3 times more expensive than the motors, as well as the fact that without a proper hinge the linear actuator could only work on a small range of angles, our team decided to use electric motors that are connected to wheels.

Finally, Design 1 uses two wheels on the rear and a marble ball on the front, while Design 2 uses a square base with four wheels. The marble ball can be shown advantageous through the following moment equation. Thus, consider the Figures below.

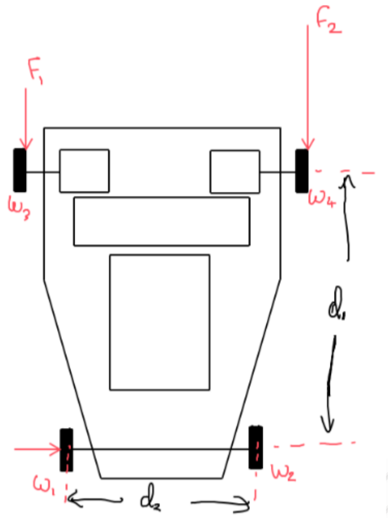


Figure 6: Vehicle four wheels

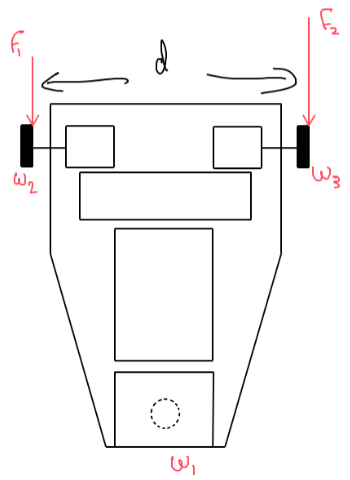


Figure 7: Vehicle one-marble, two rear wheels

Figure 6 has a moment that is generated on w_1 & w_2 whereas on Figure 7, wheel has a degree of freedom and allows the movement.

As a result, the team decided to use Design 1, with infrared sensors instead of a pixicam and three wheels instead of four.

PROTOTYPE DEVELOPMENT

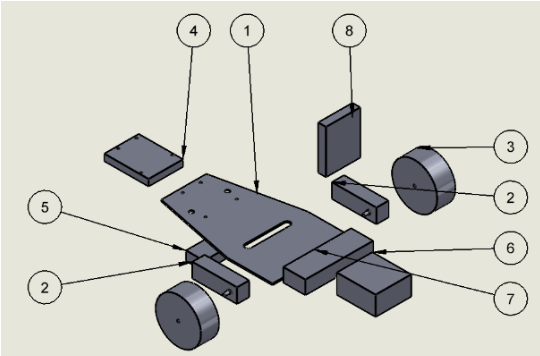


Figure 8: Exploded Isometric view of the vehicle

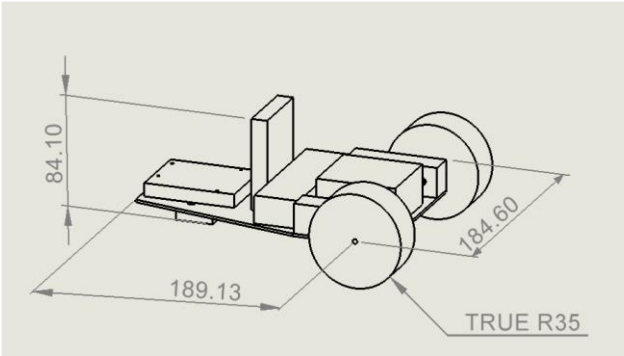


Figure 9: Assembly drawing of the vehicle.

Mechanical Stream:

From the concept evaluation process, Figures 8 & 9 depict the final design of the vehicle through their exploded assembly and isometric representations. Where possible, all components within the assembly are represented as blocks for simplicity, detailed in the table below.

Table 3: Bill of Materials for Assembly

Item No.	Part No.	Description	QTY	Cost/per	Price ($)	Mass (g)	Dimensions (mm) (L*W*H)
1	DVehBas1	Vehicle Base	1	N/A	$6.60	48.78	A5*2
2&3	DMotGea1&2	Motor & wheels	2	$5.45	$10.90	144	Other
4	DArd1	Arduino	1	$15.00	$15.00	25	68.6*53.4*10
5	DSwiWhe1	Swivel wheel	1	$6.00	$6.00	10	45*28*14
6	DMotDri1	Motor driver	1	$10.95	$10.95	33	69*56*36
7	DBat1	Battery	1	$28.00	$28.00	179	105*33*21
8	DBre1	Breadboard	1	$5.95	$5.95	30	68*53*12
N/A	DIR1	Infrared Sensor	1	$5.45	$5.45	10	48*17.3*11.5
				TOTAL:	$88.85	479.78	

By Table 3 the quantities, costs and theoretical masses are provided along with the box dimensions used for each component. It is important to gather from Table 3 and Figure 9 that there is compliance with the design specifications, which to recall are, the vehicle is to be: less than 500g; less than $100 total cost, and within 250*200*250 (L*W*H). For the base of the vehicle, it was decided to use acrylic due to its high strength, low cost, and wide availability. Thus, a A5*2 (LWH) size acrylic sheet is to be laser cut from and used for the body of the vehicle. This will allow other designs to be engraved on it for aesthetics such as the logo for our team.

Electrical Stream:

There were six electrical components used in the design which were: A 9V battery, two electric motors, an L298N motor controller, an Arduino, as well as an infrared sensor. The parts were each chosen to be 1. Compatible with Arduino, 2. Lightweight, and 3. Affordable. The battery is our power source, driving the motor and facilitating the autonomous nature of the device. The motor controller acts as a middleman between the Arduino and the electric motors, allowing us to digitally control the direction that the motors spin, as well as use pulse width modulation to increase or decrease speed as well as bias motors. This in conjunction with our motors provides our design with locomotion, as well as a method of steering, as the motor bias creates a centripetal force that rotates the device. The Arduino allows us to ascertain information from sensors and use that along with digital code to control the movement of our wheels. Finally, the infrared sensor distinguishes between light and dark colours to tell our device how close it is to the edge of the lane, allowing the Arduino to steer the motors accordingly.

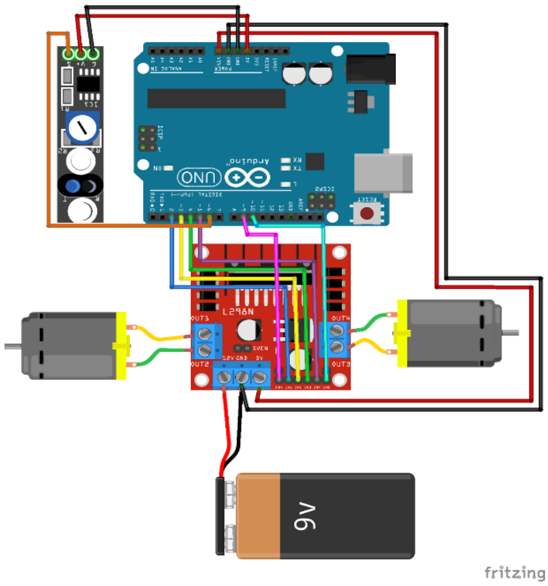


Figure 10: Fritzing circuit assembly

The design of the circuit is simple and efficient. The battery is connected to the motor controller, which is in turn connected to both the motors and the Arduino. This allows the motor controller to not only power the Arduino with its 5V output, but also take signals from the Arduino and apply it to the motors. The connections in Pins 2-5 of the Arduino control spin direction. Pins 9 and 10 of the Arduino control the PWM (pulse width modulation), which allows us to use digital information to tell the motors how fast to spin. All of this is how the Arduino sends information to the motor controller to inform the motors, but there needs to be a reason for that information being sent. This is where the IR sensor comes in, powered by the Arduino, and connected to pin 6. This connection allows the Arduino to pick up data from the sensor on the device's position relative to the black lines marked on the track, thus allowing us to code it to stay within the lane.

Computing Stream:

In the coding aspect of our project, the goal is to program the Arduino to independently steer the car based on the information from the Infrared (IR) sensor. This means our Arduino must make instantaneous decisions about the car's speed and direction based on the sensor's input. We start by including essential libraries, which are packages that provide crucial functions for managing the motors and processing data from the sensor. Then Global variables are employed (motor1/2, IR sensor pin) making them accessible and usable throughout the entire code. The "setup" function gets the IR sensor ready to receive and interpret infrared signals, preparing it for it to run. The main loop function, like its name suggests, keeps looping/ repeating, continuously managing the sensor's data, and making decisions by reading (digitalRead(IR_SENSOR_PIN)) the infrared sensor based on the car's precise position on the track, giving feedback to the motor control when it detects changes in signal (from white to black or vice versa), it triggers decision-making logic. For example, if the IR sensor goes from "HIGH" (spin) to "LOW" (not spin), the code might interpret this as the car crossing a black line, and it can make steering adjustments based on this information to keep the car following the track correctly. Motor control plays a huge role in the success of our project as it ensures that the project's velocity and orientation are adjusted in response to data received from the IR sensor (done in further testing stages like setting up the speed).

PROJECT PLAN

Table 4: Gantt Chart

Project: Redback Autonomous Vehicle Project

Project start date: 20/09/2023

Milestone marker: 1

Milestone description	Assigned to	Progress	Start	Days
Mechanical Stream	Cameron, Damola		20/09/2023	
Design Chassis		100%	12/10/2023	8
Analyse cost/weight of materials		90%	18/10/2023	5
Order necessary parts		50%	20/10/2023	5
Build Vehicle		0%	23/10/2023	7
Review		0%	28/10/2023	8
Electrical Stream	Shayyan, Ariel			
Research parts needed and circuit design		100%	17/10/2023	3
Create tinkercad circuit to check design		100%	18/10/2023	4
Order necessary parts		100%	19/10/2023	3
Build circuit		0%	23/10/2023	5
Review		0%	26/10/2023	4
Computing Stream	Ayusha, Junjie			
research on arduino coding needed		100%	28/09/2023	4
design code		100%	12/10/2023	10
Write code for IR sensor		60%	18/10/2023	8
Testing/adjusting code		0%	25/10/2023	5
Review		0%	28/10/2023	20
Testing				
Compliance testing			30/10/2023	1
Final Competition			16/11/2023	1
System test			25/10/2023	8
Reviewing and adapting code/circuit			28/10/2023	20

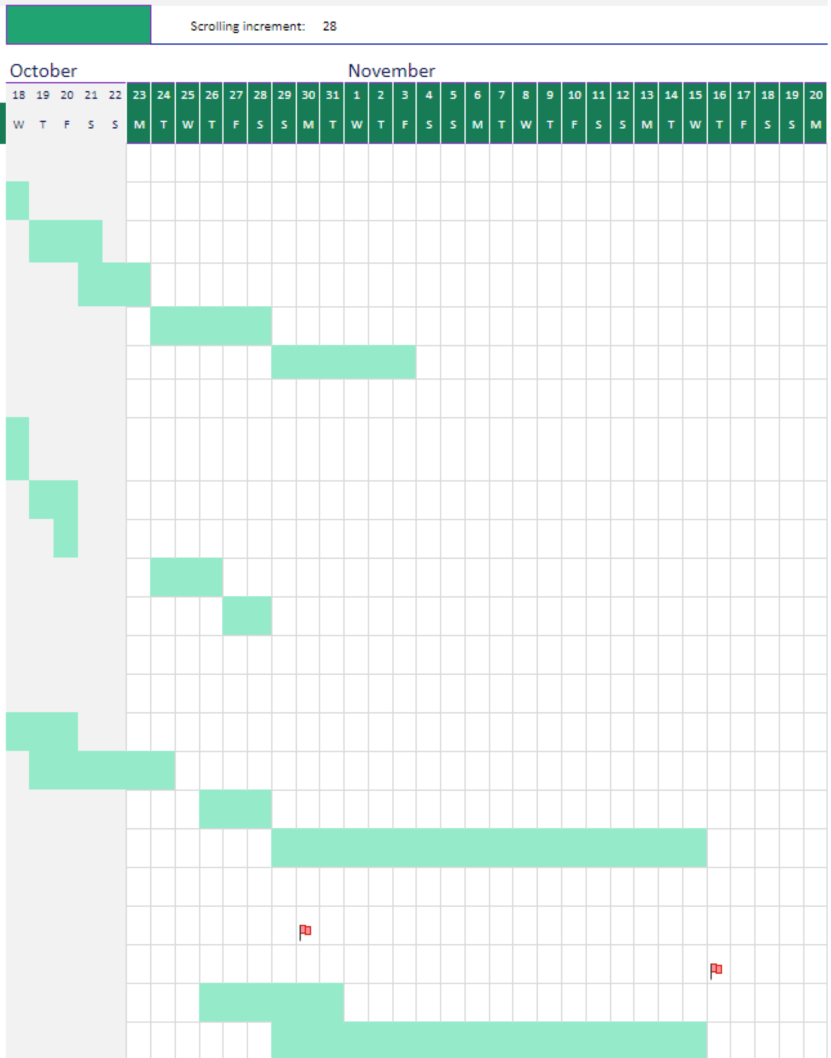


Table 5: Project risk analysis

Risk	Risk Time Frame	Likelihood	Impact	Contributing Factors	Prevention
Weight of the vehicle exceeds 500g.	Once we receive the parts (20-23/10)	Unlikely. Part details and sum is previously mentioned.	Exceeding 500g will result in a fail.	Improper calculations of weights.	Have alternative solutions. Min-max components.
Requiring more components that push us over the price limit.	After we build and test our circuit (21-25/10)	Unlikely. The circuit is planned and simulated on TinkerCad. Small components can be reacquired. Faulty parts will be reordered.	Missing or faulty components means that the vehicle can't run optimally or at all resulting in a fail.	Bad planning by the team. Not using circuit softwares (Tinkercad).	With further research it will be simple to find cheaper / different parts for the job.
Prototype takes too long to build. Not enough time for the other parts.	In the review process of our device (23-27/10)	Possible and likely. Might be difficult to debug errors and come up with solutions. Optimisation may then take longer.	Providing a product unable to complete its task will result in a fail in proving compliance.	Bad time management. Unrealistic goals	Work more hours to fix the issue. Consult mentors or others on the issue.
Team members become sick/unable to work.	Can happen any time. However, building & review is crucial (21-27/10)	Unknown/Unlikely. This is unable to be determined but poses a threat due to seemingly random behaviour.	Missing members means the team cannot work best, decreasing the quality of the product, which can result a fail.	Being unlucky. COVID19 is still lurking. Overworking and burning out.	All members agreed willing to help out other streams if needed. Distribute workload.
Prototype breaks or fails	Between review process and compliance testing (23-30/10)	Unlikely. This could be from bad planning, oversights, accidents or mishaps.	If the prototype breaks (depending on the part) it may not pass compliance.	Not using proper electrical circuit analysis. Simulated vs actual is different. Errors in code during testing.	Order or make more parts coming out of pocket.

CONCLUSION

In accordance with the steps outlined in the engineering design process, the problem has been defined using a problem statement, various design concepts have been generated and evaluated, and a final concept design has been chosen. Decisions have been made regarding the computing, electrical, and manufacturing aspects of the design, all which are required for the manufacture of a working prototype.

Following up on the selection of a final design, a project plan has been drawn up, one which outlines the next steps to be taken in preparation for the compliance testing and the final competition. According to the plan, components needed for the manufacture will be purchased and a prototype of the final design will be made ahead of the compliance testing. The prototype should meet all the requirements to pass the compliance test. Afterwards, finishing touches will be put on the prototype to prepare for the final competition.

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