DESN1000

Redback Autonomous Car

Term 3

Final Design Report

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Team 2- Autobot Dynamos

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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 had to brainstorm ideas to make an innovative, Lane-Following autonomous robot. The miniature car was required to 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 final design for the challenge was a 3-wheeled, AA-battery powered robot. The base was laser cut from 2mm acrylic because of the high structural integrity of acrylic that outweighs other alternatives. The vehicle cover was 3D printed for its advanced shape. We used a dual motor, 3-wheel steering system because two motors as opposed to one allow double the power output.

The power source for the design was chosen carefully to maximise energy efficiency. Initially, 9V battery was used but the battery did not last long enough to allow the car to traverse three laps around the track. Through research on ways to generate a more effective 9V power source with a larger capacity, it was quickly settled on using six AA batteries to power the device. While this worked well for the project, a better idea would be to use the 11-volt LiPo battery in the future due to its longevity, reliability, and ease of recharging.

The team decided on using four individual IR sensors to analyse its surroundings as they had a very simple and effective way of signalling its location with respect to the black lines on the track. IR sensors are very easy on the pocket and weigh around 5 grams per unit, allowing the team to easily make weight constraints without sacrificing on other features of the robot. However, using a 5(or more)-channel IR sensor may improve the reliability and precision of the robot, while enabling it to move faster around the track and complete the laps much quicker.

In the final race, the goal of completing three laps of a racetrack autonomously was accomplished. The design did well, placing fifth and sixth for aesthetics and innovation respectively. Overall, this performance put the team at fourth place out of all teams that participated in the competition. The final design was well within the budget, size, and weight restrictions. Nonetheless, there are opportunities to optimise the design for increased speed, fine-tune the steering system, consider alternative sensor configurations, and incorporate redundancy measures.

CONTRIBUTION STATEMENT

Ayusha Priyadarshani	-Worked on Executive Summary, Contribution Statement, and Introduction -Edited and formatted the final design report -Wrote code for compliance testing and final competition -Assembled the prototype and final model -Organised and participated in team meetings -Team Leader
Shayyan Sarlak	-Worked on Final Design, Final Competition and Reflections -Constructed the circuit -Organised and participated in team meetings -Team Leader
Cameron Newman	-Worked on Final Design -Made Dimetric & Isometric drawings of vehicle design -Cut the vehicle base and 3D printed the cover -Worked out the moment equation for turning effect -Organised and participated in group meetings -Logged meeting minutes -Hardworking team member
Oyindamola Taiwo-Olowa	-Worked on Final Competition and Reflections -Made design sketches on SolidWorks -Cut the vehicle base and 3D printed the cover -Participated in group meetings -Reliable team member
Junjie Liang	-Wrote Conclusions and Recommendations -Tested various versions of the code to determine the most optimal speed and alignment of sensors. -Participated in group meetings -Enthusiastic team member
Driyarkara Ariel Brahmantyo	-Worked on Final Design -Constructed the circuit -Participated in group meetings -Reliable team member

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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 (Autonomous driving's future: Convenient and connected, 2023).

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 (Tri-level study of the causes of traffic accidents). 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.

In response to the challenge of transportation safety, and in collaboration with Redback Racing, the project challenges each team to us to scale this idea down to a much smaller and simpler car that can reliably traverse the preset racetrack at a high performance (fastest time for 3 laps). With a given budget of $100, a weight and size constraint of 500g and 250x200x250mm, the vehicle is to safely traverse the track while remaining within the lanes. In addition, the vehicle should be an innovative design and aesthetically pleasing to the observer.

FINAL DESIGN

2.1. Mechanical

The mechanical component for the vehicle includes designing the shapes, orientations and configurations of all parts. In addition, the materials and manufacturing of each component and making evaluations as to why and how parts are used and assembled. The key to this component is being able to convey the ideas to other members as clear and concisely as possible to ensure that there is a quality final product produced.

2.1.1. The Final Product

For a brief overview, this is the assembly for the final product. All electrical components are represented as blocks with dimensions provided under their product specifications (See Table__1. below) due to their complex shapes that are considered insignificant in the production of a digital model.

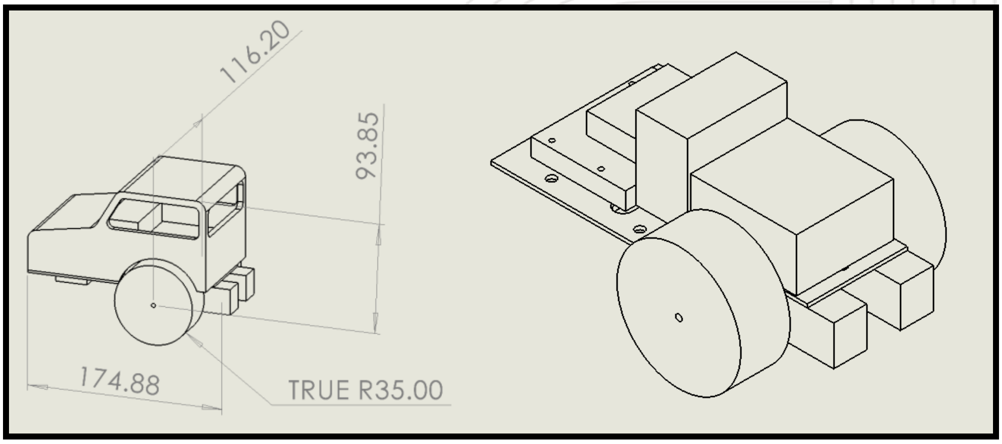

Figure__1. Dimetric & Isometric Drawings of vehicle design (with/without cover).

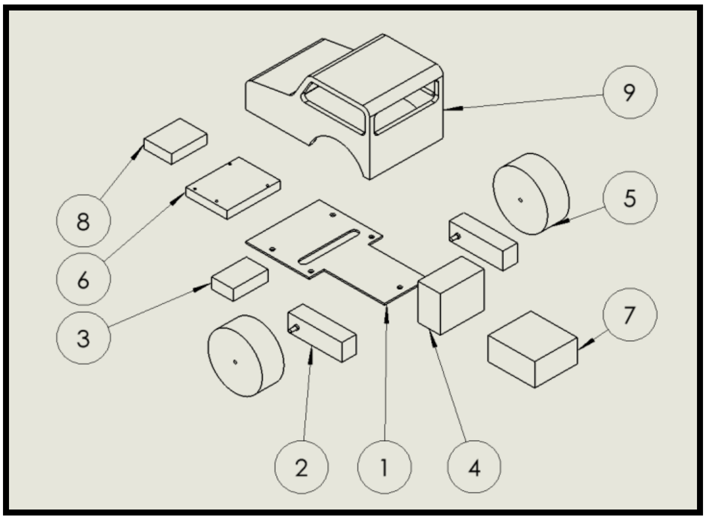

Figure__2. Exploded Isometric view of vehicle design.

Table__1. Bill of Materials for vehicle inc. cost, weight and size.

Item No.	Part No.	Description	QTY	Mass/per (g)	Cost/per	Price ($)	Mass (g)	Dimensions (mm) (L*W*H)
1	DVehBas1	Vehicle Base	1	N/A	N/A	$6.60	48.78	160*95*2
2&5	DMotGea1&2	Motor & wheels	2	72	$5.45	$10.90	144	Other
3	DSwiWhe1	Swivel wheel	1	10	$6.00	$6.00	10	45*28*14
4	DBat1	Battery	1	84.22	$28.00	$28.00	84.22	105*33*21
6	DArd1	Arduino	1	25	$15.00	$15.00	25	68.6*53.4*10
7	DMotDri1	Motor driver	1	33	$10.95	$10.95	33	69*56*36
8	DBre1	Breadboard	1	30	$5.95	$5.95	30	68*53*12
9	DCov	Vehicle Cover	1	104	$0.00	$0.00	104	160*95*80
N/A	DIR1	Infrared Sensor	2	10	$5.45	$10.90	20	48*17.3*11.5
					Total	$94.30	499.00	174.88*116.20*93.85

Within the physical product alone many of the project requirements are needed to be withheld. This includes the weight, cost and size of the vehicle, which Table__1. shows compliance with each of the project requirements.

2.1.2. Innovation and Aesthetics

Further within the design of the vehicle includes the innovation and aesthetics of the vehicle. For the innovation aspect it was decided to use a dual motor, 3-wheel steering system this is because two motors as opposed to one allows double the power output. This also allows for biassing the motors, which creates a steering effect.

This can be shown by first making a few assumptions, they are: the vehicle is a rigid body; the centre of mass is directly over the vehicle centre, that is the centroid is half the width. The turning effect is simulated by applying two non-zero forces denoted by F1,F2 applied at wheels 2&3 denoted by w2,w3 and allow w1 to be the swivel wheel. For this instance, say that the vehicle is to turn left, that is F1<F2. This is to be represented in the figure below.

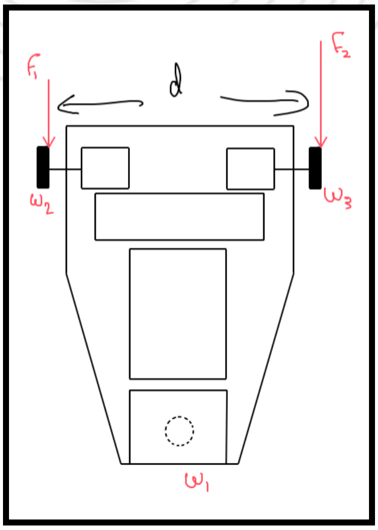

Figure__3. Diagram of vehicle as described above.

From Figure__3. there is no moment on w_1 (assuming no friction on w_1) but due to the friction a moment is generated on w_2. This allows the vehicle to pivot and is taken advantage of by increasing the difference between the two forces. As the moment is created over the centroid.

$$\sum M_{\bar{x}} = F_2(\frac{d}{2}) - F_1(\frac{d}{2}), \text{recall } (\frac{d}{2}) \text{ is the centroid.}$$

Eqn 1. Moment equation for turning effect.

Thus, this is the innovation behind using 3-wheels for steering as opposed to other solutions.
On the other hand, for the aesthetics of the vehicle a design was chosen that resembles the popular English car known as the Reliant Robin, to accommodate the 3-wheel design. Within the project this was executed through an attachable cover that resembles its shape.

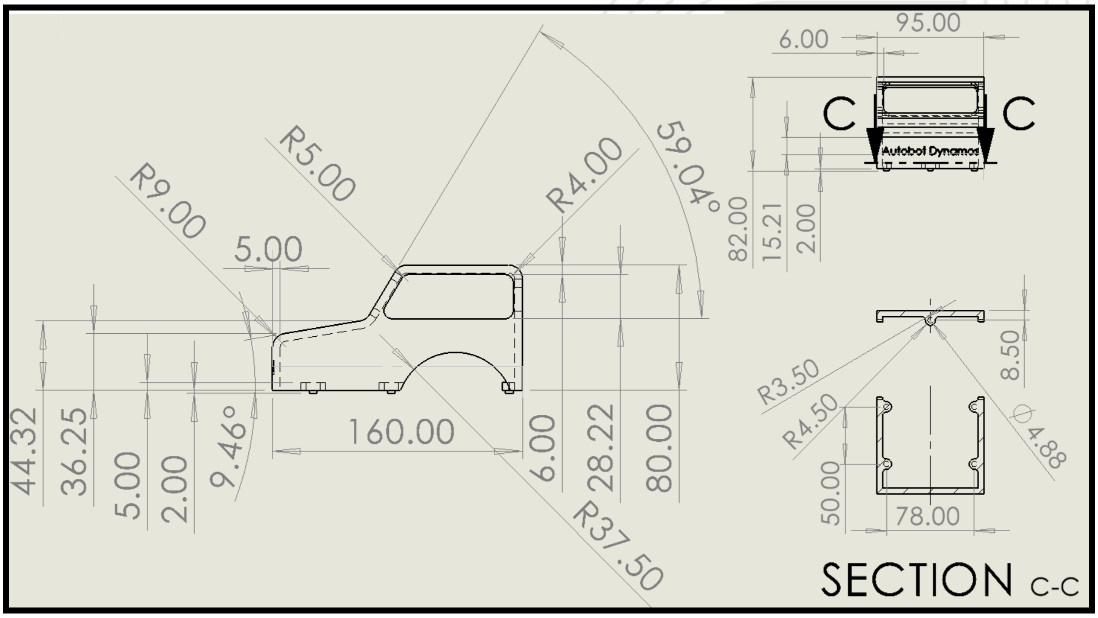

Figure__4. Left Side, Front and Section C-C views of the Vehicle Cover respectively.

Although the vehicle looks rather dapper with the cover on, another feature of the cover is that it hides the accumulation of wires underneath.

In the manufacturing aspect of the vehicle, the base of the vehicle was to be laser cut from 2mm acrylic, this is because of the high structural integrity of acrylic that outweighs other alternatives like 2mm plywood. On the other hand, the vehicle cover was 3D printed for its advanced shape, although handy for timesaving, 3D printing is the most practical option because it removes the skill required for handcrafted products and shifts it into CAD modelling.

For the assembly of the two components, a H9/d10 hole basis tolerancing system was used. This is because of the nature of the fit categorised as a loose clearance fit. However, this tolerance was used to also account for errors in 3D printing and laser cutting. This then allowed the two pieces to in essence snap together like Lego pieces which allows for easy assembly and removal.

2.2. Electrical stream

The electrical component for the vehicle includes the wiring and connection of all the individual parts of the vehicle to make one whole working product.

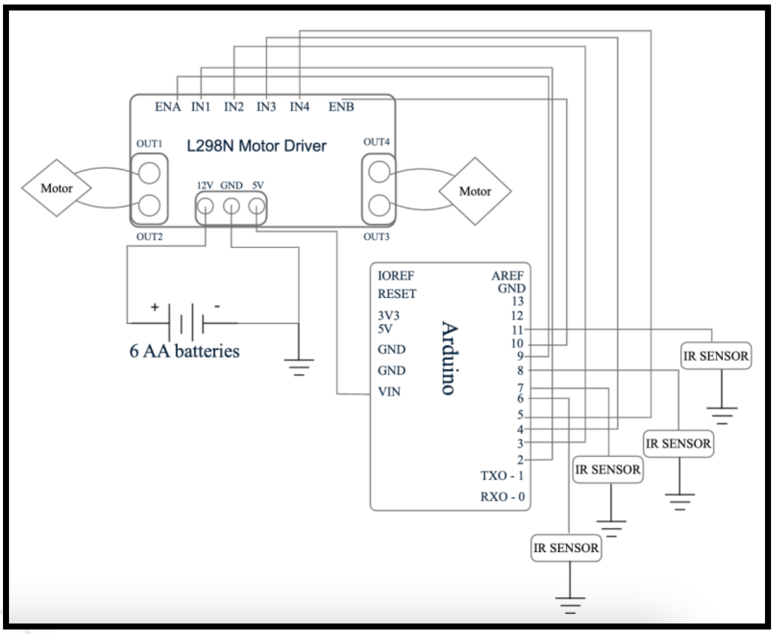

Figure__5. Electrical Circuit Diagram.

The power source for the design was chosen carefully to maximise energy efficiency, while conforming with the power specifications of our electrical component. The motors were limited by a 5-volt operating voltage, meaning the 9V power source needed to be stepped down with a voltage regulator. Initially, a single 9V battery was used, but it was quickly discovered that it discharged too quickly. The battery wouldn't last long enough to allow the device to traverse three laps around the track. Through research on ways to generate a more effective 9V power source with a larger capacity, it was quickly settled on using AA batteries to power the device. Most 9V batteries range from 300-500 mAH, while AA batteries can range from 1000-2000 mAh. From basic circuit analysis, voltage sources placed in series have an equivalent voltage, equal to the sum of each individual source. Therefore, if a total of 9 Volts from 1.5V batteries 6 of them are required, which is what was used in the final design.

The main component used to control the motors was the L298N motor driver. This was a necessity, as the Arduino itself cannot provide a high enough current to reliably drive electrical motors. In addition to this, the H-bridge motor driver is able to pick up signals from the microcontroller, allowing us to control the direction of rotation as well as the speed of the motors via pulse width modulation signals. Motor drivers are essentially current amplifiers followed by input signals.
The autonomous nature of the vehicle was facilitated by IR sensors. More specifically, four single channel IR sensors spaced evenly across the front and sides of the device. The benefits of the IR

sensors when compared to other methods comes in 1. Cost, 2. Weight, and 3. Ease of configuration. Each sensor only costs a couple of dollars, as opposed to something like a $100 pixycam. They each weigh around 5 grams, allowing us to easily make weight constraints without sacrificing on other features of the robot. Finally, the IR sensors had a very simple and effective way of signalling its location with respect to the black lines on the track. A 1 or a 0 would be sent to the Arduino, which with proper code allows the microcontroller and the motor driver to bias one of the motors, thus creating a steering effect. Overall, the sensor was simple and reliable.

There was a shared ground between all the electrical components and the negative terminal of the battery, allowing the current to safely discharge instead of building up in places where it would be dangerous.

Finally, the motors used in the circuit were simple brushed DC motors, this was to complement the DC power source. The current drawn through the motor, in conjunction with the permanent magnets built into it created a torque due to the motor effect. This was aided by the split ring commutator and brushes to ensure the direction of torque was consistent. The motors were our source of locomotion and steering, allowing us to convert electrical energy into mechanical energy.

2.3. Computing

The coding stream is responsible for developing the software and algorithms that enable the vehicle to autonomously navigate a bounded track. This includes integrating appropriate sensors, crafting decision-making logic based on sensor inputs, and optimising the code for efficient and reliable performance on the given track. The coding stream plays a crucial role in translating the physics and logic into executable instructions, ensuring the seamless execution of autonomous operations for our vehicle.

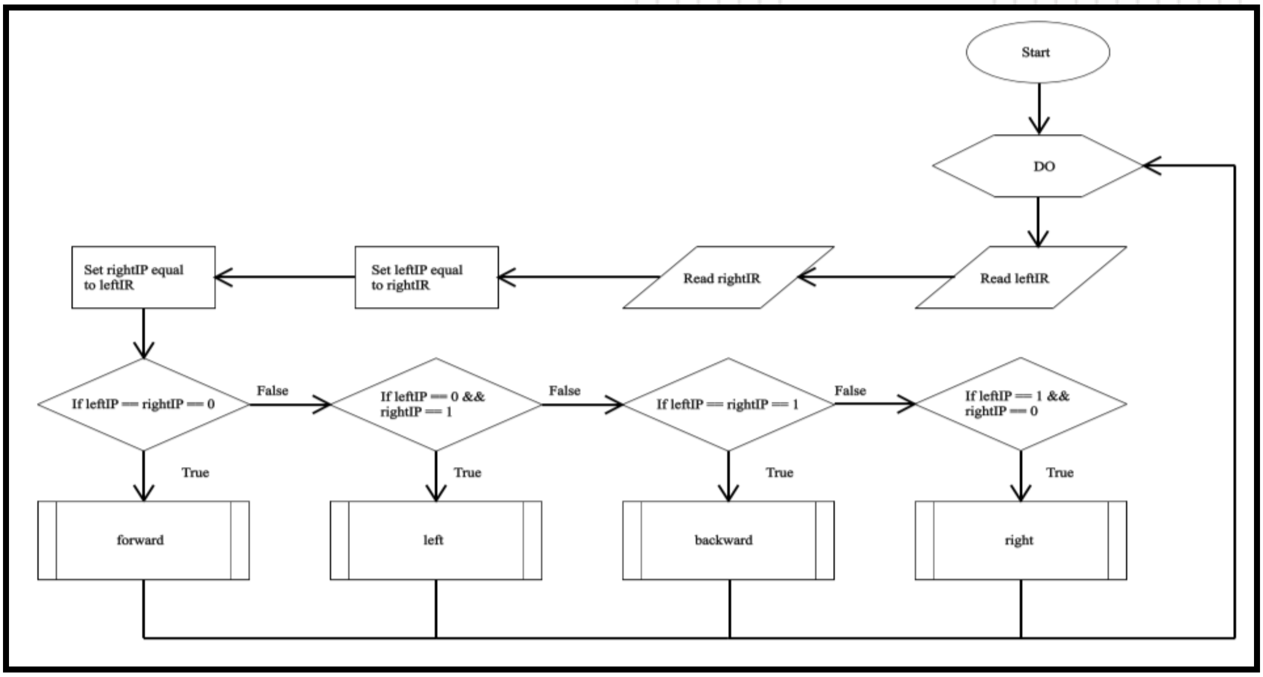

Figure __6. Pseudo Flowchart of navigation cod

2.3.1. Code logic

The core functionality of the code revolves around instantaneous decision-making based on input from the IR sensor. Consider the situation where the vehicle is approaching a barrier. The initial step involves reading signals from both the left and right IR sensors. Then, from the readings of the sensors, the left input (IP) is set equal to the right IR signal vice versa. This is because the IR sensor is passively receiving a true input (1) so when the vehicle comes across an obstruction that interferes with the reading this returns a false input (0) as the sensor is not receiving the IR waves. The code then employs conditional statements to interpret these signals and make informed decisions.

If both left and right inputs equal 0, the vehicle moves forward.
If the left input equals 0 and the right input equals 1, the vehicle turns left.
The vehicle turns right if the left input equals 1 and the right input equals 0.
If both inputs equal 1, the vehicle moves backward.

Figure __6. above visually represents these decision-making processes.

2.3.2. Placement of IR Sensors:

Strategic placement of the IR sensors significantly influences the vehicle's performance. Placed close together at the front of the vehicle, the sensors ensure clear readings and effective forecasting of upcoming turns. To enhance its predictive capabilities, the sensors are tilted at an angle, enabling the vehicle to forecast turns and act accordingly. Additionally, the use of multiple IR sensors accommodates varying approach angles, crucial for navigating tighter turns with precision.

2.3.3. Modification of Code:

Continuous refinement of the code involved detailed modifications. Introducing delays to the code allowed the vehicle time to execute steering adjustments effectively. Additionally, fine-tuning the pulse-width modulation (PWM) cycle through rigorous track testing balanced performance and consistency.
The traditional approach involves slowing down one wheel while speeding up the other. However, during this turning process, the vehicle's overall speed is reduced, and the turning radius is influenced by the speed differential between the two wheels. By contrast, the decision to keep both wheels moving during a turn involves modifying the power inputs to the motors relative to their turning radius for the centre of the turn. Consider a vehicle turning around a corner with a constant angular velocity. It is assumed that the vehicle is a rigid body and that the path of its motion is described below.

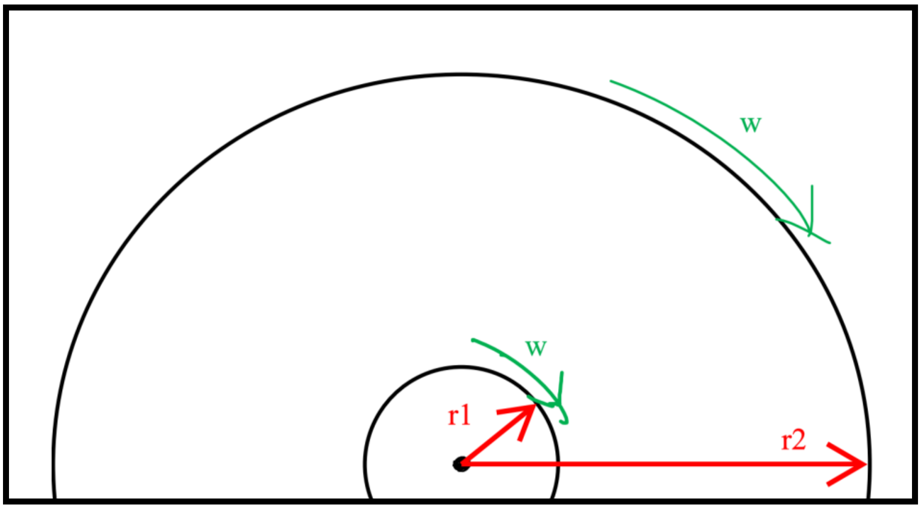

Figure__7. Path of the vehicle.

Let the black lines represent the path of the wheels, the angular velocity to be denoted by w and the radius of the inner & outer wheels from the centre of the turn to be denoted by r_1, r_2 respectively. Thus, the tangential velocity for each of the wheels is represented by,

$$v_t = wr,\ \text{where } v_t \text{ is the tangential velocity.}$$

This gives the equations for each of the wheels,

$$v_{1,t} = wr_1 \text{ and } v_{2,t} = wr_2.$$

Which when rearranged for angular velocity,

$$w = \frac{v_{1,t}}{r_1} = \frac{v_{2,t}}{r_2}, \text{ are equated since angular velocity is constant.}$$

Then further equating,

$$v_{1,t} = \frac{v_{2,t} r_1}{r_2}.$$

Eqn__1. Tangential velocity of the inner wheel from outer wheel and radius of turn.

Although the power input for the motors does not directly correlate to the tangential velocity, only angular velocity of the wheels, as both wheels are under the same conditions this will only affect performance by a scale factor.

2.4. Final Design Pictures

Figure__8. Final Design of the Vehicle.

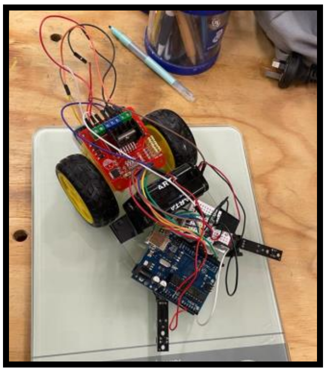

Figure__9. Electrical Circuit on the vehicle

FINAL COMPETITION

3.1. Final Competition Results

Table__2: Final Rank

Placements:
5th fastest time 2:10
5th for aesthetics
6th for innovation
Overall, 6th of 9 teams.

3.1.1. Memorable performances

Team UFO's design had the fastest consistent lap time on the day. Their paper cover, and thin wooden base and wheels made it one of the lightest designs. This allowed the robot to steer and move easily, especially considering the very thin wheels had a small amount of friction with the platform. They used multi-channel IR sensors which gave multiple pieces of precise data on the proximity of the black lines allowing the device to steer accordingly. Overall, their design was extremely effective without being superfluous in any manner.

Figure__10: Team UFO

Team Batman's device was also very quick but had an error in the final race which caused it to veer off the track, putting it in second place. Their design was optimised to maximise the speed of the device by minimising the weight and friction, while using a higher voltage energy source to provide more current to their motors. The base was built with foam with a very low density to cut weight. They removed the rubber wheels off their tires, which did reduce friction but also reduced traction, making it difficult to discern whether it was a beneficial design choice. Finally, they used an 11-volt power source and two 5-volt DC motors attached to a wheel, steering by biassing one wheel. While the weight wasn't optimal, their 11-volt LiPo battery provided more current than the traditional 9V battery, while having a longer lasting life.

Figure__11: Team Batman

Team “boom mic arm” had one of the most unique looking designs of the day, with their extended arm IR sensor configuration. While most teams had two sets of IR sensors at the front of their robot, indicating when a black line was in front of their left or right side which gave a sense of their position, team “boom mic arm” had only one set of IR sensors. These 3 or 4 channel sensors followed the right side of the lane, constantly staying above the black lane to tell the Arduino when the line below it would deviate to the left or right. Rather than steering when the sensors got closer to a black line, the robot would steer when the black line got further away from it. This allowed them to cut down on the cost of the sensors. Overall, the rest of the design was quite consistent with what we saw with many other teams.

Figure__12: Team Boom Mic Arm

3.1.2. Reflections on previous and final designs

From the design proposal, there were only small differences in each design that would affect the efficacy of the robot. These considerations were which sensor to use, how many/what style of wheels we should have, and what method of steering we should use. One of the previous designs had four wheels and a linear actuator for steering. This design would have exceeded the budget and weight restrictions, as well as being too large to traverse the track swiftly. The other design was pretty close to the final rendition, only that it made use of a pixicam instead of the IR sensors. Although this design would have fit within the budget and size restrictions, it would have exceeded the weight and would have required a more complex code with little benefit as it would not have been as effective as the IR sensors.

3.1.2.1. Successful Reiterations

1. The original base was a large, thin piece of laser cut wood, which was too wide to be effective in the lane. The acrylic base was cheap, easy to laser cut, lightweight, shatter resistant and very small. This made it optimal for our robot’s purposes.

2. The DC geared motor wheels we used were quite cheap (only 8 dollars each), very easy to use, reliable, and had an operating voltage ideal to the speed we needed our robot to drive.

3.1.2.2. Ineffective Reiterations

1. The design was originally powered by a single 9-volt battery. However, this discharged too quickly, making the voltage output inconsistent and stopping us from completing 3 whole laps. This problem was solved by replacing the 9-volt battery with 6 AA batteries, allowing it to have a lighter, cheaper and longer lasting power source that had the same power output. While this worked well for the purpose, a better idea would be to use the 11-volt LiPo battery in the future. While it does add to the weight, its longevity, reliability, and ease of recharging makes it easier to manage long term than our final design.

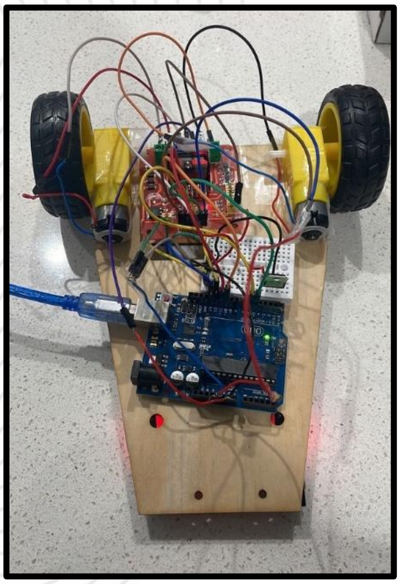

Figure__13: Compliance Test Design- Prototype 1

2. The design started off using a single channel infrared sensor on each side. However, this sensor did not provide a detailed enough signal, as the device kept crossing over the black lane. To improve this, another infrared sensor on each side of the device, attaching them close enough to the ground to ensure they were picking up a reliable signal. This eventually worked, however not very reliably. In the future, it would be more effective to use a multi-channel IR sensor such as the ones used by team (UFO) and team (foam). Using this would have provided a more exact input data, which could have been used to program the device to be more precise.

3. All the electrical components were taped onto the acrylic base. While this was fairly strong enough to secure the components to the base, it dropped points for aesthetics and was very messy in the long run. In the future, the components would either be screwed or soldered onto the board, unless it was something that needed to be quickly attached and removed. Similarly, as the design used a solderless breadboard and thin wires, there were times where the wires would disconnect. To mitigate this in the future, the connections could be soldered together, or heat shrink tape could be used to secure them.

3.1.2.3. Design Limitations

1. One of the limitations of every design is the approximate size dimensions. While space could be saved by stacking the components vertically on the base, the device needed to be wide enough to be stable. Due to this, every design on the day was roughly 150mm wide.

2. Another limitation is how advanced the sensor is that teams were able to use. Due to the weight and budget restrictions, there are only a limited set of sensors that are appropriate to use for the purposes of the RAC project. This includes the pixicam, IR sensors, some LIDAR sensors, and others.

3.2. Team Performance Reflections

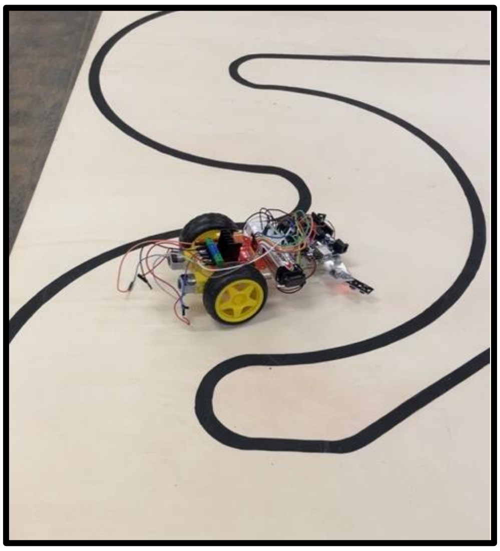

Figure__14: Final Design Testing

Overall, the team performed satisfactorily during DESN1000. No deadlines were missed, no assessments were failed, and in the final race, the goal of completing three laps of a racetrack autonomously was accomplished.

The final design was well within the budget, size, and weight restrictions. However, it was not very reliable, as it still required a bit of modification on the final competition day to traverse the track successfully. Although it was able to make the three laps around the track, it was not very fast, placing at the fifth fastest time of two minutes and ten seconds. As for the other aspects of the competition, the design did fairly well, placing at fifth and sixth for aesthetics and innovation respectively. Overall, this performance put the team at fourth place out of all teams that participated in the competition.

Throughout the course, the team planned the present and future tasks effectively. Every week there was a team meeting to discuss the current week's work, as well as plans for moving forward to ensure everyone was on task.

Delegation of tasks came in the team's weekly meetings. Each time an assessment was approaching, the work would be equally split, and then sent to the team leader Ayusha a few days early to compile it into a single document. Similarly, if there was technical stream work that needed to be completed for the robot, it would be equally split between the two people in the stream. Luckily, there were no issues with this, as there was a diverse skill set amongst the team, and everyone was happy to contribute in whatever way they could.

Through the careful delegation of work and forward planning, the team was able to collaborate very well. There was no bad blood between any of the team members, and very few instances where one person needed to work more to help someone who fell back on their work due to unforeseen circumstances. Because of everyone's team-oriented attitude, and common goal of doing well in the course, cooperation between members was always excellent.

CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusion

In reflection on the DESN1000 competition, the journey of designing and crafting an autonomous vehicle has given an insightful exploration of innovation, resilience, and teamwork.

The mechanical stream has introduced a distinctive 3-wheel steering system inspired by the iconic Reliant Robin. This not only adds a touch of automotive history to our design but also outlines efficiency and adaptability in autonomous navigation.
Aesthetic takes the spotlight with an eye-catching crafted cover, seamlessly concealing the chaos of wiring beneath and contributing to the overall visual appeal. This dual-purpose design reflects our commitment to both form and function, ensuring an organised internal structure.

In the coding domain, the focus has been on programming the Arduino to make instantaneous decisions based on data from the Infrared (IR) sensor. The code details, incorporating essential libraries, global variables, and decision-making logic, were thoughtfully designed to ensure optimal performance. Motor control stands out as a key element, dynamically adjusting both velocity and orientation in response to inputs from the IR sensor. The project's success in autonomously navigating the track is an indication of the effectiveness of the chosen IR sensor over the Pixi cam. Placing the sensors strategically close to the ground and tilted at an angle enables clear readings, forecasting upcoming turns for precise steering adjustments. The modification of code, including delays for steering adjustments and PWM cycle balancing, ensures efficiency on the track.

4.2. Recommendations

While the team's vehicle successfully completed autonomous laps, there are opportunities to enhance speed, aesthetics, and innovation. Practical suggestions involve optimising the design for increased speed, fine-tuning the steering system, considering alternative sensor configurations, and incorporating redundancy measures.

On looking back at the journey, the team has learned valuable lessons to help future projects and guide DESN1000 students. Soft deadlines are crucial for getting tasks done on time, and being proactive in managing time makes a big difference in how smoothly things run. Planning the project and assigning tasks early is a smart move to avoid last-minute stress and keep everything organised. From the start, open communication and collaboration are essential. Breaking the ice early helps build a positive team dynamic, making teamwork more seamless. Taking the initiative is also key for example instead of waiting for things to happen, being proactive creates an efficient and collaborative work environment.
Looking ahead, the insights gathered through experience translate into valuable recommendations for future projects and DESN1000 students. The alternating design approach, balancing aesthetics with functionality, emerges as a key takeaway. The lessons learned, challenges overcome, and successes achieved pave the way for continued improvements in autonomous vehicle design