

University of Wales Trinity Saint David

Wales Institute of Science and Art



Prifysgol Cymru
Y Drindod Dewi Sant
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Trinity Saint David

Group Design Project

ACHA5014

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1. Introduction

The IMechE design challenge, created to uncover young talent and push students to innovate, spending time in laboratories creating and testing their piece of work. Which performs tasks set by the IMechE competition. The project was supervised by Kelvin Lake, he provided guidance and feedback throughout the project.

The Brief of the ImechE challenge we were tasked with undertaking is that we have to design and build an autonomous vehicle which can, under its own power and control, move from a starting position, make contact with a wall, then reverse direction and stop as accurately as possible on a target. Due to the specific level of the challenge we are taking part in, we also need a programmable element as the control of the vehicle. This must be done within a budget of £80.

This project was meant to be undertaken by 5 group members however due to unforeseen circumstances Ben Slade was unable to participate and so it was required for 4 group members to carry out this project as a result.

2. Project Organisation

Dewi- Research into previous winner & CAD designs.

Dewi had the responsibility of researching previous winners in the IMechE Design Challenge. He found all this information on the IMechE website looking at winners from 2021. Observing the difference between what choices teams made and correlating that how highly they scored in the competition. Dewi considered the decrease in the budget compared to the reference source which had a ten pound increase in their budget. Evaluating each component, from the sensors, to what material they used. Dewi proceeded with mocking up ideas for in cad, and finalised them for production and testing. Appropriate evaluation and communication between Dewi and Jacob is paramount, discussing where the limitations in budget begin, and room for expansion in material costs is available regarding 3D printing.

Morgan- Energy Source Research and electrical hardware assembly

Morgan had the responsibility in ensuring the autonomous vehicle had a suitable energy source that met the requirements of all electronic components to allow for movement. Initially, extensive research was carried out so that numerous energy sources could be collected and the most appropriate method of powering the vehicle could be derived. The list of energy sources were collected and submitted into a table to discuss their advantages, disadvantages and environmental rating on how sustainable each source was. This is so a specification of an environmentally friendly source that provided the correct requirements for the additional components could be collated. The most viable energy source could then be chosen that is best suited to the group's specifications while maintaining a low cost for the £80 budget. The next task was to choose the most suitable motor that fit the energy requirements of the energy source (due to Ben not having completed this) with an appropriate RPM to fit the correct speed requirement for the vehicle. Lastly, Morgan then assisted Max with the wiring of the energy source to the hardware of the components and assisted in assembling the hardware to ensure the vehicle is ready for testing.

Jacob- Material research and resources

Jacob Jones was responsible for the material selection process, sourcing of materials/components and overseeing the budget. Jacob's role involves carrying out extensive research of materials and components to identify the best fit and price range for the project. In material selection, Jacob must consider all project specifications, requirements, and budget in relation to the specification given by the IMechE. Evaluations must be made of each possible material regarding their effectiveness to the project, environmental impact, and price. Once the appropriate evaluations have been made, Jacob will need to present his findings to the group for further confirmation. To monitor the current budget, a Bill of Materials (BOM) must be made. The BOM will give the group an idea of how much of the budget has been used and how much remains. Jacob must work with each member of the group to ensure the project does not exceed the budget.

Max- Motors, Sensors, Programmable element and coding

Max's initial role was researching numerous sensors and programmable elements as both are required by the brief for the IMECHE challenge. He then broke down the data and created a table displaying the data in an easy to read format for the rest of the group to reference in regards to queries about the sensors. Max then did a similar table for programmable elements and motors. In regards to testing Max, took responsibility for all the hardware and software

work, including learning about the Arduino code and setup, learning how to use the sensors and generate useful data from them as well as learn about motors and motor controllers. Once the individual components were working separately, Max worked at connecting them together in order to create the autonomous control system required by the brief in order to drive the vehicle. Due to unforeseen circumstances Max had to take over motor research from Ben.

3. Summary of the work completed/ Contributions to the project (Individual sections)

After careful consideration and observation, after assessing the previous competition winners, the group came to the conclusion that 55mm was the approximate wheel size of the top two winners. Smaller wheel sizes were considered, however after testing the theoretical energy consumption of 35mm wheel sizes. We decided as a group that 55mm would be fit for purpose. Dewi spent considerable time, analysing the winners from 2021 taking note on what sensors they used, approximate wheel size, what materials previous competition winners used and the general layout of how components are structured on their device.

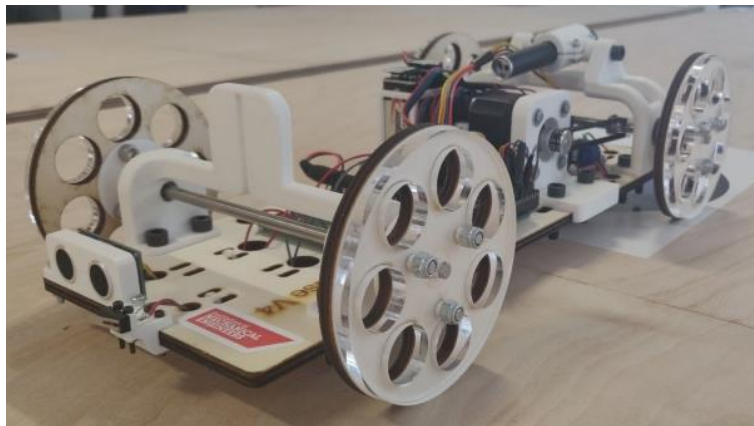


Figure 1- winners from Great London Region



Figure 2- Team A from university college London (IMechE 2021) (1)

After observing the previous competition entries as shown above in figure 1 & 2 . Dewi came to the conclusion that Ultrasonic sensors were the most commonly used, this is because they are affordable, and accurate forms of distance measuring. Using this information as well as the data from Max the group decided to integrate it into our design.

Dewi had never had hands-on experience with this component. Measuring each individual component was time consuming. Looking online Dewi found additional assistance, with accurate cad models from other users on GrabCAD. Dewi was able to continue designing his sensor mount and account for components that were protruding from the board as shown in figure 3. The final sensor mount can be seen in figure 4. Take note of the additional cut

outs in the model which were accounted for thanks to the research and visible points of note in the model. See further comments on the iterations on the ultrasonic model in section 5 of the report.

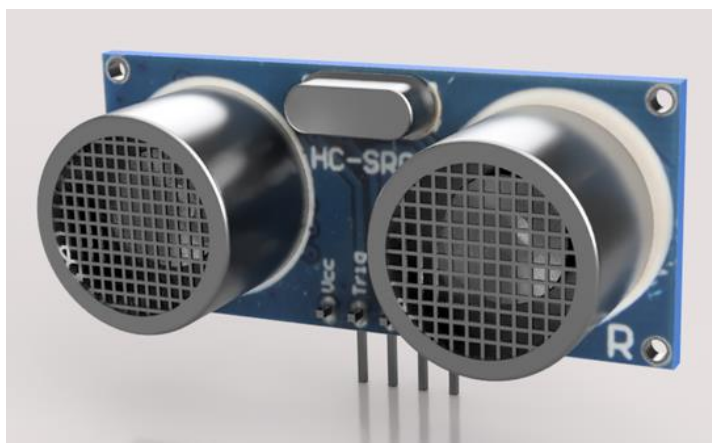


Figure 3- Ultrasonic sensor HC-SR04 (GrabCAD 2017)(2)

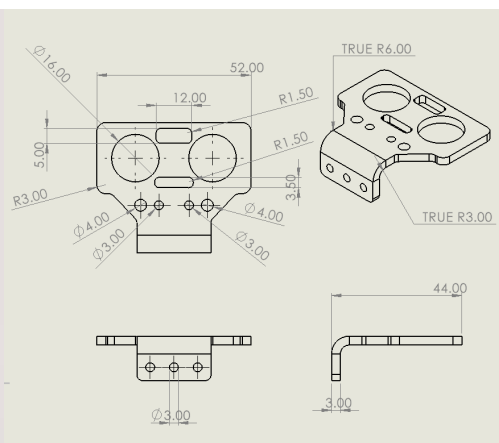


Figure 4- Ultrasonic sensor mount- (Dewi)

Dewi took the information gathered and went with the decision of a chassis that is 300mm x 150mm x 5mm using plywood. Calculating the cost between 3D printing and purchasing plywood, plywood was deemed the optimal decision alongside its benefits competing against a 3D printed chassis like its stiffness, likelihood of bowing under load and price. These same factors were applied to the wheels, plywood wheels of the same thickness of the chassis meant minimal waste.

In our testing stage, Max found that there was a minimum distance that the sensor could detect before it became inaccurate. Which required the holes on the chassis to be brought further back by 30mm.

After assessing previous competition winners the group came to the unanimous decision that rear wheel drive was the best course of action. Four wheel drive was considered in our research however, discussing the budget with Jacob, and the complexity of coding with Max, we came to the decision that two motors at the rear, one on each side, was our best price to performance option with relative ease for coding.

This decision meant that our model needed a connected pair of front wheels. This was achieved by having an 3mm diameter axle across the chassis and contained by the front wheel mount as shown below. Due to the shape and

potential waste of material to create the mount, 3D printing was the choice of manufacturing. Additive manufacturing in this scenario was the most cost effective choice.

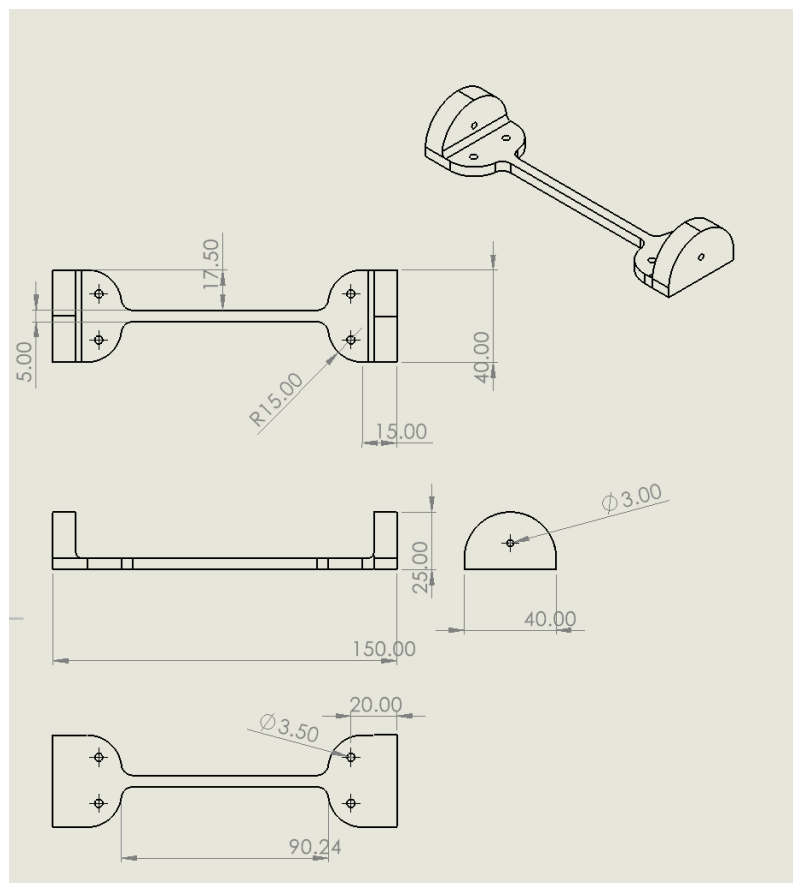


Figure 5- Front wheel mount - (Dewi)

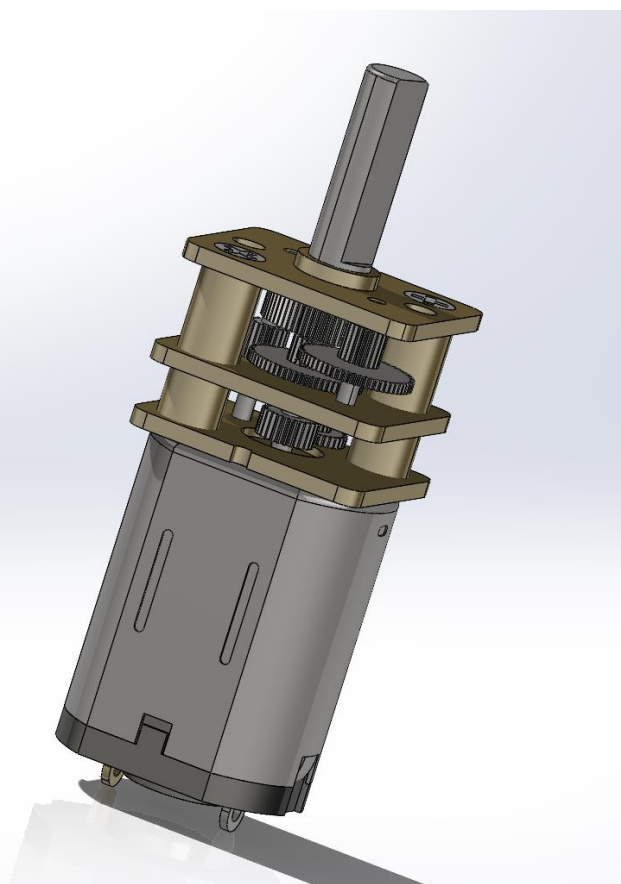


Figure 6- N20 motor (GrabCAD 2023)(3) (4)

Dewi successfully made motor mounts(Figure 7) for the N20 motors(Figure 6), having never had previous experience with this motor, researching and discovering CAD models on a community forum reduced modelling

time. 3D printing the motor mount was the best course of action, the filament of choice allows for residual pressure to be applied to the motor.

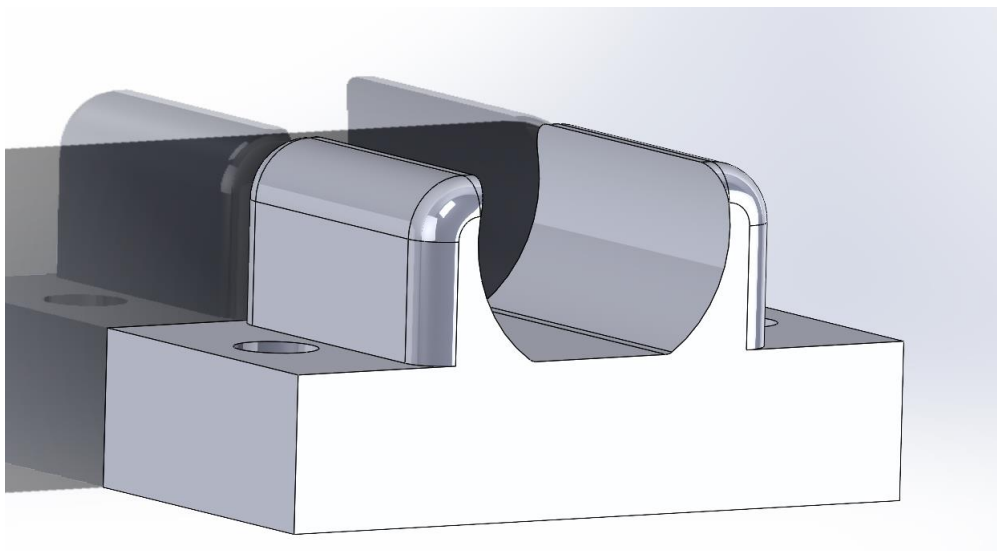


Figure 7- Motor mount - (Dewi)

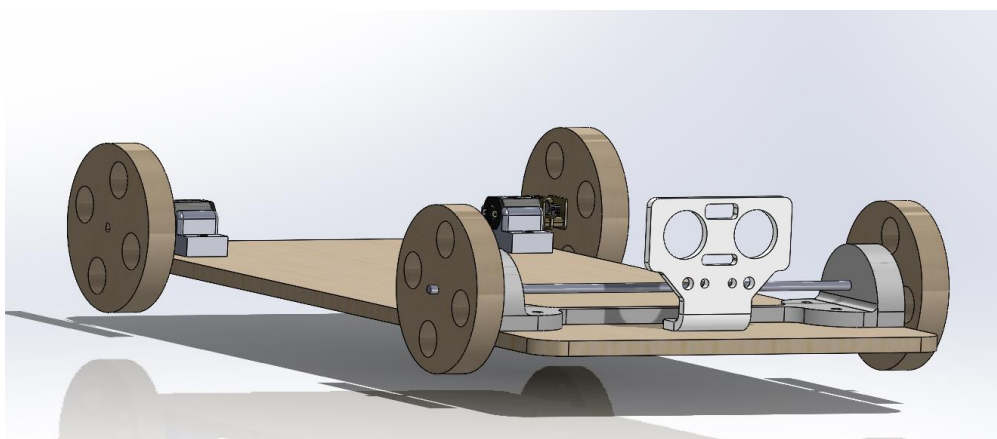


Figure 9- Final assembly (Dewi)

Max-

Programmable element

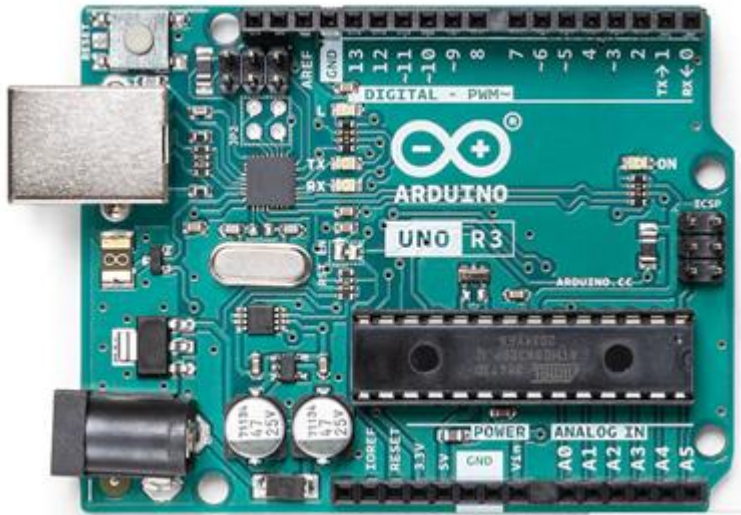
As stated in the allocation of work section, Max chose to research sensors, programmable elements and the peripherals.

What initially appeared to be the simplest choice was the programmable element, a compulsory element for our level of the Imeché challenge, after some searching Max found that there were 3 main options that were recommended for this type of task, the Arduino uno, the BBC Microbit and the Raspberry Pi. All of these are extremely small computing units with inputs and outputs of various types. Each one has its own Pros and Cons, below is a table outlining a few.

Arduino Uno	Mircobit	Raspberry Pi
Cheapest	Lots of function built in	Powerful computing elements
Large amount of programming libraries available for access	Very beginner friendly language options (was created as an educational tool)	Can run multiple scripts at once
High voltage output, useful for lots of sensors types	2 nd most powerful	Can interface with more peripheral components

The culmination of this research in conjunction with the research undertaken by Dewi is that the Arduino is not only most suited for our task but is also the most commonly used programmable element used by the winning teams. Due to the fact that Max had no experience in this area before this project the simple software (Arduino IDE) and the huge amount of programming libraries for access mean it would be very accessible to people with no prior experience. Also due to our budget constraints the low cost is a large factor, we could have paid more for a more powerful option in the Raspberry Pi but

we don't need that much power or versatility and so it would be a waste of our very limited funds.



The Arduino UNO rev 3 (12)

Sensors

Max began his research into sensors by finding a list of common sensors online and then looking into each sensor and adding information about each one to a table where he then started cutting down the list to only the applicable sensors for our project. Our initial list of sensors consisted of: a

proximity sensor, a rotary sensor, an accelerometer, an IR sensor, a light sensor, an ultrasonic sensor, a touch sensor and a colour sensor.

Here is the table developed to compare the sensors.

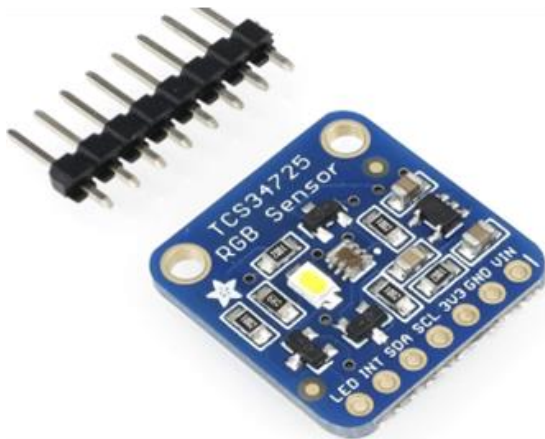
Type of sensor	Functionality	Pros	Cons	Price range	Voltage
Proximity sensors	Non-contact sensor	Accurate continuous data	Best used for metals and not wood or plastic	£10+	4.5-25V
Rotary sensor	Records rotation	With some maths, accurate distance tracking if attached to wheels	Does not sense distance but can be used to calculate distance travelled	£6 for 1 £8 for 5	4.5-5.5v
Accelerometer	Measures directional acceleration	Can detect Jerking	Not great for direct measuring distance or proximity	£7 for 3	18-25v
IR sensor	Detects objects in front of sensor	Accurate, cheap, non-contact	Less accurate than other non-contact sensors	£3.50 for 3	3-5v
Light sensor	Detects brightness of light		Not great for measuring distance	£5	3.3-5v
Ultrasonic sensor	Ultrasonic distance measurement	Accurate distance measurement	Non-contact so could be less accurate than a physical switch	£4.5(+/- £2)	5v
Touch sensor	Senses human contact	N/A	Used for human contact	£3 for 3	5.5
Colour sensor	RGB sensor for recognizing specific colours	Great for target acquisition	Expensive	£8(+/-£2)	3-5v

Using this table Max started cutting down through the list starting with the sensors which are not applicable for our needs. The touch sensor is for recognising human contact and useless for our project. The light sensor is also unapplicable in our use case as it just detects intensity of light. The proximity sensor is designed for use with metal and does not work properly or accurately with wood or polymer. We started looking at which sensors are only semi-applicable and would require lots of work to make work for our task. This includes the accelerometer which can't detect distance, only

acceleration, also the rotary sensor as whilst this could be used to see how far the vehicle has moved, it doesn't tell us how close the vehicle is to the wall.

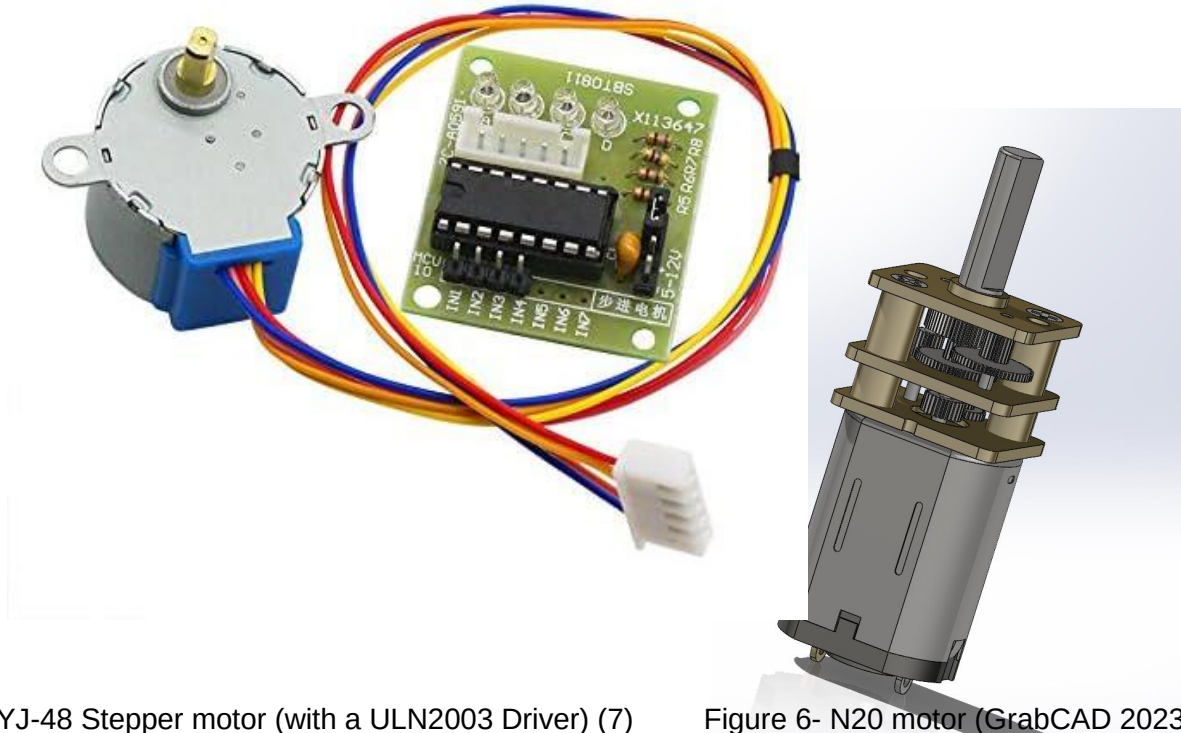
This left us with the IR sensor, the ultrasonic sensor and the colour sensor. Coincidentally these sensors are the sensors most commonly used by the winning teams as Dewi found from his previous winners research. Both the IR sensor and the Ultrasonic sensor are non-contact distance measuring devices and so after more research into each sensor the common consensus is that the ultrasound sensor is more accurate than the IR sensor.

Max's research concluded with the decision to go forward with the Arduino UNO rev 3 as the programmable element of the project due to its simplicity and beginner friendly code libraries. For sensors Max's data combined with Dewi's information about the past winners indicated that the best option for development would be a HC-SR04 Ultrasonic sensor (5) and a TCS34725 RGB Light colour sensor (6).



Max decided to take both the N20 DC 6v 300rpm motor as well as the 28BYJ-48 Stepper motor for further testing and development as they had both been used by a lot of the competition winners, are compatible with the

Arduino and were available for testing at the university.



28BYJ-48 Stepper motor (with a ULN2003 Driver) (7)

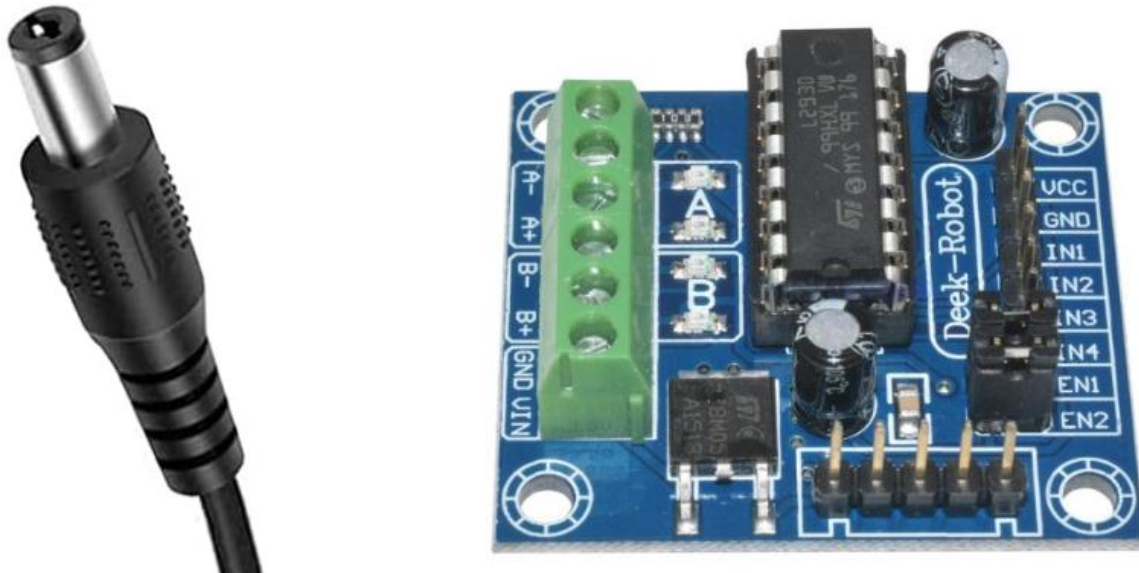
Figure 6- N20 motor (GrabCAD 2023)(3) (4)

Once Max had decided what components the group would be making use off he began testing with the Arduino, by first following a guide (8) on setting up the 'blink test' a common code which is used to check if the Arduino is working and configured correctly. It simply required an LED to be connected to Gnd and a digital pin and makes that pin HIGH and LOW on a loop. Once this was achieved Max moved onto working with the Ultrasonic sensor (5). This uses a trigger and echo chambre in conjunction with the Arduino Pulse function to send out a pulse of Ultrasonic sound waves and then detected when they are received by the echo chambre. By using the time taken from the pulse being sent to the pulse being received and the known speed of sound, Max was able to generate a code with output a distance in CM to the serial monitor, from the Arduino. During this testing Max realise that below 3cm the value for distance would become unreliable and thus made Dewi aware that the sensor would have to be moved at least 3cm back away from the front of the chassis for maximum accuracy. Once he had a variable of distance in cm that could be used in later logic coding, Max moved onto the motors. For both motors, for accurate control, a motor controller is required. Max did some research into controlling the DC N20 motor (4) without a motor controller and instead using a hardware based analog solution with MOSFETs however although the speed of the motor could be adjusted using a PWM pin, it would not be as accurate control as using a motor controller in conjunction with a PWM pin. After testing with the stepper motor and building his skills, Max decided to drop the stepper from use in the final design as due to the budget constraints any areas where price could be lowered had to be explored. The only loss of function from switching to a DC motor over the stepper is less accurate acceleration control and having to measure distance instead of control it.

Max used a a 4 channel motor controller powered by a L293D chip with the N20 motor in order to achieve directional control as well as speed control. This was required for 2 reasons, first, the tolerances on the motors are not strict and thus 2 of the same motors turn at slightly different speeds which would cause the vehicle to turn, secondly, the vehicle needs to slow down before contact with the wall in order to avoid a rebound setting it off course.

At this point Morgan assisted Max in figuring out a solution on how to power all the components and decided the best way would be to connect an Arduino Power In adapter (The 9V 1.5A universal ac power supply)(9) to the battery connector as well as connect wires from the Vin and Gnd on the motor controller to

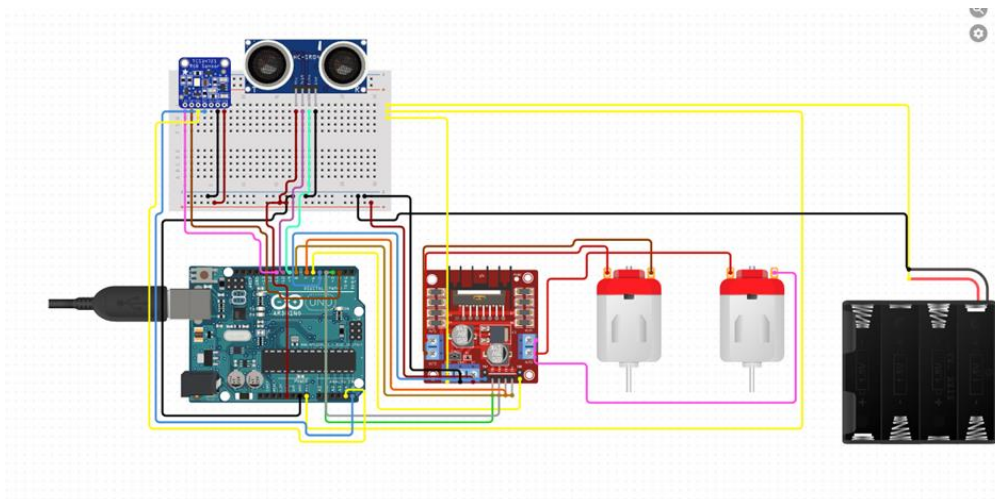
the battery connector. Keeping the current going into the motor separate from the Arduino is required to avoid blowing the Arduino from overdraw. Both sensors will be powered via the Arduino.



The 9V 1.5A universal ac power supply(9)
chip(10)

4 channel motor controller powered by a L293D

Max and Morgan then figured out how to connect everything together and begin the initial logic code that will eventually drive the vehicle.



Electronics diagram (11)

Here is a rough diagram of how our setup will look; however, instead of using the Vin pin on the Arduino, the final setup will have the power going into the Arduino using the universal power supply adapter. From

this point, going forwards, Max and Morgan will keep testing with the colour sensor, finish the programming, figure out a solution to attaching all the electronics to the chassis and tune the system for accuracy.

Jacob- Material selection

A material selector's role is pivotal in group projects to facilitate and identify appropriate materials that are essential for the project's success. Tasked with assessing the project's specifications, the material selector must collaborate with other team members to get an understanding of specific needs and requirements. Factors that must be considered as a material selector are the budget, project timeline and in this case, vehicle requirements. To be a successful material selector, extensive research must be carried out to identify suitable materials that align with the group's goals. This includes cost effectiveness, environmental impact of material and durability. Effective communication is essential for the material selector to succeed in the role. Other team members must evaluate proposed materials, and all agree upon the final decision. In summary, the material selector bridges conceptual ideas with the materials required to be successful.

Vehicle Body:

In the project, Jacob oversaw this role. This role was important to the group's success as a wrong choice of material would cause setbacks in the vehicle's development and performance. Choosing the correct material required considering factors such as the budget, environmental impact of the material and accessibility. The initial research carried out looked at possible material research for the vehicle body. To find the correct fit for our material choice, the pros and cons of each material were thoroughly analysed. After a large amount of thought, the initial materials were narrowed down to 3 options. To do this, a table was made in excel to identify how each material rated against the specifications.

material	Material Specifications									
	strength to weight ratio	Machinability	Cost	Environmental impact	stiffness	Aesthetic	waste			
Plywood	4	4	5	2	2	3	3	Key:		
MDF	2	4	5	2	4	3	3	1	Very bad	
3D printed filament	4	4	2	3	3	4	5	2	Bad	
Carbon Fiber	3	3	1	2	3	5	3	3	Moderate	
Sheet metal (Mild Steel)	4	4	3	3	3	1	3	4	Good	
Acrylic	4	3	2	2	4	4	3	5	Very good	

Figure 1. Material specification matrix.

As seen in the above figure, the table has been set up to show how each material scores on a scale from 1-5, with 1 being very bad and 5 being very good, which is displayed in the key. It is clear to see from the table that none of the materials score high in all categories. For example, Plywood scores high in strength to weight ratio, machinability and cost but lacks in the environmental impact and stiffness sections. Compromises must be made in order to decide upon the best fitting material for the project. Cost is the primary factor in the selection process, therefore a material like carbon fibre would not be justifiable due to its high price.

After careful consideration, the three final materials decided upon are as follows: medium density fibreboard, Plywood, and a 3D printed filament. The requirements for the material set at the start of the project were a good strength-weight ratio, cost effective and an ease of sourcing. The final material choices were presented to the group at the weekly meeting, and after a brief discussion with the team members, it was decided that either plywood or MDF would be the best choice for the vehicle body. One point raised in the group meeting was the environmental impact of the production of plywood and MDF. As there are energy and environmental students taking part in the project, the environmental impact of plywood was questioned. Following the meeting, additional research was carried out to determine whether the material choices were correct. From the research, it was found that plywood is a biodegradable material that is made of thin sheets of wood bonded together by adhesive. The environmental benefit of using plywood is the amount of material that can be prepared from one tree for its use compared to being used as solid wood (Joanna, 2022). It can also be argued that MDF is also a sustainable material. Because MDF is mainly constructed from wood fibres, shavings, and other offcuts, it can be classed as recyclable

(SILHAVY, 2020). The research concluded that plywood had a similar environmental impact to the medium density fibreboard and seeing that plywood was better suited to the project's requirements (As seen in Figure 1), the final decision was made.

The sourcing of Plywood was the next step in the process. Research was carried out to locate local businesses who stock plywood sheets at a relatively cheap price. In Swansea there are a vast number of builders merchants/DIY stores that trade in plywood sheets. Deciding which producer to source from was the next task. Factors that were considered when deciding on the manufacturer were the price per sheet, distance from the IQ building and delivery costs/time. After careful consideration, the supplier to be chosen was Wickes (Cwmdu industrial estate, Cwmbwrla, SA8 5LD). Although they offer £7 delivery for orders under £85, it was decided that collecting the material was in the group's best interests. The size of the sheet that would be purchased is 5.5mm thick x 607mm wide x 1829mm tall with a price of £15. Obviously, the vehicle design would be nowhere near this size, but it was decided that a larger sheet would give us more material to use on prototypes.

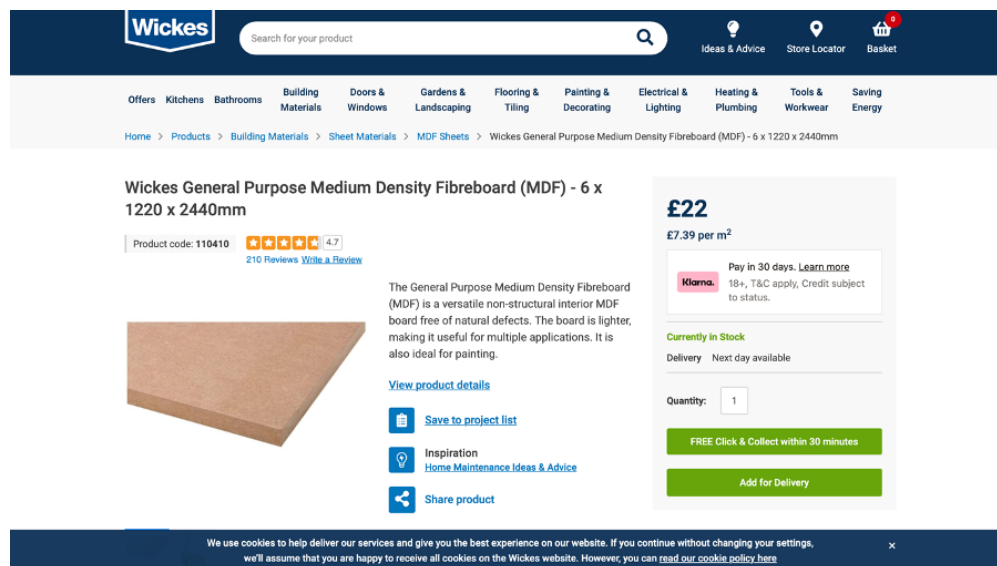


Figure 2, Wickes Building Supplies

Other than being lightweight and inexpensive, plywood also offers an ease of machinability. Laser cutting is the easiest process of forming a vehicle body from plywood. Luckily, an in-house laser cutting machine is available in the university. This benefits the project as the IMechE have stated that "if laser cutting is available as in-house facility, no additional cost shall be applied". (IMechE, IMechE Design Challenge 2024, 2023). According to the specifications given, the cost of material used will be a proportion of the overall cost of the sheet. The formula and an example of dimensions given in the specification are as follows:

Dimensions of example:

5mm thick hardwood plywood, W1220mm x H2440mm, area of required dimension 2400mm², cost of £45

Formula:

$$Price = \frac{\text{total price}}{\text{Dimensions of sheet}} \times \text{dimension required}$$

$$Price = \frac{45}{1220 \times 2440} \times 2400 = £0.04$$

Figure 3, Example prices given by IMechE

From the formula given, the vehicle body's price can be calculated below.
5.5mm thick hardwood plywood, W607mm x H1829mm, area of required dimension, cost of £15

$$Price = \frac{\text{total price}}{\text{Dimensions of sheet}} \times \text{dimension required}$$

$$Price = \frac{15}{607 \times 1829} \times 45000 = £0.61$$

Figure 4, The groups calculated vehicle body price

Wheels for vehicle:

The next task in material selection was deciding upon the material required for the wheels. To get an idea of what materials would be suitable, Dewi (Student No. 2112054) carried out research on previous winners and competitors of the design challenge. In his research, he found that plywood wheels had been used more often than not. He showed us his findings in the weekly meetings which led to the beliefs that the cost effectiveness and machinability of plywood was a deciding factor in the selection process. After a brief discussion with the team, all members agreed that plywood would be the material selection for the wheels. One benefit mentioned in the meeting was the weight of the plywood wheels. As discussed, when deciding upon the material for the vehicle body, plywood is light and machinable. To further reduce the weight of the wheels, material can be removed by a laser cutter.

But considerations must be taken regarding the structural integrity of the part. Too little material could cause the vehicle to fail.

The clear benefit of this material selection is the cost. Given that a sheet of plywood has been acquired for the vehicle body, it would be logical to employ the same sheet for the wheels. This approach not only streamlines the process but also conserves time and effort. As stated by the IMechE, in house laser cutting carries no extra cost compared to 3D printing for example. To calculate the cost of the plywood wheels, the same formula given for laser cutting can be used:

Dimensions of wheels

5.5mm thick hardwood plywood, 55mm diameter area required.

$$Price = \frac{\text{total price}}{\text{Dimensions of sheet}} \times \text{dimension required}$$

$$Price = \frac{15}{607 \times 1829} \times 2375.83 = \text{£}0.03 \text{ per wheel}$$

Figure 5, the groups calculated wheel price

The total price for the plywood wheels: £0.03 x 4 = £0.12

3D printed components.

The final task in the material selection process was selecting a material to hold various electrical components and wheel mounts. Looking at the materials already researched, plywood and MDF would require extreme precision and time to create parts required. The other option considered was 3D printing the components. 3D printing offers a multitude of advantages, from precise and intricate designs to functional tailored parts specific to the project's requirements. Models of each component were made in SolidWorks by the design leader Dewi.

The components were meticulously crafted to secure electrical elements seamlessly onto the vehicle's body, enhancing the overall aesthetics of the design. Dewi was able to mock up various designs with component weight also in mind. The IMechE state that "If additive manufacturing (3D printing) is available as "in house" facility, a standard – flat cost of 10p/g (£0.10/gram) shall be applied to any component produced this way" (IMechE, IMechE Design Challenge 2024, 2023). Therefore, the mass of the components is a major factor regarding the budget. One way of reducing the mass of the components is by reducing the percentage infill. Percentage infill in 3D

printing refers to the density of the internal structure. When an object is 3D printed, it is usually not completely solid throughout but often printed with a pattern inside to conserve material. The percentage infill represents the amount of space inside the object that is a percentage of the total volume. For example, if an object is printed with a 20% infill percentage, 20% of that object will be filled with material, while the remaining 80% will be a void. Therefore, a lower infill percentage, a lower overall mass. Although using a low percentage infill can have downsides, with reduced structural integrity being one. This results in fewer internal supports, causing increased fragility and deformation. For that reason, a suitable infill percentage must be chosen with both advantages and disadvantages in mind. To calculate the overall price of the 3D printed components, the flat cost of £0.10/g given by the IMechE must be used in conjunction with the mass of each printed part.

Bill of Materials (BoM)

A bill of materials is a comprehensive list of all components, parts and materials required to manufacture the automated vehicle. It includes details such as part numbers, quantity, costs, total mass, and manufacturing techniques. The BoM serves as a crucial document throughout the development of the product as it can be referenced to ensure the budget is not exceeded. At any development in the project where a part or electrical component needs to be purchased/manufactured it must be included in the bill of materials. During the first term of the university year, an interim viva needed to be presented to the group supervisor (Kelvin Lake) and other lecturers (Ryan James and Jordan Jenkins). Within this presentation, a preliminary bill of materials was required to give an overview of how the group was progressing in prototyping and testing with regards to the budget. The IMechE have stated that a budget of £80 is what's required to produce the automated vehicle. They also state that "The total cost shall not exceed the IMechE BoM in excess of 10%" (IMechE, IMechE Design Challenge 2024, 2023). Looking at the below figure, the total cost estimated in the preliminary BoM totalled £80.97 (within the 10% excess range). As no in-depth prototyping or testing had been carried out by the point of the BoM's creation, the electrical components were estimations of what was to be used, based on previous competitors designs. Another estimation in the BoM was the mass of the 3D printed components. The components masses were calculated in the Solidworks software using a different material than what was specified, therefore the mass was larger than expected. This was resolved following the Viva.

Device area	Part Number	Part Name	Quantity	Unit cost (£/g : £/mm - inc VAT	Total cost (£- VAT inc)	Material	Desity (kg/mm³)	Total mass (g)	Manufacturin g technique	Supplier
Mechanical structure	M01	Body of vehicle	1	£0.02	£0.02	Plywood	600	272	laser cutting	wickes
	M02	Wheels	4	£0.03	£0.12	Plywood	600	25.88	laser cutting	wickes
	M03	ultrasonic mount	1	£0.60	£0.60	PLA	1240	5.97	3D printing	Amazon
	M04	Wheel mounts	2	£4.70	£9.40	PLA	1240	46.89	3D printing	Amazon
Electrical Components	E01	Nickel metal hydride battery	2	£3.22	£6.44	N/A	N/A	50	COts	Amazon
	E02	Ultrasonic distance senor	2	£3.90	£7.80	N/A	N/A	8	COts	4Tronix
	E03	Arduino Controlle	1	£20	£20	N/A	N/A	25	COts	Store.arduino
	E04	TCS34725 RGB Light Color Sensor	4	£6.00	£23.99	N/A	N/A	7.2	COts	Amazon
	E05	RS PRO geared motor	2	£6.30	£12.60	N/A	N/A	138	COts	uk.rs-online
				Total:	£80.97			Total mass :	578.94	

Figure 6, preliminary Bill of Materials

Device area	Part Number	Part Name	Quantity	Unit cost (£/g : £/mm - inc VAT)	Total cost (£- VAT inc)	Material	Desity (kg/mm³)	Total mass (g)	Manufacturing technique	Supplier
Mechanical structure	M01	Body of vehicle	1	£0.61	£0.61	Plywood	600	145.8	laser cutting	wickes
	M02	Wheels	4	£0.03	£0.12	Plywood	600	52.28	laser cutting	wickes
	M03	ultrasonic mount	1	?	?	PLA	1240		3D printing	Amazon
	M04	Wheel mounts	2	?	?	PLA	1240		3D printing	Amazon
	M05	Wheel axle	1	?	?	PLA	1240		3D printing	Amazon
	M06	Battery casing	1	£0.80	£0.80	PLA	1240	30	COts	RS components
Electrical Components	E01	HiQuick 2800mAh 1.2V rechargable battery	4	£1.31	£5.24	N/A	N/A	115	COts	Amazon
	E02	Hcso4 Ultrasonic senor	1	£1.45	£1.45	N/A	N/A	8.5	COts	Kunkune
	E03	Arduino uno r3	1	£25.63	£25.63	N/A	N/A	25	COts	Store.arduino
	E04	Mini L293D Motor Drive	1	£3.91	£3.91	N/A	N/A	35	COts	Kunkune
	E05	TCS34725 RGB Light Color Sensor	2	£3.50	£6.99	N/A	N/A	6.46	COts	Amazon
	E06	200RPM Motor with gearbox replacement N20	2	£6.61	£13.22	N/A	N/A	40	COts	Amazon
				Total:	£57.97			Total mass :	458.04	

Figure 7, Final Bill of Materials

The Final Bill of materials was created following prototyping and testing. At the time of creation of the report, the bill of materials was not able to be completed due to missing information. The missing data was the mass of the 3D printed components for the mechanical structure. The reason for the missing data was that the components had not yet been printed due to miscommunications within the group. This is an issue that will be quickly resolved, prior to the final hand in date to the IMechE. Looking at the budget, the team have over £20 remaining to spend on the 3D printed components and other additional parts.

Morgan-

Energy Sources

To power the autonomous vehicle for the challenge, it was important to consider a wide range of energy sources. This role was carried out by Morgan and is crucial in the group project to facilitate and identify the most suitable energy sources that are vital for the project's movement for success. To ensure an understanding of the movement of the autonomous vehicle, it was vital to collaborate with the other team members to obtain an understanding of the specific needs and requirements of the operational components that need powering. Therefore, by carrying out extensive research to identify suitable energy sources that align appropriately with the group's goals, a suitable energy source can be selected to make sure the vehicle can function correctly.

The first task Morgan was to carry out is the research of a variety of energy sources for the vehicle, this included, solar power, carbon dioxide gas cylinder, hydrogen power and a range of battery choices such as alkaline, lithium ion and nickel metal hydride. It was important to select the most appropriate energy source, to ensure the vehicle could be transported effectively by the electrical components that operated it. The consequence of this task not being carried out, could result in the vehicle failing and setback its performance in the challenge if it had either too little power or an extensive amount. If the energy source is inadequate, the vehicle will either not complete the course or cause the electronic components, such as the motor, to work too quickly or cause them to be defective. Next, it was important to rule out the unviable sources and pick the best contenders, in order to make the best decision on which method of powering the vehicle is most suitable. The top two chosen consisted of a hydrogen fuel cell coupled with a hydrogen storage cylinder and a nickel metal hydride battery.

It was initially decided that a hydrogen fuel cell (see figure 1A1) along with a hydrogen storage cylinder (to supply the fuel cell) would be used as the energy for the vehicle. The reasoning for this is that the group decided to employ an environmentally friendly method to power the vehicle as 2 members of the group are studying Energy and Environmental Engineering. This ensures the autonomous vehicle is powered sustainably as the hydrogen fuel cell uses hydrogen gas fed to the anode and air fed to the cathode to produce an electrical current and water as a byproduct, converting the chemical energy from the hydrogen into electrical energy to power the motor of the car.

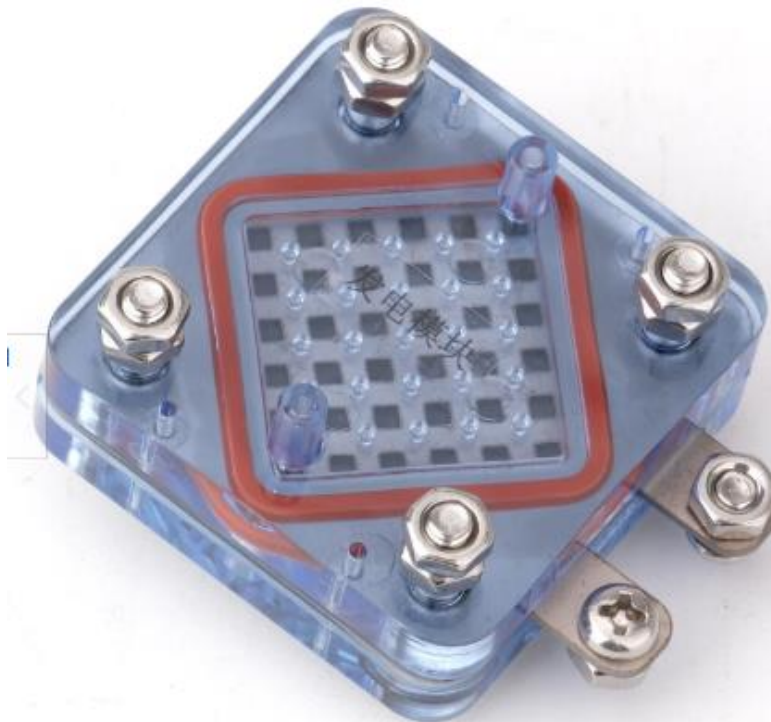


Figure 1A1- *Hydrogen Fuel Cell Power Generation Module*. Available at: [Fuel Cell Power Generation Module High-Quality Self-Breathing Fuel Cell Parts | eBay](#)

After conducting research, it was demonstrated that one hydrogen fuel cell produces a voltage of approximately 1V, a current of 1A at 0.6V, providing a temperature of 25°C. This highlights that many fuel cells will be required to power the project as a minimum of 6 volts will be required to ensure the vehicle operates effectively. Hence, a theoretical amount of 6 hydrogen fuel cells will be required to power the vehicle, however, in reality 7 will be required to compensate for voltage drops. The price of a fuel cell is £23.33, which shows that using a hydrogen fuel cell as an energy source would cause the team to go over budget as multiple fuel cells arranged in parallel will be required to produce the suitable output voltage to run the components. Due to the requirement of 7 fuel cells needing to be used, this would cost the team £163.31, this method was therefore unviable to use in the challenge.

In addition, a cylinder for storing hydrogen would be required to power the fuel cell. However, when researching the methods of storing the hydrogen, it was displayed that the most suitable method of storage was the Hydrostik Pro (see figure 2A1). However, it was then additionally proven that this would not be viable for the project as a cylinder has a cost of €59 (£50.49), additionally demonstrating a cost over the budget. This demonstrates further research is needed to find an alternative energy source.



Figure 2A1- Horizon Fuel Cell Europe (n.d), *Hydrostik Pro*, Available at: <https://www.horizoneducational.com/hydrostik-pro/p1222>

Moreover, the alternative energy source concluded by Morgan for the vehicle was to use two 9V nickel metal hydride rechargeable batteries. Due to lithium not being permitted in the competition, this was the most suitable option for the use of a rechargeable battery. Employing a rechargeable battery was to ensure the project is as environmentally friendly as possible as they are able to be reused many times for a number of purposes. Although it is not the most sustainable compared to other methods of producing energy, a compromise to function had to be made as the budget did not allow for a number of the alternatives, such as the hydrogen fuel cell. Furthermore, the cost for a multipack of four 9V nickel metal hydride batteries was £12.88, which allows us to price them on the bill of materials for £6.44 as two are to be used in the vehicle. This ensures an extremely low cost for the energy source, which allows for an increased budget spend on other aspects of the project.

The 9V batteries were initially decided for use for the autonomous vehicle. However, when communicating with Max it was decided to use a substitution of five AA nickel metal hydride batteries. This is due to testing being carried out with four AA batteries, as the 9V batteries had not been ordered for use before the testing date and these were the batteries available for use from the university. However, it was found that during the initial testing, the four batteries would not power the 6V motor effectively but did power the other components. Furthermore, it was concluded that five AA batteries are to be used for the project, as calculations display that they are suitable to power the arduino, sensors and other electronic components effectively and meet the requirements for the required voltage and current output.

Motor Selection

Furthermore, the next role Morgan was tasked with was the research and allocation of an applicable motor for the vehicle, as Ben was not able to carry this out, so this was delegated to him. To make sure the autonomous vehicle

can operate effectively to transport all other components and at an appropriate speed, it was important to consider the most suitable to meet the requirements. This includes selecting a motor with an appropriate voltage requirement for the energy source, ensuring it has a suitable torque to transport the weight of the vehicle and has a fitting RPM to operate at the correct speed. To do this task, research needed to be carried out to choose the optimum motor. Initially, research on numerous stepper motors was undertaken as this particular type of motor was the first used by Max to test the code for the Arduino. However, it was subsequently found that stepper motors are not suitable as they work by breaking full rotations of the shaft into smaller part rotations, to allow the motor to move through a set angle of rotations (RS Components Ltd., n.d.). Consequently, the decision for a DC motor was proposed as this type of motor completes full rotations at a selected speed by the motor controller in order to move the vehicle as required. The next task for choosing a DC motor was to test the available options that were already present in the university and select the most viable. These consisted of an N20 12V 300RPM, N20 6V 300RPM and an N20 6V 150RPM. After receiving feedback from the team, it was concluded that the most suitable motor was the N20 6V 300RPM. This is due to the 12V motor and the 150 RPM motor rotating at too low of a speed.

Connecting Energy Source to Additional Components

The last role that needed to be carried out by Morgan was to collaborate with Max to find a suitable method for connecting the batteries to the electrical components. This is necessary to ensure a suitable connection is made between the batteries and components so that the risk of disconnection during the operation of the vehicle is mitigated. Furthermore, a proper connection of the wiring minimises the resistance of connections and reduces the voltage drops across components, making sure it is as efficient as possible. The first task for this role was to find the most appropriate way of connecting the battery to the Arduino. This was found by using a battery holder which has a positive and negative terminal to connect a battery connector which allows the wires from the connector to connect to the circuit.

The next task was to discover the most appropriate approach to connect two individual wires together in order to form a parallel circuit, with one loop feeding from the battery to the Arduino and ultrasonic sensor and the second loop from the battery to the motor controller and motor. This was carried out by using a battery connector with crocodile clips, with the positive wire to the positive of the Arduino jack input and an additional positive crocodile clip and by connecting the negative wire of the battery connector to the negative wire of the Arduino jack input and another negative crocodile clip. Once the circuit was wired up, it was then required to use the PWM pins on the Arduino to the ENa and ENb pins on the motor controller. This ensures motor speed can be altered using code. Morgan's final task for the circuit was to assist Max by carrying out the practical work, for example, stripping and connecting

wires from the Arduino to the motor controller, to increase the time efficiency on ensuring the electrical components are connected together for the programming ready so further testing can be carried out.

4. Achievements and progress relative to initial project plan and timing chart

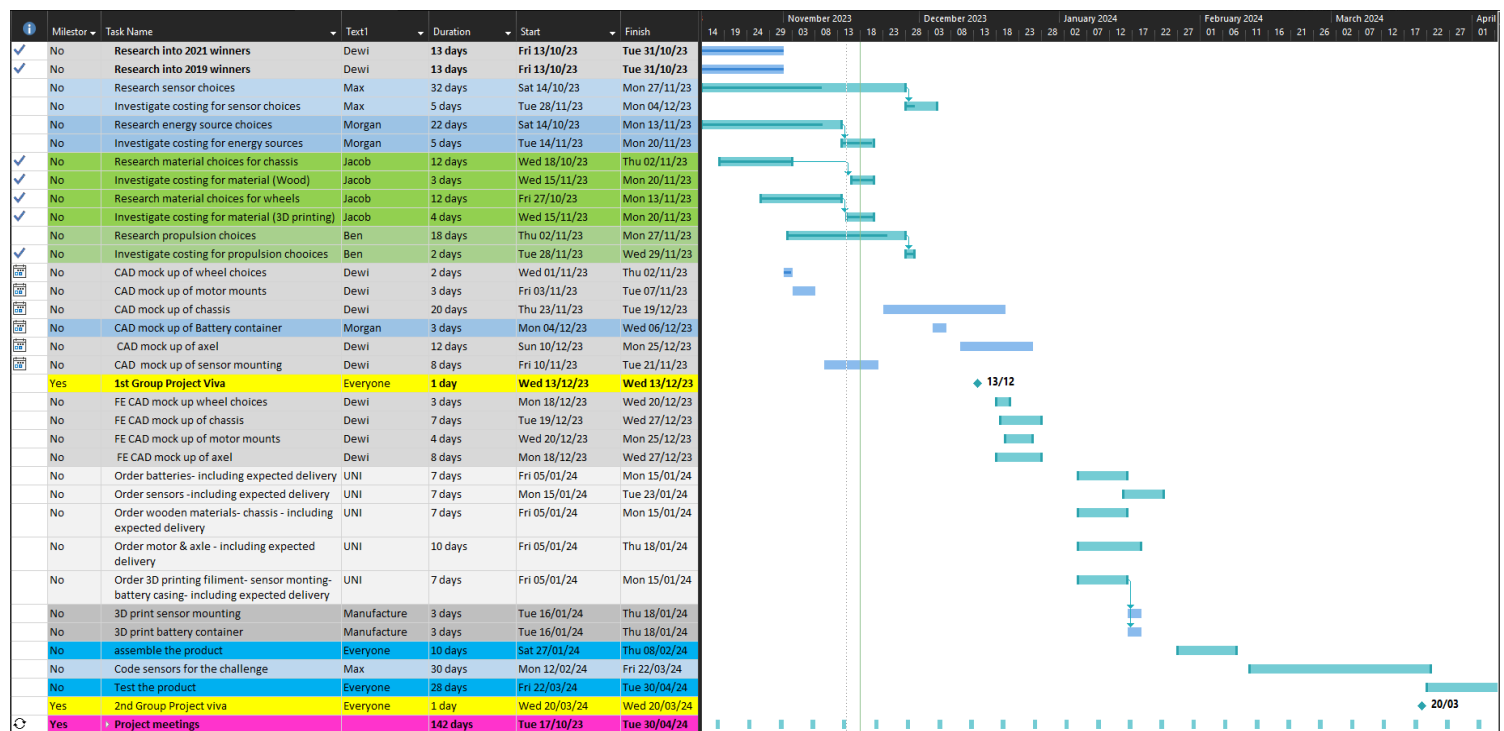


Figure 8 - Gantt chart planning (Dewi)

Reviewing our progress and schedule we were relatively on schedule with our progress. There were delays in research regarding motors due to inactivity with group members. Following this it was delegated to other party members. Testing was also problematic due to roadblocks with this competition being our first time. There was a steep learning curve, increasing our research time. If we were to revisit the gantt chart and amend the timings. We would reshuffle our organisation and delegation of work.

Reviewing the gantt chart Dewi would reallocate his resources in FE CAD mock up to further research in assisting Max in colour sensor research, because FE CAD mock up in hindsight was impractical. Printing the CAD designs sooner and initiating testing as soon as possible after the interim viva would have allocated more time to amending our design.

In regards to the electronics, getting more hands on part and heads together would have been very beneficial. This speed of development increased when Morgan began assisting Max. In regards to meeting the set goals, the ultrasound sensor, motor, and motor controller have got to the position we were aiming for at this time. The colour sensor is not currently in the same position of development as the ultrasound sensor due to lack of time hands on. Max and Morgan are planning to implement the colour sensor into the control system before the VIVA on the 20th of

March. Aside from the colour sensor all other aspects of the electronics have met our goals and are in a good place for final tuning before the competition.

5. Review of success and failures of the project

Dewi found making motor mounts (Figure 6) difficult, having never hands -on experience with the component previously, researching on the GrabCAD significantly reduced potential for failure. If Dewi was to revisit this competition, he would 3D print the component towards the beginning of the year, and initiate testing on fitment sooner. Dewi would also increase the distance of the holes from the holder by 2mm, allowing for standardised nuts and bolts. Dewi would also decrease the height of the lower protruding sections, ensuring one singular standardised bolt height across the whole assembly. Decreasing the amount of different bolt heights in the assembly, lowering the overall cost of joinery components.

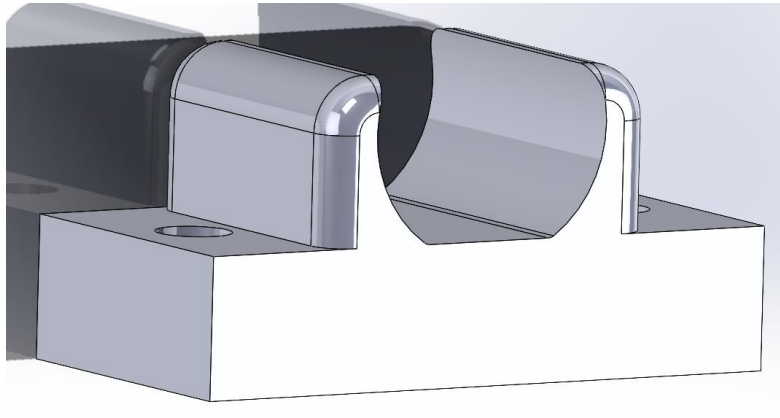


Figure 6- N20 Motor mount- (Dewi)

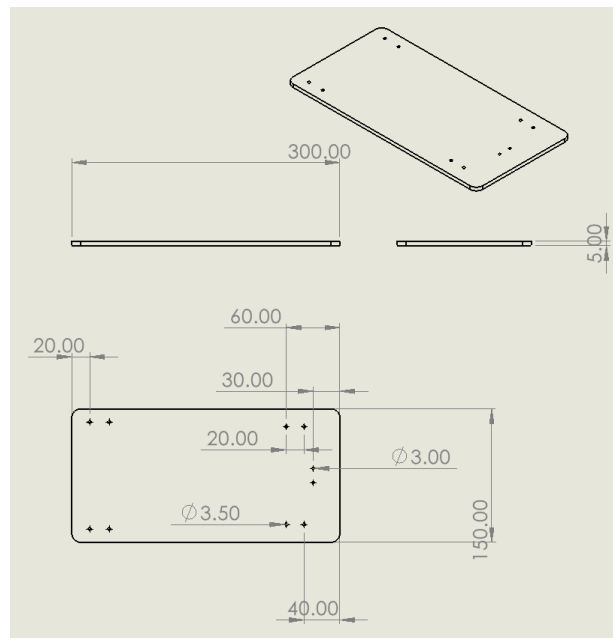


Figure 10- Chassis (Dewi)

Reviewing the decisions made, Dewi would have modelled the motor mounts, battery casing, adrunion location and wheel mounts towards the beginning of the assignment. Evaluating the footprint and layout of all components, reducing the area of the chassis (figure 10) where possible. As it stands, the chassis has considerable unutilised

space, Reduce the width and length of the chassis would have decreased material cost marginally. 300 x 150 x 5mm was a decisive action, and allowed for flexibility in the sizing of components at the start of the project.

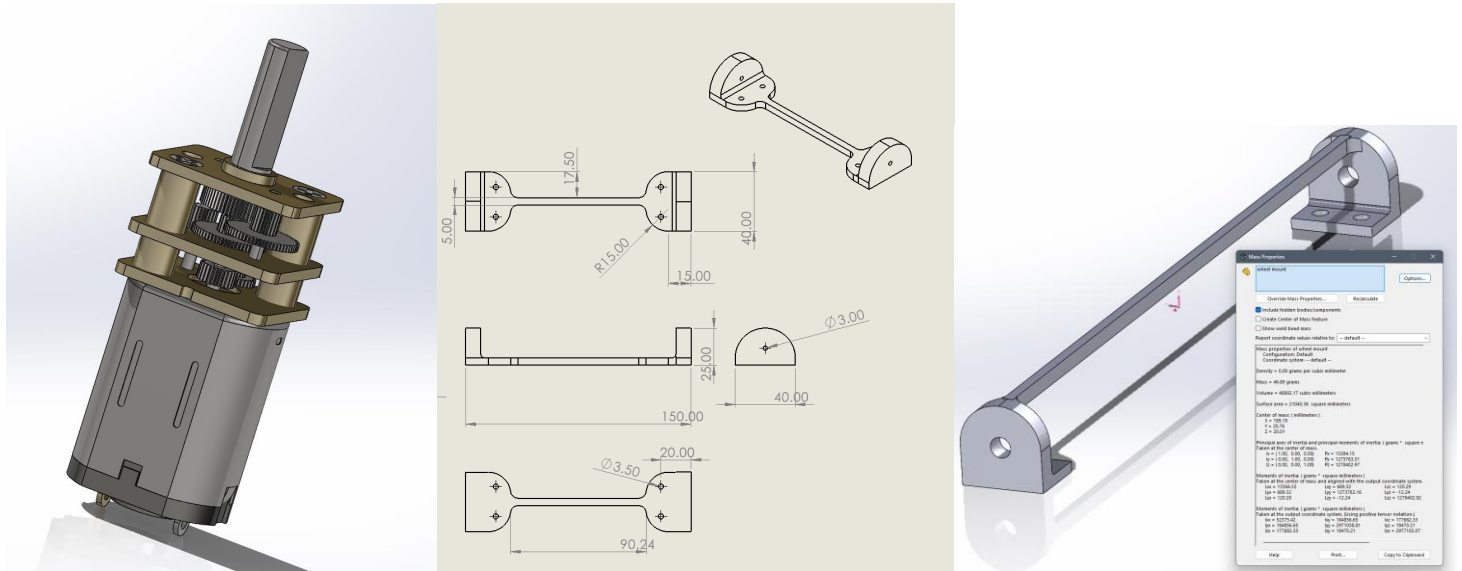


Figure 6- N20 motor - (GrabCAD)(3)(4) Figure 5- wheel mount (Dewi) Figure 11- version one wheel mount (Dewi)

The motor above was heavily suggested by Ryan, a lecturer at UWTSD; the group had no previous experience of electrical motors. The group had an understanding of combustion engine cars and how that power is sent to the wheels of a car. However, when hands on with the motor and receiving feedback from Ryan, we were told that the tolerance of the shaft from the manufacturer is not accurate and not well produced. The CAD model above measured the shaft at 3mm. During testing it was discovered that Ryan was correct and there was considerable movement between the shaft and prototyped wheels. Currently there is no solution, due to time constraints and additional assignments at present. In review given more time, the group would have researched higher quality manufactured electrical motors, with less fluctuating tolerance in the shaft.

Assessing version one of the wheel mount (figure 11) it was fit for purpose, however when considering manufacturing methods, the raised horizontal beam proved complicated. Concerns of 3D printing failure and discussions with Kelvin led to the decision that the horizontal beam would be relocated to the bottom of the mount. This was a positive outcome, assessing the stages of additive manufacturing, the horizontal beam would be printed at the same plane as the mounting hardware. No lattice supports decreased the amount of material used. Whereas

version one would have required lattice supports, subsequently increasing material used and potential waste of valued time.

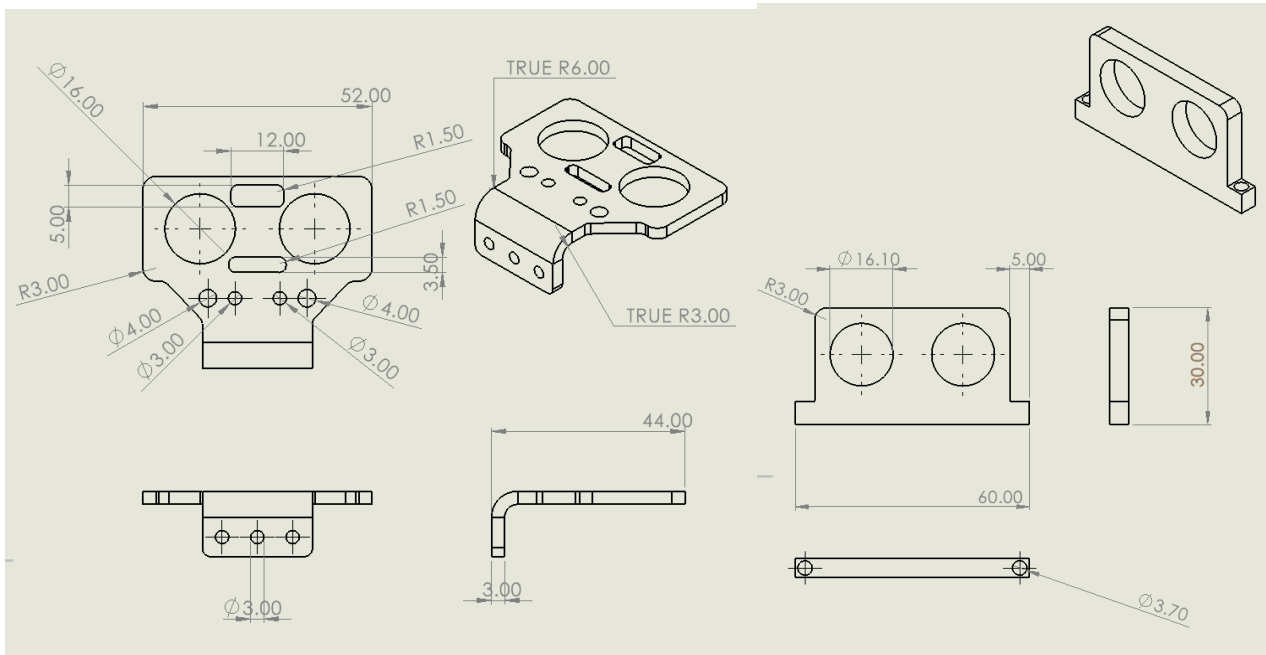


Figure 4- Ultrasonic mount (Dewi)

Figure 11- version 1 ultrasonic mount (Dewi)

Scrutinising version 1 of the ultrasonic mount Dewi did not take into account the protrude components on the ultrasonic sensor (figure 3), which led to additional cuts being made in the final version. It should also be of note that Dewi allowed for too high of a tolerance in the cut outs for the lenses 0.10mm was too large and did not allow for a press fit. 3D printing is ± 0.1 mm accurate, accounting for this in the version one would have heavily weighted the print and fitment to be -0.1 tolerant, the final version excluded this potential.

In regards to electronics all of the testing and research went very well aside from the colour sensor due to the more complex nature of the component as well as not being hands-on until very recently to the submission of this report. Another few hours will be needed by Max and Morgan to get the sensor working on its own and then add it to the overall system. At time of writing the group has not fabricated all of the connectors and mounts for the electronics however we have temporary testing connections in place, which will be reasonably simple to swap out. In terms of the programming of the vehicle Max has all the tools he needs to complete the task however the real success or failure of this project will be in how accurate the end product is. This will require significant testing and tuning and could be a time constrained task to do within the remaining time before the competition. Although not every option looked into was used (for example the stepper motor and IR sensor) the knowledge gained from this testing and research was instrumental for allowing Max to understand all of the components and how they interact with each other.

Furthermore, one of the failures that required corrective measures was with the AA batteries as an energy source. During the testing of the fabricated parallel circuit, it was found by Morgan and Max that one of the motors was rotating at a decreased speed than the other. The reasoning for this was found when Morgan made a very basic circuit diagram (see figure 3A1) to observe and calculate the required voltages of each loop of the circuit, and

concluded that it was due to 4 AA batteries producing a voltage output of 5V, whereas, the voltage requirement of the motors is 6V. Due to the lack of voltage the resistance in the component was too high for the current to pass through properly, which reduced the function of the motor. Therefore, it was concluded that 5 batteries were required. In addition, before this issue was encountered, there was no Arduino DC input for the AA batteries to be connected. So, we had to ask our lecturer Ryan to solder a blank male connection to a battery connector in order to connect the energy source to the Arduino and assemble the circuit.

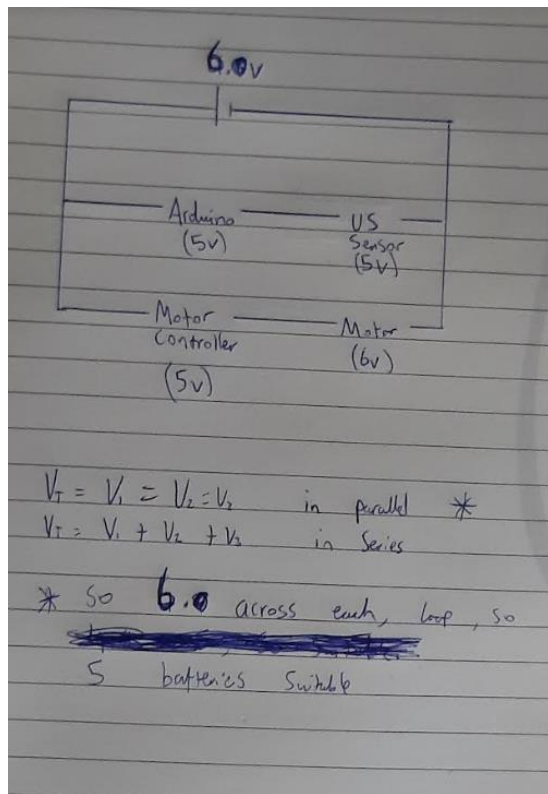


Figure 3A1- Morgan (2205285)

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