Imperial College London

EEERover Report

Team Soltrax

EEE1 Project

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Submitted to:

Dr Stott

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Abstract

The following report dives into the world of rovers and planet exploration. This team report goes into detail on designing and testing a working rover. The rover has the ability to move and survey a terrain whilst discovering data from its new environment, specifically aliens.

For this report our aliens communicate through electromagnetic signals. Notably:

- Radio waves transmit their name.
- Infrared Pulse slows with age.
- Magnetic fields are emitted by the aliens, with a specific polarity.

The aim of this rover is to be able to decipher different alien names, ages, and magnetic polarity.

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1.Introduction

1.1 The Project Brief

'You are requested to design a remotely controlled rover that can explore a remote planet and survey the alien creatures that live there. Using a variety of electromagnetic signals, you must find out the name, age and magnetic polarity of each alien.' (Scott, *Project Brief: EEERover* 2023)
Furthermore, the rover must meet the following requirements:

- Operational requirements: The rover must be able to manoeuvre to negotiate the environment. Additionally, it must be able to find the characteristics of all the aliens.
- Functional requirements: The rover's remote-control interface must be logical and easy to use. The rover itself must be robust and reliable.
- Non – functional requirements: The rovers must be cost and weight effective. The team had a budget of £60.

1.2 Testing Environment

The environmental conditions for rover testing were room temperature/ humidity/ rain and wind. The testing arena also contained other rovers operating at once. The rover needed to navigate on a smooth surface and around uncrossable obstacles. These obstacles include rocks, domes and the arena edge. Some obstacles gave off their own signals to act as noise/interference for the rover sensors.

1.3 Project Management

1.3.1 Time Management

The project had to be completed within 5 weeks. As a team, roles were distributed according to everyone's strengths and weaknesses. To make sure they were on track, small deadlines were made throughout the week. The Gantt Chart can be found in the appendices. In addition to this, they created and followed a Gantt chart throughout the project. Finally for each meeting there was always a scribe. This allowed the team to revisit key points from a meeting whenever required. Subsequently, it ensured all team members were on the same page, thus knowing what their responsibilities were after the meeting.

1.3.2 Responsibility of group members

Mehwish Bhatti was responsible for the movement of the rovers. They ensured that the rover had the best mobility for its environment. After that they assisted in the design and building of the rover. More specifically they worked on the chassis CAD design.

Jennifer Emezie was allocated as the Organisational Development Lead. This meant that they would scribe group meetings, set deadlines and create the Gantt chart. Their main role was to ensure the team was on track with time. Additionally, they took the role of report writer and editor. They felt comfortable taking this role due to their prior experience in report writing. Most importantly they were responsible for finding the magnetism of the alien.

Orlan Forshaw was the most confident in programming hence was allocated Technical Lead. They were keen to learn more about HTML as well as continuing with C++. They were ready to take on the challenge of creating the webpage for the team's control interface. They designed the whole website to ensure the team could move the rover whilst displaying the data that was being received.

Zoe Zheng had the task of obtaining the alien's name from a radio frequency. They worked with Matthew to come up with the most efficient reliable way of interpreting the radio waves. In addition to this they dipped into coding where they looked at interpreting an output for their respective data.

Matthew Godsmark took the role of treasurer in the group. They approved all the orders and made sure the team was on track with their budget. They also worked with Zoe to determine the name of the aliens.

Abby Finka started off the project with obtaining the age of the aliens. They researched to obtain the most appropriate solution for the rover. They later dipped into the design of the rover with Mehwish. Due to their prior knowledge in 3D printing they were keen to take on this role. At times they had also assisted Jennifer with the alien's magnetism. For this reason, Abby was elected to be Project Leader. Throughout the project they have been able to support all team members when needed.

2. Sensors

To ensure the team had the best solution for the task at hand, the first few weeks of the project was dedicated to research and testing. After this, the team began implementing and testing their designs.

2.1 Name

This section presents the design and implementation of a name sensor. The sensor was designed to receive radio frequency signals encoded with ASCII characters, which are then processed to extract the alien names.

2.1.1 The Brief Requirements

The task was to implement a circuit to read the name of the alien. The alien's name was transmitted through radio communication using a carrier frequency of 61kHz (previously 89 kHz but later changed), modulated with two-level amplitude-shift keying. The name was encoded in ASCII characters framed with UART packets with 1 start bit and 1 stop bit and transmitted at a data rate of 600 bits per second. Each name starts with #. (Scott, *Project Brief: EEERover* 2023)

The team had to find a way to decipher these radio signals that were both suitable for the rover and web page output.

2.1.2 Research

The radio signal that the aliens emitted needed to be converted into an electrical signal. The signal was then processed into a readable digital signal. This was finally decoded into ASCII characters to be read. The data was fully processed using the followings steps:

- Radio Wave Conversion: The radio waves needed to be converted into a usable electrical signal. To accomplish this, an air-tuned coil inductor (used as an antenna) was employed in conjunction with a parallel LC resonant filter. The LC circuit can be tuned to resonate at a desired frequency and block out all other signals.

- Signal Amplification: Due to low amplitude of the electrical signal, the output from the LC resonant filter was amplified in-order to be demodulated. The most suitable amplifier for this was a non-inverting amplifier.

- Rectification: Given that the radio signal was amplitude modulated, envelope detection was employed to demodulate the signal. This required the signal to be rectified. A few rectifiers that were considered are a half-wave rectifier, a full-wave rectifier, and a precision rectifier.

- Binary Signal Conversion: After demodulation, the demodulated signal must be converted into a binary representation. To accomplish this, a comparator was used. The comparator compares the rectified signal to a predetermined threshold voltage, generating a binary output. This binary representation was essential for further processing and interpretation.

- UART Communication and Decoding: The adafruit metro m0 board features built-in UART communication capabilities. By connecting the binary signal to the board's RX/TX pins, the board automatically decodes the signal into bytes. One byte represents one letter of the alien's name. Hence only a little programming was required to read the name of the aliens on the website.

Identifiable issues before testing:

1. Op-amp

The data rate of 600 bits per second and a 61kHz carrier frequency meant an op-amp with a relatively high slew rate was required. Likewise, a good Gain-Bandwidth Product for the amplifier was also required.

As a result, the final op-amp used was an mcp6022. It had a GBP of 10MHz and a slew rate of 7V/µs (*10 MHz Op Amps MCP6021/1R/2/3/4 Datasheet* 2009) which met the team's requirements. It also had a supply voltage range of 2.5V to 5.5V which worked with the Adafruit supply voltage of 3.3V or 5V. In addition to this, its cost was £1.89 which was within budget.

2. Rectifier

- Choosing the most appropriate rectifier for this scenario required comparing the advantages and disadvantages of each rectifier:

  - The half-wave rectifier had the least number of components out of the three and so would be the lightest and cheapest.

  - The full-wave rectifier allows for shorter rectification time as the signal was rectified more frequently. This could reduce the delay until the signal drops below the comparator threshold voltage. When compared to the half-wave rectifier, this rectifier took twice as much voltage from the signal. This was because the full-wave rectifier used two diodes.

  - The precision rectifier accommodated for the voltage drop across the diode but required another op amp and so cost more.

As a result, the team chose to use a half-wave rectifier within the rover. This was because its only major downside was the voltage drop across the diode which can be accommodated by amplifying the signal.

2.1.3 Simulations

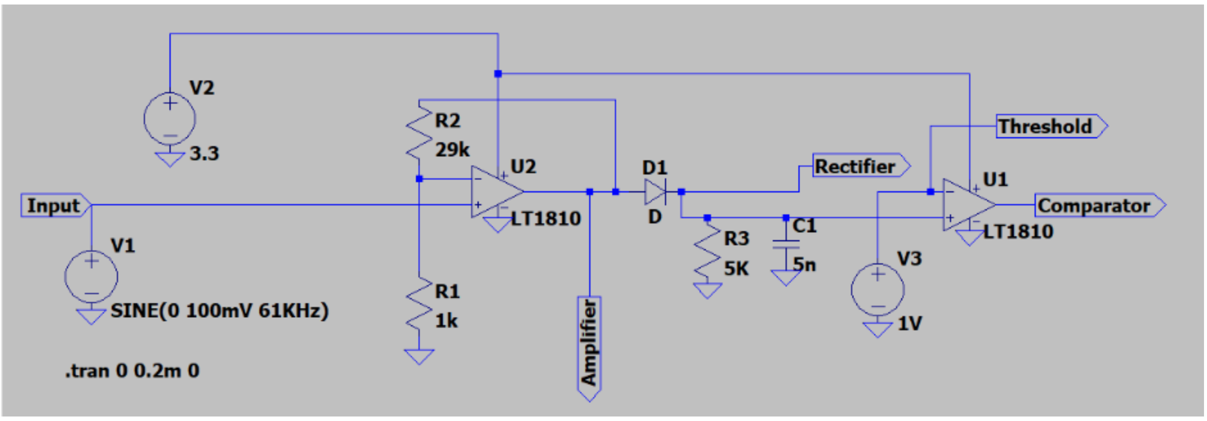


Figure 1.1: LT spice circuit of name sensor

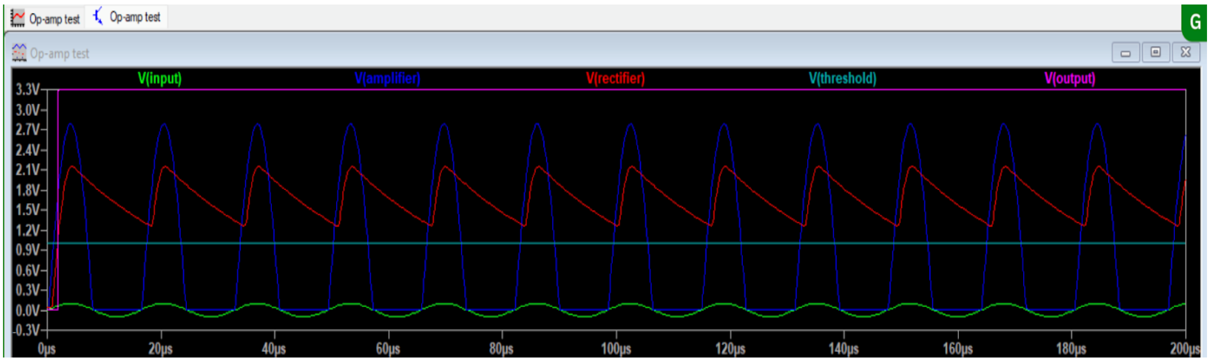


Figure 1.2: Simulation of name sensor.

As shown in figure 1.1, the LC filter was removed from the spice circuit and replaced by a sine wave of frequency 61kHz and amplitude 100mV. This enabled amplifier, rectifier, and comparator testing. Further pre-production tests would be required on the LC filter as it is not easy to test the LC filter in spice with real life limitations (range, noise…).

In figure 1.1, The LT1810 op-amp was used because the mcp6022 was not in the library of components. No values are final in the circuit diagram.

In figure 1.2, this simulation was to prove that the planned circuit works (not including the LC filter). The simulation showed that when a signal was present (the green signal), the output was high (the pink signal which was equal to 3.3V). This test showed that the circuit was working.

2.1.4 Assembling the prototype

The name sensor consists of two blocks:

1. Radio receiver: a LC filter that incorporated a tuned coiled antenna which extracts the resonant frequency
2. Signal processing unit: this consisted of a non-inverting amplifier, which amplified the signal. A rectifier that performed an envelope detection to demodulate the AM signal. Lastly, a comparator that converted the

demodulated signal, which was in the form of amplitude shift keying, into digital signals.

Collectively, they enable the name sensor to capture, process, and convert the received signal into a digital output, enabling the identification of specific alien names.

2.1.5 Initial Prototype

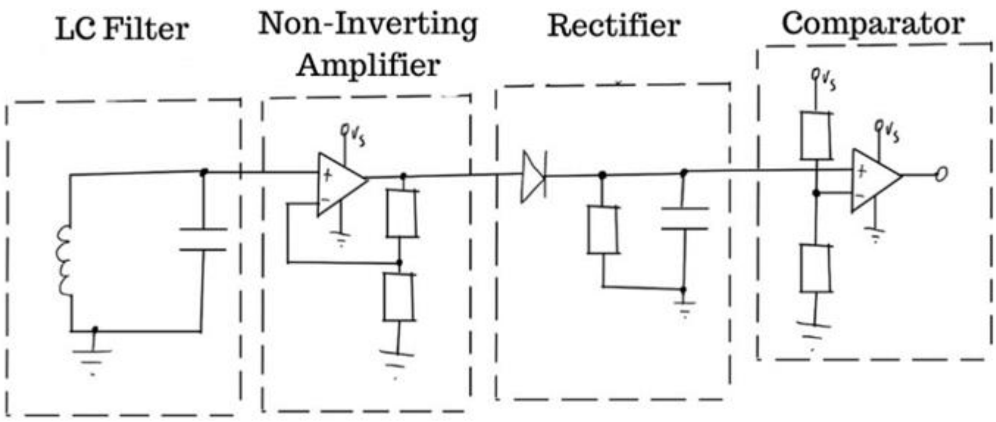


Figure 1.3: Schematics for name sensor prototype

In the initial prototype, prior to the modification in the carrier frequency, the LC filter was constructed and tuned to a carrier frequency of 89kHz, and a LT1366 op-amp was used. In the process of constructing the antenna, a wire was wound around a circular object and secured using tape. This configuration resulted in an inductance value of 224μH. By utilising the equation 2πf = 1/((LC)^1/2), where f represents a frequency of 89000Hz, the calculated capacitance was determined to be 14nF. To achieve this capacitance, parallel placement of two capacitors was employed (3.9nF and 10nF capacitor). In Figure 1.3, the non-inverting amplifier was configured with a gain of 31. This was accomplished by utilising two resistors, a 30kΩ and 1kΩ resistor. For the rectifier stage, a 10kΩ resistor and a 1nF capacitor were chosen. This combination resulted in a time constant of 10μs for the rectified signal. Within the circuit, the source voltage (Vs) was maintained at 3.3V. Additionally, a potential divider connected to the negative input of the comparator incorporated two resistors with values of 10kΩ and 1kΩ. This configuration produced an input value of 300mV.

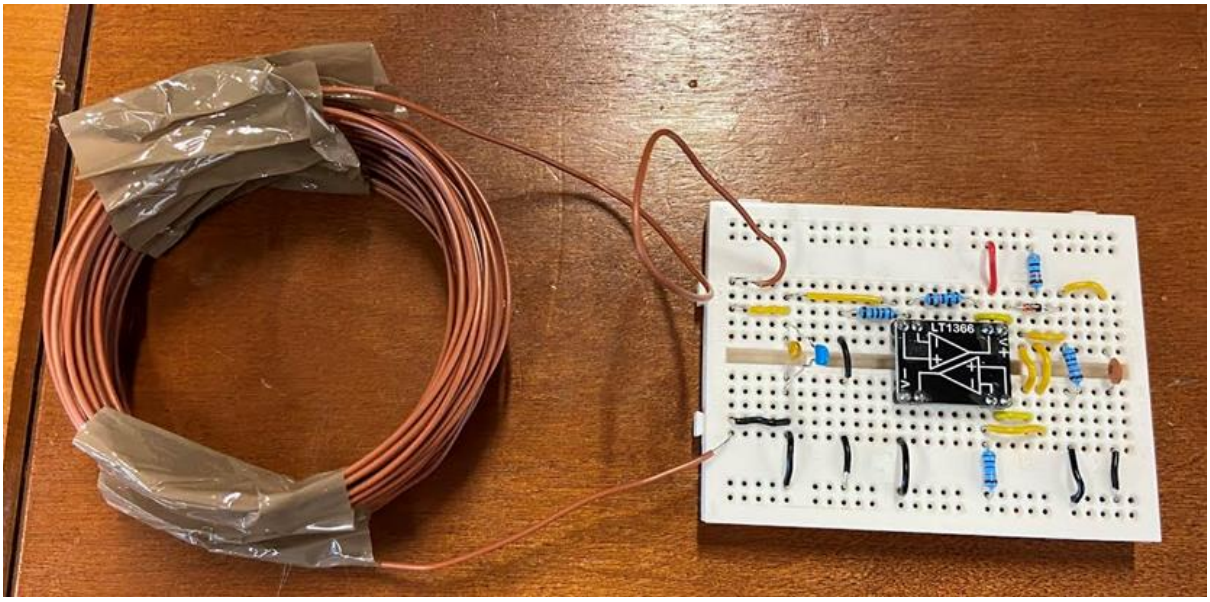


Figure 1.4: First Prototype with LT1366 op-amp

Figure 1.4 shows the circuit with the LT1366 op-amp temporarily, as the MCP6022 had not arrived yet. It was determined that the LT1366 op-amp was unsuitable due to its limited gain-bandwidth product (GBP) of 400kHz and a slew rate of 130mV/µs. Subsequently, upon the arrival of the MCP 6022 op-amp, the LT1366 was replaced with it to make the intermediate prototype. See section 3.1.6.

2.1.6 Intermediate Prototype

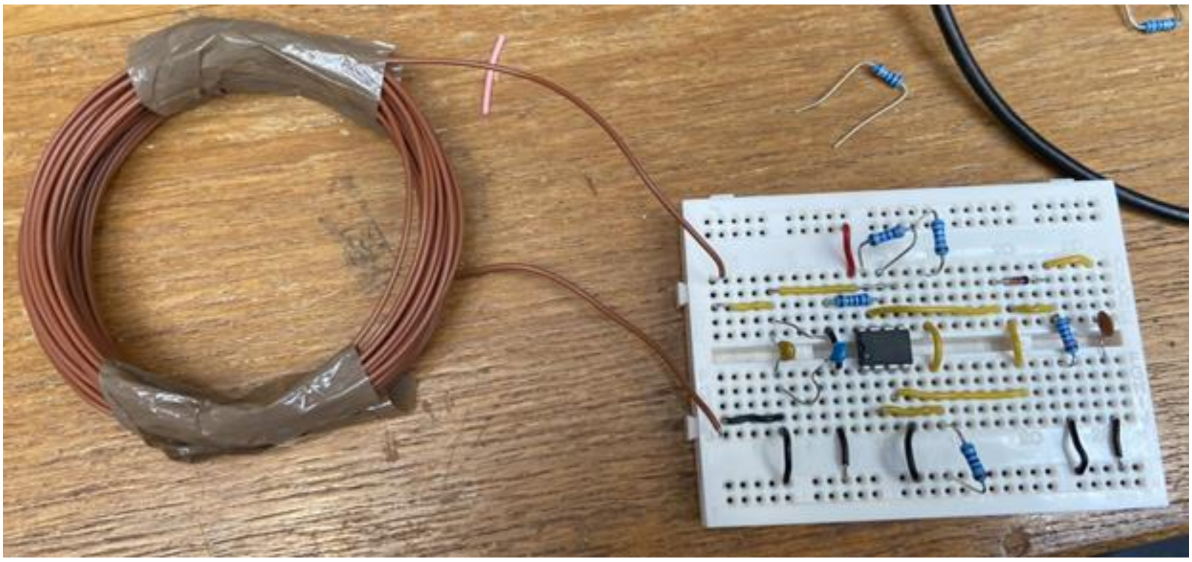


Figure 1.5: Intermediate prototype with MCP6022 op-amp

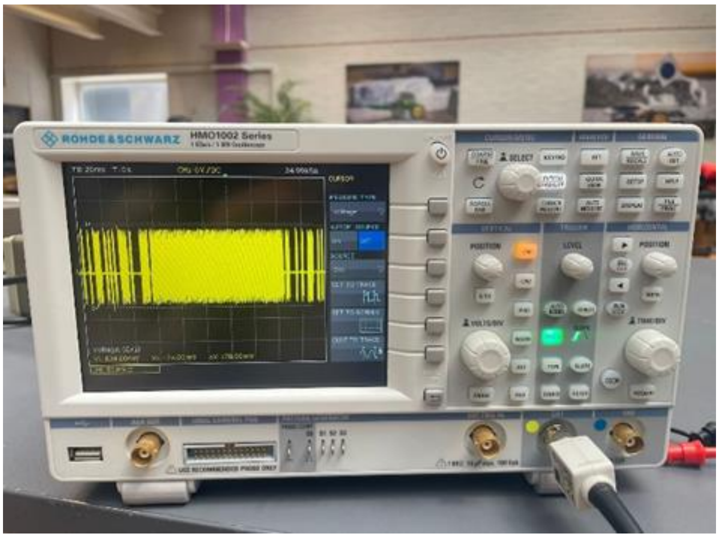


Figure 1.6: Oscilloscope trace of the radio signal received with the intermediate prototype

Figure 1.6 presents an oscilloscope trace that depicts the signal received by the antenna in the intermediate prototype of our name sensor. Notably, the antenna within the radio receiver successfully captured the alien signal without any noticeable noise interference.

However, the antenna in the intermediate prototype, while capable of receiving the signal, initially exhibited a limited signal detection range. In this case, the detection range was measured as the maximum distance the antenna could be from the alien and still receive a signal. It was only able to effectively pick up a signal when the alien was positioned inside the coil.

The team attempted to upgrade the wire used for the antenna to a 0.1mm thick uninsulated copper wire, due to its effectiveness in receiving signals. To add on, copper's low resistance minimises energy loss as heat which makes it an ideal material for consistent performance.

The copper wire acquired for £10.80 was specifically highlighted as suitable for use in "Inductors for electronics" (Block Single Copper Wire 2023). However, upon conducting tests, it became apparent that the wire exhibited a considerably high resistance, rendering it inefficient with significant energy loss. Furthermore, in our pursuit to construct the antenna, the team procured a significant length of copper wire (approximately 1km) and proceeded to wrap it around the antenna core. Despite the team's efforts, the resulting inductance fell short of the desired magnitude. Recognizing the constraints imposed by the limited supply of materials, the team made the decision to explore alternative solutions to overcome this setback.

The final solution was to use the same type of wire used in the first antenna with an increased antenna core diameter. In addition to this the overall length of the coil also increased. Another way to increase the range was to decrease the comparator threshold voltage (the voltage required to output a high signal). This resulted in a solution where:

- The coil inductance was: 253µH.

- The threshold voltage at the comparator input was changed from 300mV to 20mV with 160kΩ and 1kΩ resistors.

- Detection range: 5cm.

With a new inductance, the capacitor in the LC filter needed to change. Using the same equation from before but f = 61000Hz, the new capacitance = 27nF. Limited capacitor values resulted in a 22nF and 3.9nF capacitor in parallel. Resultant capacitance = 25.9nF.

2.1.7 FinalPrototype

The final prototype integrated the newly designed antenna onto the existing circuitry. This inclusion of the upgraded antenna enhanced the overall performance and functionality of the final prototype.

Figure 1.7: The new antenna

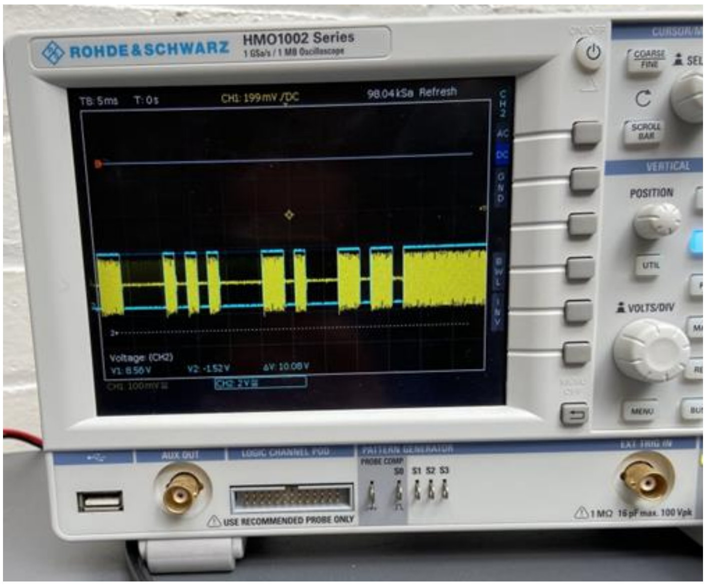


Figure 1.8: Oscilloscope trace of the LC filter output and comparator output.

Figure 1.8 illustrates the comparison between the outputted digital signal (blue line) and the signal outputted by the LC filter (yellow line), showcasing the functionality of the final version of the antenna. The output of the antenna goes high when the signal is present and low when the signal is not present, indicating successful detection. This outcome is attributed to the antenna's optimised inductance, which enables the accurate capture of the resonant frequency and ensures precise reception of the radio signal.

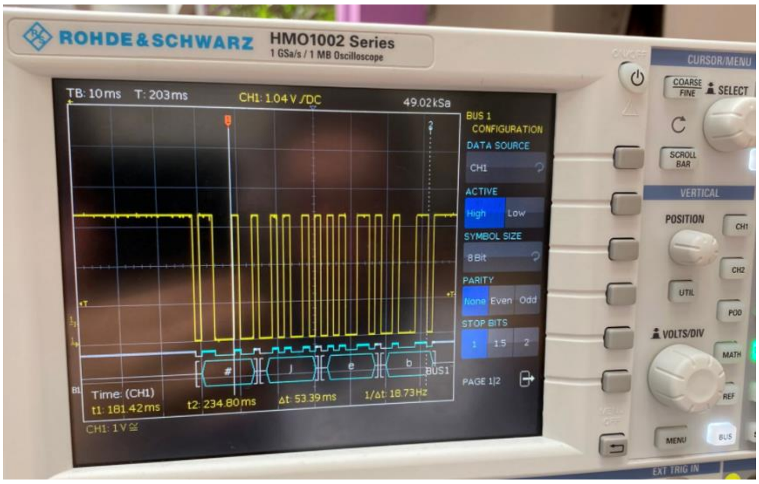


Figure 1.9: Oscilloscope trace of name

In the final stage of the testing process, the radio receiver and the signal processing unit were integrated to create the complete "Name Sensor." The output of the sensor was connected to an oscilloscope for testing purposes, using an alien as the input near the antenna. Figure 1.9 displays an oscilloscope reading capturing the name "JEB" from the alien, thereby validating the operational functionality of the name sensor.

2.1.8 Implementing in Code

```
receivedChar = char(Serial1.read());

while (receivedChar != '#')
{
  receivedChar = char(Serial1.read());
}
for (int i = 0; i < 3; i++){
  Server_Message += String(char(Serial1.read()));
}
Serial.println(Server_Message);
```

Figure 1.10: Section of Name Code

Using the RX pin, the code checks the ASCII value of these bytes until it finds a "#". Once it does, it prints the following three ASCII values (the alien's name). This section is then terminated.

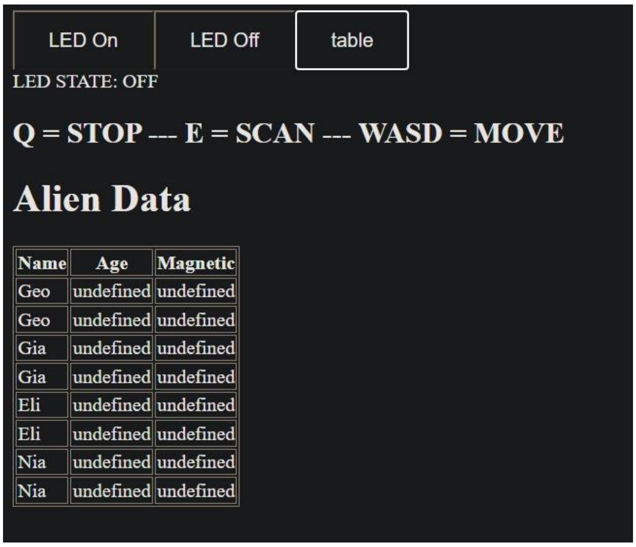


Figure 1.11: Website Interface with alien name

As a result, the data can be successfully read by the rover and the name of the alien was clearly shown on the website (Figure 1.11)

2.1.9 Rover Implementation

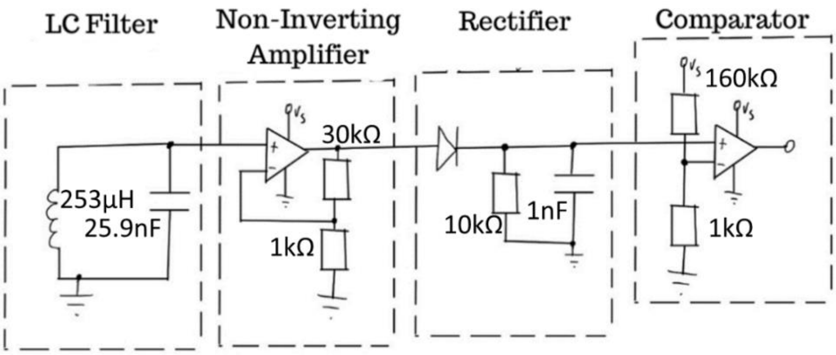


Figure 1.12: Schematics for the final prototype of the signal processing unit.

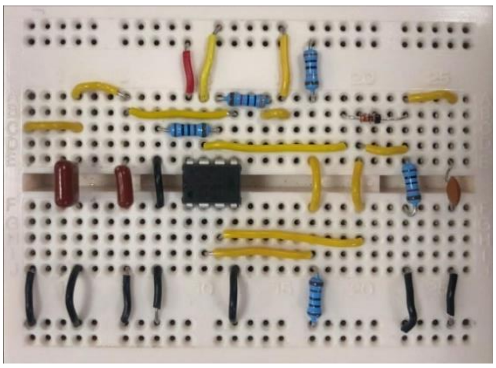


Figure 1.13: Final Prototype Breadboard

With a working circuit, all that was left was to implement it into the rover. The circuit breadboard, Figure 1.12, has been mounted to the chassis. A mount had been designed to hold onto the antenna, more about this in the Design Choices & Prototype section of the brief. A rotating antenna that detects where the signal was coming from was considered but due to a time constraint, this was not possible to make. The fixed mount holding caused the antenna's range to be reduced to 3.5cm. This wasn't a problem as it was easy to drive the rover 3 cm in front of the alien.

2.2 Age

The aim of this section is to explore how the rover will detect the alien pulse to determine its age. The sensor receives a pulse of IR radiation where the period relates to the alien's age.

2.2.1 The Brief Requirements

The brief described that all the aliens had a given age. They had a pulse that can be detected optically and slows with age. The pulse was emitted as infrared radiation with a wavelength of 950nm. The period of this pulse increases at exactly 1ms per century of lifetime. (Scott, *Project Brief: EEERover* 2023) Therefore, a sensor that could detect this signal and find the alien's age was required.

2.2.2 Potential Issues

A few potential issues were identified when discussing approaches to this problem. The main issue was that ambient light in the arena could cause interference and potentially lead to incorrect readings. To avoid this problem, the team ensured that the final sensor was only sensitive to a certain wavelength. This was the wavelength of the alien emission thus minimising the issue of ambient light. The team tested this in the prototypes however a better understanding would be gained when testing in the arena. Additionally, the optical power given by the alien was expected to be weak, so an amplification circuit was needed.

2.2.3 Research

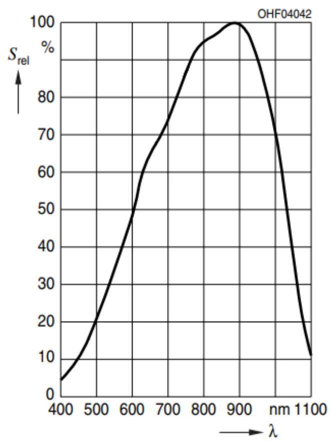


Figure 2.1: Graph showing peak Relative Spectral Sensitivity of SFH300-3/4 Phototransistor (SFH 300 Datasheet 2022)

The first approach that was considered was to use 2 SFH300-3/4 Phototransistors. These were readily available in the lab and could detect the 950nm wavelengths as required. However, the wavelength of maximum sensitivity was 880nm, as can be seen in Figure 2.1 (*SFH 300 Datasheet* 2022). Therefore, further research was required to avoid issues with ambient light. To eliminate these problems the team considered configuring 2 phototransistors as a differential amplifier. One phototransistor would receive ambient light, and the other would pick up the alien emission. Therefore, the differential amplifier would only amplify the IR pulse, as the low common mode gain would ignore the ambient light.

An alternative approach would be to purchase a new sensor that would be more suited to the problem. The sensor was low cost and would not require extra circuitry. There were alternative phototransistors, however, the team felt that it would have similar issues as the existing components they had tested. This is why they were not strongly considered.

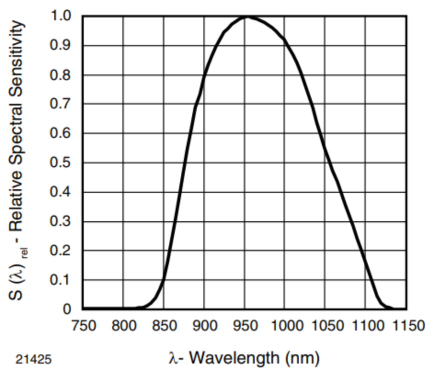


Figure 2.2: Graph showing peak Relative Spectral Sensitivity of TSOP4136 (IR Receiver Datasheet 2016)

The team researched IR receiver modules. They are designed to pick up IR radiation while filtering out the ambient visible light. The TSOP4136 was ultimately decided to be the ideal choice. The reason for this was its peak relative spectral sensitivity at 950 nm as seen in figure 2.2. (*IR Receiver Datasheet* 2016) This was ideal as it was the given wavelength of the alien emission, meaning that it will pick up the emission most efficiently. Compared to Figure 2.1, the graph in Figure 2.2 is shifted, meaning there was a greater sensitivity in the wavelengths emitted by the alien. Additionally, it had a supply voltage range of 2.5V - 5.5V, therefore can operate with 3.3V supply as planned. Furthermore, it was described to have an improved immunity against ambient light which was optimal to avoid issues stated above. Lastly, with a small cost of £1.28 the TSOP4136 was the appropriate choice and was purchased by the team.

2.2.4 The Prototypes

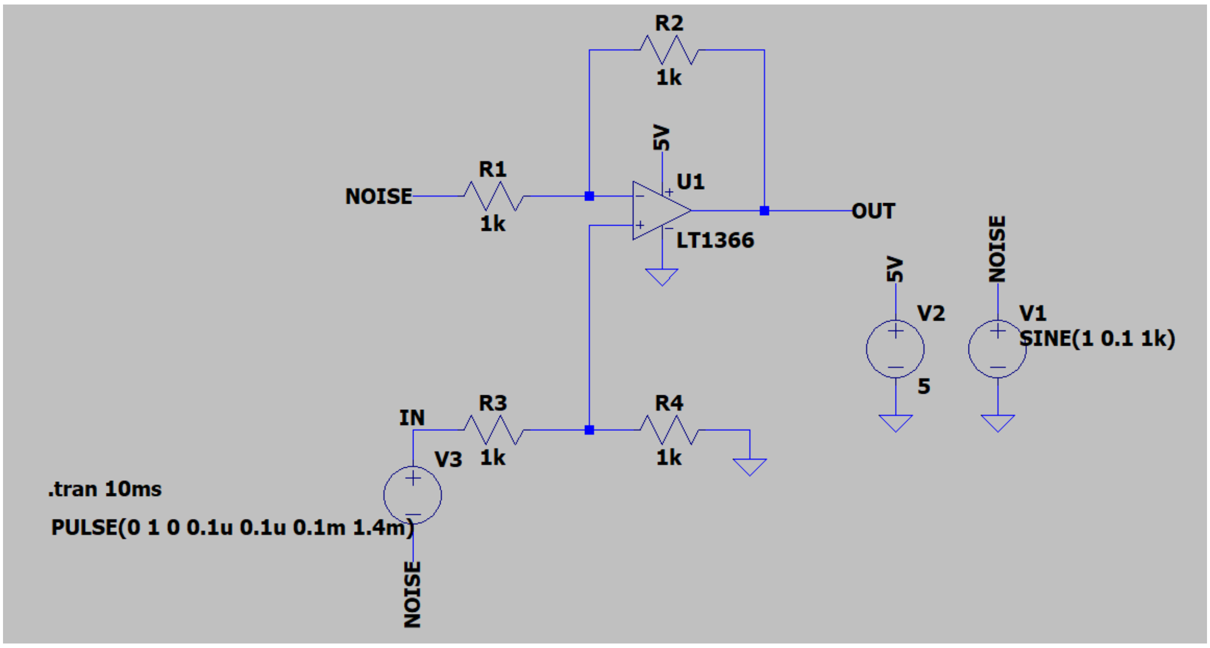


Figure 2.3: Simulated differential amplifier circuit

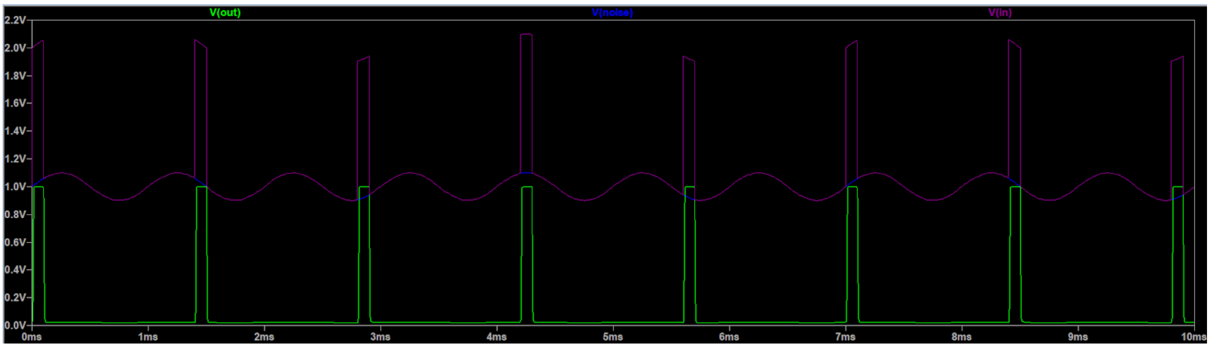


Figure 2.4: LTSpice simulation of circuit in figure 2.3

Due to their availability in labs, the first prototypes used the phototransistor circuits. The differential amplifier circuit was simulated in LTSpice as seen in figure 2.3. The simulation uses a sine wave as an arbitrary function to model the noise created by ambient light. Therefore, one input to the differential amplifier is just the 'ambient light' and the other also includes the pulse. The simulation shown in figure 2.4 shows that the output amplifies the pulse and ignores the sine wave as required, providing proof of concept.

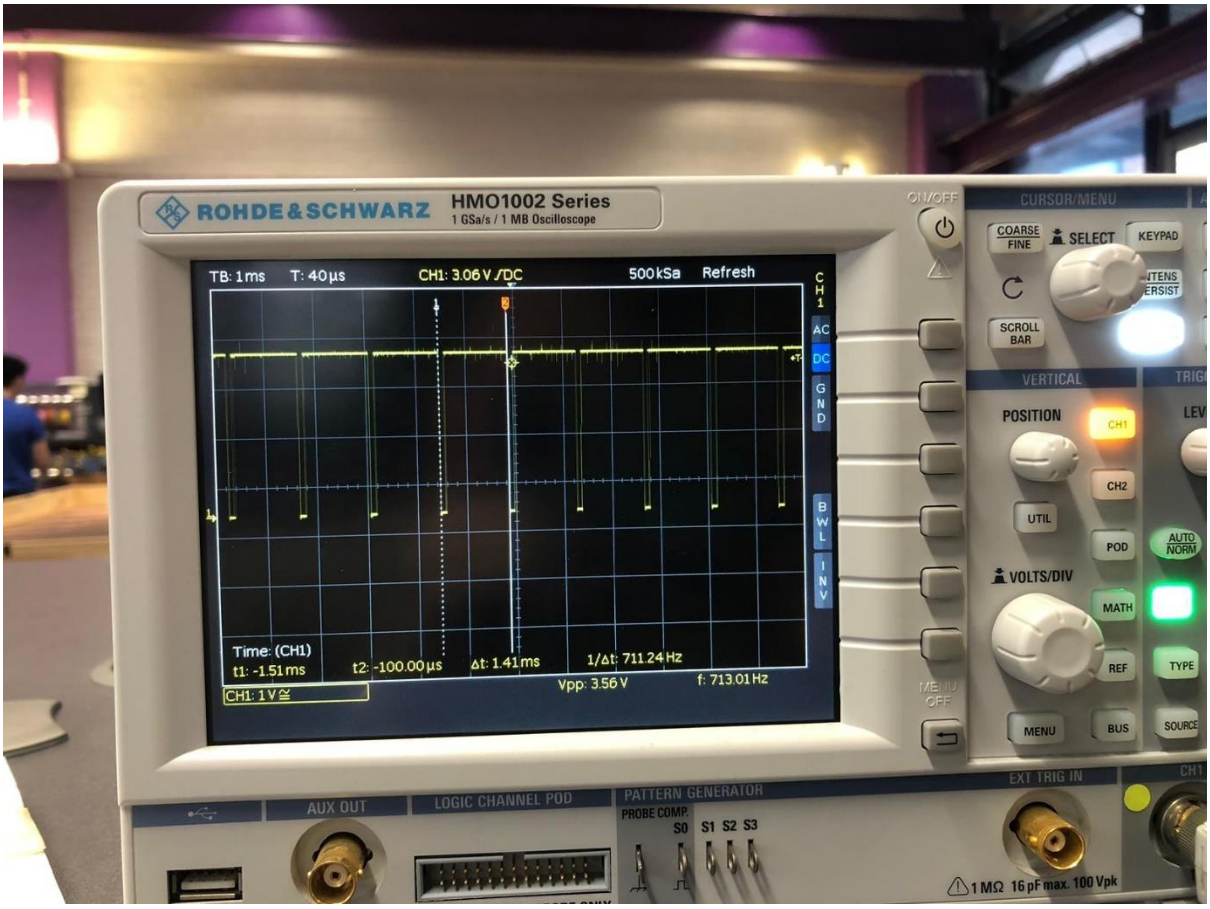


Figure 2.5: Output of TSOP4136 oscilloscope trace

Once the TSOP4136 sensor arrived this prototype was created, which worked immediately.
The team decided to run the prototype's output signals through an oscilloscope. This was the clearest way to see the signals without it being affected by its microcontroller interpretation. The IR receiver provided a clear output signal on the oscilloscope representing the inverted alien emission as seen in Figure 2.5. The trace shows the IR pulse clearly, and using cursor measure the period was determined to be 1.41ms, giving an age of 141 years. The trace has clear HIGH and LOW sections so can be easily interpreted by a digital pin on the microcontroller, resulting in simpler code to determine the age.

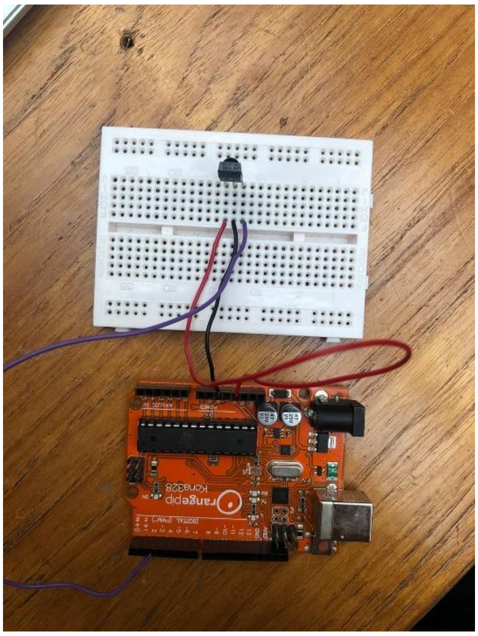


Figure 2.6: Connecting TSOP4136 to OrangePip

The sensor was connected as shown in Figure 2.6. It required 3 pin inputs, supply voltage, ground and output. The supply voltage used was 3.3V as this was the logic level of the Metro board. The sensor returned the output to the board and therefore the signal needed to be between 0 and 3.3V to prevent damage. The output pin of the sensor was connected to a digital pin on the board as the value of the signal was irrelevant, only whether it was HIGH or LOW, which could be represented by 1 or 0 on the board. For the final implementation, the circuit used the Metro board, instead of the OrangePip.

2.2.5 Final implementation

The TSOP4136 was decided to be the better solution. The results were much clearer and more reliable. The sensor did not require any circuitry apart from connecting the supply voltage, ground and connecting the output to the board. This was advantageous as the team's priority was keeping the rover weight at a minimum. A less complex circuitry meant that there would be no unnecessary components included in the breadboard.

To measure the pulse of the signal the code used the arduino reference PulseIn() (pulseIn() 2019). It measured the amount of time the signal was HIGH and LOW separately and then combined them to get the overall period. PulseIn() returns the time in microseconds, so it had to be converted to get the age in years.

```
high_time = pulseIn(signal_pin, HIGH);
low_time = pulseIn(signal_pin, LOW);
tmp_age = (high_time + low_time) / 10;
```

Figure 2.7: Arduino code to measure period

To make the code more robust, this result would be checked multiple times before being returned. The brief said that the age should be found to the nearest decade. Therefore, the code loops over figure 2.7 and will only return the age if the value was the same (to the nearest decade) 20 times consecutively. This allows the rover to ignore erroneous data and only return a value if it is correct. Hence increasing the rover reliability.

2.2.6 Final Testing

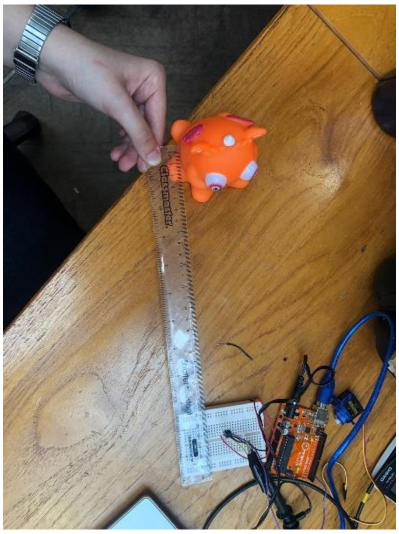


Figure 2.8: Demonstrating testing of range of TSOP4136

When testing the sensor alone (independent of the rover), the results were found to be reliable with a range of around 25 cm (as seen in Figure 2.8. This meant that the sensor would not be a limiting factor in the demo. The team did except that in practice the sensor was unlikely to be used over a large range. This is since the other sensors that were attached to the rover had a more limited range.

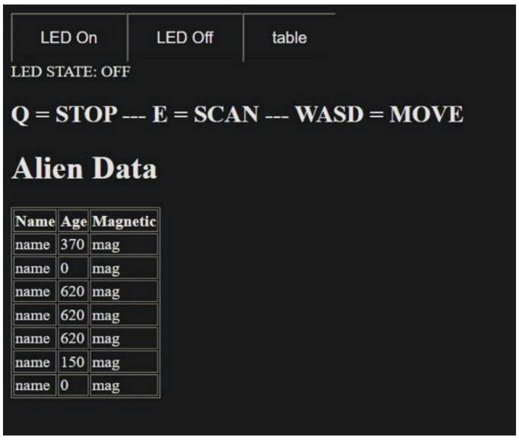


Figure 2.9: The Website interface with gathered values for all alien characteristics

The IR sensor was then integrated into the final rover and controlled over through the website. This presented new challenges to the team as the code did not work straight away. A timeout was added to the pulseIn() function as it defaulted to 1 second which meant that the value took too long to return.

However, once the issues were resolved the testing was successful and the code returned an age to the website. This can be seen in figure 2.9.

2.3 Magnetism

The following section contains information on how the alien polarity was detected by the rover. Depending on the magnetic field present, the sensor was able to produce a varying voltage output. Certain voltages were interpreted differently to produce their respective output.

2.3.1 The brief requirements

The final alien characteristic to find was its magnetism. The brief indicated some aliens had 'a static magnetic field orientated [within] their body' (Scott, *Project Brief: EEERover* 2023). This meant that the alien could have one of three states: a north pole (up spin), a south pole (down spin) or no magnetic field at all. The brief also stated that the magnets will be located 10 mm below the top of the alien head. The final rover must be able to determine the polarity of the magnet within the alien if present.

2.3.2 Initial Research

The team prioritised the components cost, size/ weight and practicality when researching to find the most appropriate device. The reason for this refers to the initial design requirements of a light weight £60 rover. In addition to this the magnets were small hence our device must be able to pick up the small magnetic field. A study by Brown university suggests that a hall effect sensor would be the best device to detect a weak magnetic field. (*Ultra-sensitive device for detecting magnetic fields* 2020)

This began the search into Hall Effect sensors and how they could be implemented into our rover. As stated in the name the Hall Effect sensor relied on the hall effect. Within the sensor there was a p-type semiconductor material. 'When the device is placed within a magnetic field, the magnetic flux lines exert a force on semiconductor material'. (*Hall Effect Sensor* 2019). As a result, the force caused the mobile charge carriers within the material to move. This would develop into a potential between two sides of the semiconductor which resulted in a hall voltage. This hall voltage output would later become the rover's indication that a magnetic field was (or was not) present.

When further research had been conducted, the team found that there were two types of sensor outputs. These depended on which type of sensor was chosen.

Output 1 – Digital

This type of output acted as a switch. It would turn the circuit on and off (output high or naught) if there was a magnetic field present. This seemed like the ideal way to detect a magnetic field. However, this simple operation was almost too simple for a rover's requirements.

There were two sensors that had a digital output:

- Omnipolar – where the output would be high only in the presence of a magnetic field.
- Unipolar – where the output would be high in the presence of a specific magnetic field i.e. a south pole.

This implied that these sensors could only handle two states. For this project the alien's had three possible states - up, down or no magnetic field. As a result, the rover would require two sensors. One that detected the presence of a magnetic field and another that detected its type. This was not ideal for the team as they desired a compact rover. Two sensors would have required more space on the rover. Additionally, data collected from two sensors increased the chances of an error or data being misread. This decreased the rover reliability making a digital output undesirable.

Output 2 – Analogue

Instead of a high voltage output, an analogue sensor would output a continuous voltage. In theory this voltage would increase in the presence of a strong magnetic field and decrease in the presence of a weak one. (Feng, *Hall Effect Proximity Sensors* 2021)

A linear hall sensor utilised this and was able to produce an output for all three alien states. In the presence of a north pole (up spin magnet) the output voltage should be zero. Then in the presence of a south pole (down spin magnet) the output voltage should be the supply voltage (the maximum voltage). Finally, and most importantly, when no magnetic field was present the output voltage should be the midpoint between 0 and the supply voltage. For this reason, the team decided to move forward with a linear hall effect sensor.

In the end, the team chose the AH49E Linear Hall Effect Sensor for their rover. It was the most appropriate choice due to its small size and simple circuit set up. This meant that it would take up less room on the rover. Additionally, its voltage range of 3 - 6.5 V seemed perfect for the Adafruit 3.3V/ 5V output. Finally, its cost of £1.15 was within budget so the team decided to purchase two. This was their precautionary measure in case something happened to the first and further delivery was not quick (*AH49E Datasheet* 2010).

2.3.3 Limitations

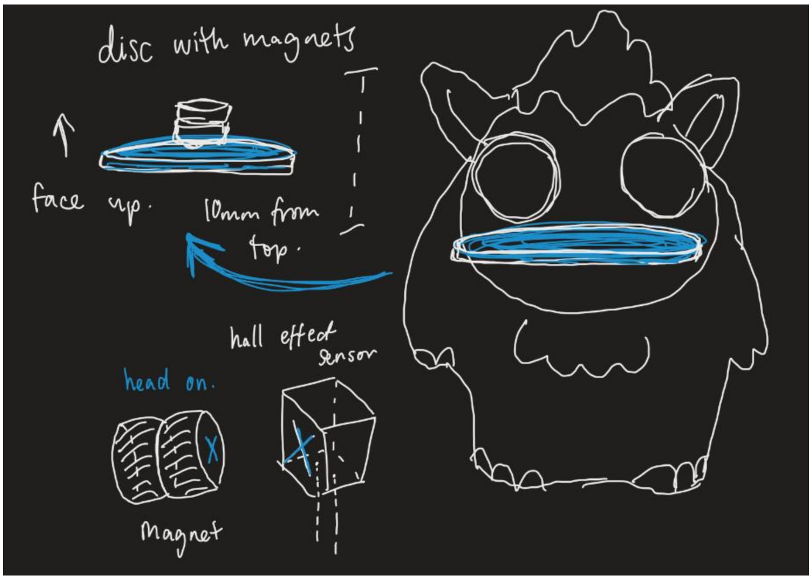


Figure 3.1: Diagram of magnet orientation compared to an alien and sensor

Before choosing a sensor, the team found that there were a few limitations to how the data could be read. More specifically, the orientation of the magnet mattered. To obtain the hall effect, magnetic flux lines are required to be perpendicular to the semiconductor surface. As a result, the orientation of the magnet must be head-on to the sensor (Figure 3.1). This meant readings would not be obtained from the side of the magnet. Consequently, when the sensor was implemented into the rover, the team had to design a way for the hall sensor to line on top of the magnet/ above the alien head.

2.3.4 Testing

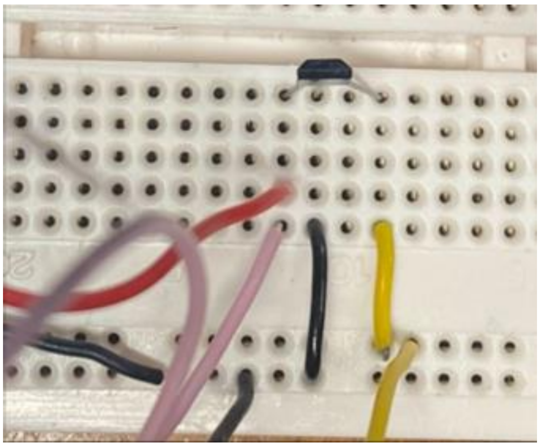


Figure 3.2: Linear Hall Sensor Circuit

After getting the AH49E sensor, testing began to see if this theory would hold. As shown in figure 3.2, the sensor's circuit was very simple. Like the IR sensor circuit, the sensor only required 3 pin inputs, supply voltage, ground, and output. The supply voltage used during testing was 5V. This meant a value of 5V was expected in the presence of a south pole, 0V for north and 2.5V for no field present.

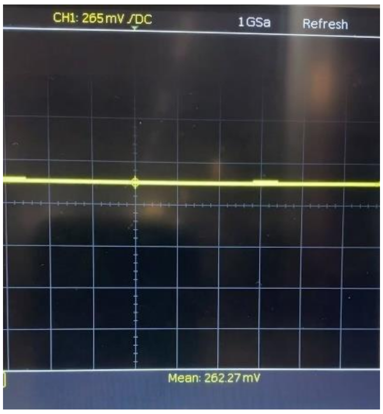


Figure 3.3: Oscilloscope reading when no magnetic field is present.

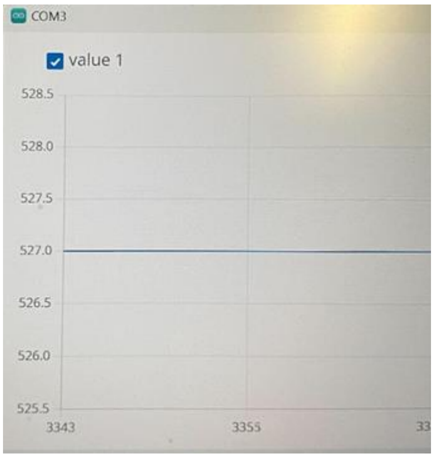


Figure 33.4: Arduino readings when no magnetic field

The first test was in the presence of no magnetic field. As shown in figure 3.3, the output voltage was approximately 2.6V which is very close to the expected 2.5V. Figure 3.4 also shows the Arduino readings which would be read by the rover. The OrangePip uses 10-bit Analog to Digital Conversion (ADC) so inputs to the analogue pins are put through the ADC and the voltage range is mapped to a range of 0-1023. Hence the voltage reading seen was 527 which is approximately the mid-point.

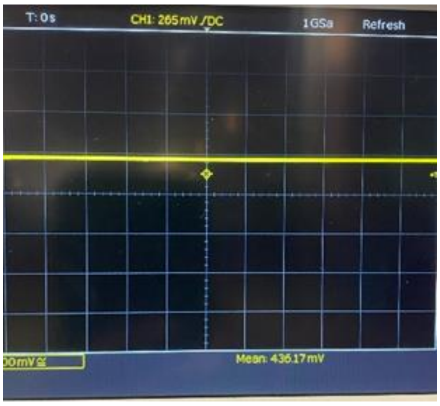


Figure 3.5: Oscilloscope reading when a south pole is present.

Figure 3.6: Arduino readings when a south pole is present.

Next was the presence of a south pole. As seen in figure 3.5 the voltage was 4.3V and in figure 3.6 the value tended towards 900.

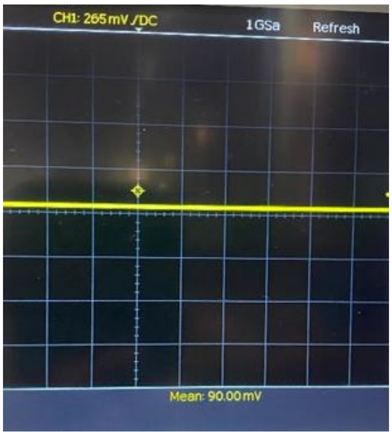


Figure 3.7: Oscilloscope reading when a north pole is present.

Figure 3.8: Arduino readings when a north pole is present.

Lastly, in the presence of a north pole, the oscilloscope and Arduino readings were 0.9V and 170. This can be seen in figure 3.7 and 3.8.

Evidently, the sensor worked perfectly however the range was a slight issue. The maximum readings (0V, 5V and 2.5V) were only obtained when the magnet was held right next to the sensor. This was an issue since the magnets were located inside the alien approximately 10 mm from its highest point. This meant our sensor would not be able to touch the magnet in the arena. Hence the team needed to figure out how to increase their sensor range.

2.3.5 Increasing sensor sensitivity.

To increase the range of the sensor, the team looked at ways to increase its sensitivity. At first a non-inverting amplifier was considered. Initially the team thought that if the signal was bigger a slight change in the voltage would be more noticeable. After a consultation, the team determined that this would be unlikely to fix the issue as everything would have been scaled up.

Another option was to include a Schmitt trigger within the circuit. The idea behind that would be deviation from the midpoint (e.g. 2.5V) the output would be forced to the maximum (5V) or negative supply voltage (-5V). This seemed appropriate as the team would now get maximum readings for a small magnetic change. The team quickly realised that this eliminated their third alien state of no magnetic field present which would disregard one of the briefs specifications - the rover can detect when no field is present.

```
if (voltage > base_level + offset){
```

Figure 3.9: Code demonstrating use of offset in comparison.

The team chose a software approach to fix the problem. The software took readings to find a baseline reading from the sensor. The code could then compare later readings to this baseline. Using a similar approach to the age value, the software looked for 10 consecutive readings before returning a value. When comparing values an offset value was used as seen in figure 3.9. This accounted for the noise in the sensor output and the changing values. This offset value was adjusted to get precise readings.

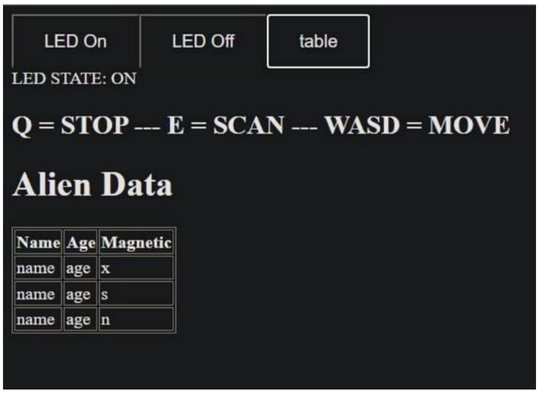


Figure 3.10: The Website interface with gathered values for alien magnetism.

This worked well for the team as the new range was now 25 mm. The team understood that this was not amazing, however, it is more than double the distance of the alien top to the magnet inside. As shown in figure 3.10, the team were able to obtain valid reading from a magnet when inside the alien.

Although the range had increased by a lot, it was still considerably lower than the other rover sensors. As a result, the team knew that some design changes had to be made. See section 4.

2.3.6 Integrating into the rover.

When the magnet sensor was mounted onto the rover and controlled using the Adafruit board, the team found some issues. This was because the ADC in the Adafruit board was much noisier, meaning that the offset value had to be very high to get any readings. The team found that adding a coupling capacitor between the ground and 3.3V rails reduced this noise and resulted in more accurate results.

3. Software

Within this section the report explores how software and code was used by the team to overcome necessary challenges such as controlling the movement of the rover remotely and broadcasting data from the Arduino to a website on a physically unconnected computer.

3.1 The Brief Requirements

The brief had two main requirements for the software:

1. The rover must be able to move around the arena while controlled remotely.
2. The rover must autonomously process the data from the aliens and transmit it to the user (Scott, *Project Brief: EEERover* 2023).

The software would be running on two platforms, namely the Adafruit and the device used to control the rover. This meant that the code needed to include three different programming languages (C++, JavaScript, and HTML) in different parts of the overall program to achieve all points in the brief.

3.2 Early Prototyping

The movement of the Rover was not a significant challenge for the team due to prior experiences that required similar skills. The only difference was how a HTML request would be implemented to pass the input from the computer to the rover.

There were different ideas in the team on how the motor controls were implemented. On the keyboard, the letters W, A,S and D were chosen to control the rover. This seemed appropriate as it is a standard input for movement. W and S control forward and backwards movement while A and D control turning left and right. The team had two ideas for the implementation of the letters W and S. On one hand, the keys could be held down to move the rover forward. This meant the rover was stuck at a set speed until the key was released. On the other hand, the keys could be used as a speed increase/decrease button so that the rover will continue at a set speed until another input was made to increase or decrease speed. Both options had their advantages and disadvantages. The final decision can be found in section 4.3.

The website was the hardest software challenge the team faced. There were many methods considered in how to solve certain issues.

A core issue was the limit on how large the code could be. The small capability of the Wi-Fi meant only a specific amount of data could be sent to start the server. One idea proposed that the server no longer ran from the Adafruit but instead, ran from the computer and then connected the Adafruit to the server. This allowed the team to escape the size limit on the device. However, this did cause other problems and required the use of third-party browser extensions which may not have been permissible. Consequently, the team attempted to stay within the size limit by compressing the code as much as possible which proved to be impossible.

The website also had other aspects where design choices were required. The data had to be sent to the computer and stored in some format as per the brief and specification. The more organised and easier to read the better but the efficiency of the HTML code was also important.
Another choice to be made was whether the sensors would gather data all the time or at certain times. There were many issues with continuously gathering data such as it is creating bad readings due to interference such as ambient light. More about this in section 3.3.

3.3 Final Design Decisions

Website size limit – To solve this problem data packets were used to set up the website, a very efficient solution. This took a lot of trial and error to be implemented but worked extremely well. The team came to this solution because it is commonly used in the real world and, when tested, proved to be very easy to work with once implemented. The only downside was it increased the time it took to initialise the website but for the rover's purpose this was largely not relevant.

Movement of the rover – The final decision was to use W and S keys which increased and decreased the speed alongside the Q key as a brake. This was done as it ensured the rover kept moving if the connection stuttered or a larger delay happened between the client and server. The brake was used to quickly stop the rover, when necessary, for example, if it approached an alien to scan. The A and D keys were tap keys, meaning that the rover would turn left or right when those keys were pressed until another input occurred. This was because it was less vital to have fine control overturning.

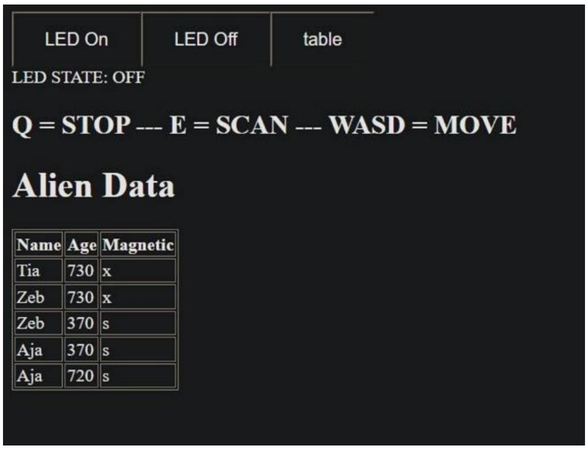


Figure 4.1: The Website interface with gathered values for all alien characteristics

Website data Storage – It was decided to use a basic HTML table which allowed the team to easily store all three bits of data needed. The format of the table was clear and related the three readings to each other. It also allowed for any reasonable amount of data (with reasonable size) to be stored. This is because the table can keep growing indefinitely without impacting the clarity of the data. This was better than simply writing the data out in a big list as it would not always be clear which age name and magnetism belonged to which alien. Without the table, this data would be difficult to check for errors on the go. With the current format it was easy to check if there were any missed readings or errors as they clearly appeared in the latest table row. This can be seen in figure 4.1.

Website data Gathering – Clearly data should only be gathered when near an alien for reasons outlined above. The implementation for this was having a button pressed manually when data should be gathered (near an alien). This would do all the stages needed to gather and store the data. When practised, this button added a row to the table, gathered all required data, returned this gathered data to the server and placed it into the designated row of the table.

The team found this method the most ideal as it minimises the amount of user input. Since only one button was required to gather the whole alien data, it was also decided to add a key short.

Limitations of Decisions– There were many limitations imposed from both technical issues and design choices. Although the limit on code was eliminated from the technical side, it still made sense to write efficient code to decrease runtime. The table function visible in Figure 4.1 for example takes a significant amount of time to run depending on many environmental factors such as interference from various sources and simply the distance from the signal source. All the data is checked as valid by comparing several readings and checking that they are consistent. If the environment was noisy (high levels of interference) these readings may take time to become consistent enough to pass the functions requirements for valid data which can cause delays of several seconds. This limitation was not possible to overcome via software. It is an inherent issue with the sensitivity of the sensors. Furthermore, the time delay was the trade-off made when the team decided to check the validity of our readings, before being sent to the server.

3.4 Future Possibilities

Time was a major trade off and in future the efficiency of reading data should be the first thing to improve, perhaps via using a faster processor than the metro board. Additionally, the team could work on improving the code efficiency. It is important to recognize that achieving the perfect code is not always possible, the coding is an ongoing process of refinement in any project.
Finally, additional keys or buttons could also be implemented for additional functionality. For example, a button to immediately maximise speed could be used when rapid acceleration was desired.

The code is available at https://github.com/abbyfinka/Soltrax-Rover

4.Design Choices

The final section of the report will discuss the design choices that were made when building the rover and how it was created.

4.1 The Brief Requirements

The requirements suggested that the rover must be manoeuvrable as well as robust. Also, there was a weight limit enforced to access one of the aliens, therefore, the rover must also be lightweight. The chassis will be made of laser cut acrylic and 3D printing will be used to attach external elements. The chassis will need to hold the sensors, the wheels and any other components that will be used whilst maintaining a small light profile.

4.2 Research

The first choice was on the number of wheels used; using four wheels or three. Since the surface of the arena was smooth, the team knew that nothing extravagant was needed.

A four wheeled rover would provide more stability due to the rover being more balanced (*Types of Wheeled Robots* 2015). Moreover, not all wheels need to be motorised, the front two wheels can connect to an axle to become free turning support wheels. The team decided that a simpler design would be just as effective hence it was not looked into any further.

A three wheeled rover required two wheels to be connected to the motors with a free turning support wheel in a triangular arrangement. This would result in a smaller, lightweight design that could still perform as needed. The team decided that a two wheeled design with a castor at the front acting as the third wheel was the best approach. Another third wheel alternative to balance the rover required a screw and plastic dome nut as seen in the EEEbug.

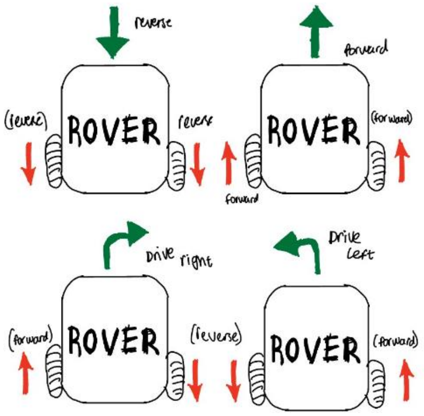


Figure 5.1: Differential Drive Diagram

To control the wheels, the team used the “Differential drive” method. This is where the wheels spin in the same speed and in the same direction (sometimes in opposition when turning) so that the rover spins on its vertical axis. This can be seen in figure 5.1.

Figure 5.2: Old wheels (left) vs new wheels (right)

It was clear to the team that the EEEBug wheels could not be used for this problem. New wheels were chosen that gave the rover sufficient traction and balance while remaining cost effective, the comparison can be seen in Figure 5.3.

Parts of the rover:

Part	Purpose
PCB	The PCB was soldered as part of the EEE labs. Its purpose was power management. It takes electrical power from a battery pack and regulates the voltage so that it behaves more like an ideal voltage source. It also provides circuit protection to reduce the damage arising from faults or errors, and connectors to supply power to other parts of the EEEBug system. There are also connectors and current sense resistors for the main motors(Scott, *Lab Skills* 2023). A H-bridge motor driver is added to the PCB for more advanced motor control.
Battery pack	Uses 4 AA batteries to provide power to the system. This battery pack was part of the EEEBug and it was decided by the team that this would provide enough power for the EEEBug to function.
Arduino	Using Adafruit Metro M0 Microcontroller Module with Adafruit WINC1500 WiFi Shield. This will control the rover, and connect to the website over WiFi to be controlled remotely.
Chassis and mounts	Made with acrylic plastic. Used to hold components whilst designed to be lightweight.
Motors	Used to make the rover move. The yellow motors

Figure 5.3: Table defining chassis parts

5.3 First prototype

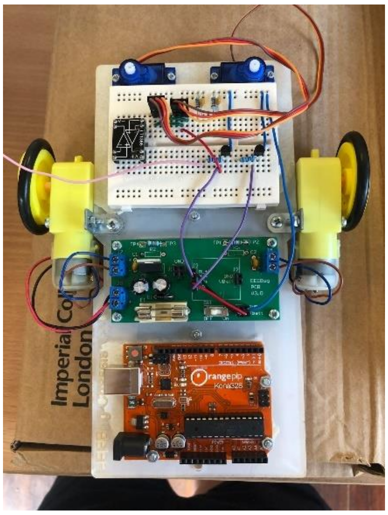


Figure 5.4: Original EEEBug

The team decided to use the original EEEBug as an initial prototype as it was already constructed and included the key elements that were needed in the design.

However, this design had certain limitations. For example, it was quite long, thus manoeuvrability was limited. Additionally, it included space for servo motors that were not needed in this problem.

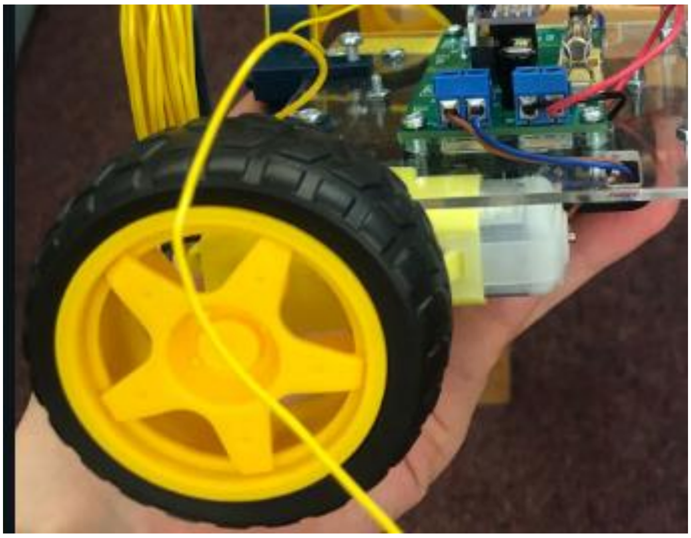


Figure 5.5: Image showing motor positioning

The EEEBug used right angle brackets to secure the motors alongside the chassis. The team felt that this mounting was not very secure. In the next design these mounts would be 3D printed instead. Moreover, to get the rover's sensors as close to the alien as possible, the rover needed to be higher above the ground. The team decided that the motors should be attached to the bottom of the chassis as shown in figure 5.5.

Some aspects of the first prototype were kept the same as the team felt they worked well. For example, mounting the battery pack on the bottom side of the chassis, below the PCB. This kept the battery pack out of the way and allowed the wires to reach the PCB as needed. These parts were also mounted near the motors so that the motors could easily be connected to the PCB. The EEBug also used an M4 machine screw and dome nut to balance the rover, which worked well as a low cost and lightweight alternative to a castor. More on this in section 5.5. As there was limited friction in the arena, this was considered as an option for the final design.

4.4 Improvements

The team then designed a more appropriate model for the rover. The priorities were to decrease the length, and remove unnecessary features, this resulted in a lightweight and manoeuvrable rover.

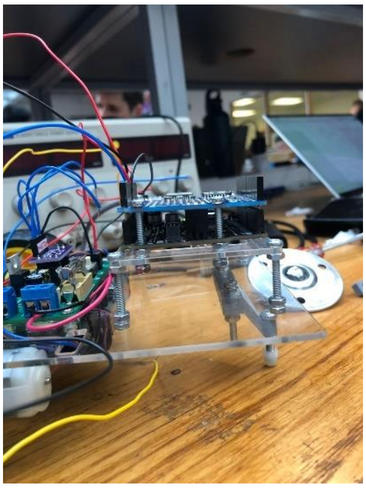


Figure 5.6: Side view of rover chassis design

To make the chassis as small as possible the team created a “top layer”. This was a smaller laser cut piece of acrylic that was mounted with screws above the main chassis, as seen in figure **5.6**. Initially, the plan was to 3D print pieces that could be screwed to the acrylic and would hold the top layer in place. Fortunately, it was found that there was enough height by securing with screws alone. The team decided that the top layer would be located at the back of the rover. This was because the battery pack and the motor mounts had covered a lot of the bottom of the chassis making it hard to find space.

The team decided to attach the Adafruit board to this top layer. This was chosen as it would be accessed the most, so it needed to be on top and available.

The top layer was designed to be around the same size as the Adafruit board. However, the breadboard would not fit under this. Instead, the team decided to make the top layer larger to be able fit around the breadboard.

4.5 Making the rover

The layers of the chassis were laser cut from 2mm clear acrylic. This acrylic type was chosen as it was lightest, yet robust enough to withstand any impacts in the arena. Other parts were made using 3D printing as it was lightweight, and quick to produce. The parts were all designed in Fusion360 as team members had prior experience using it. To secure the 3D printed parts to the chassis, machine screws were used. M3 was chosen as they were readily available in the lab.

The Chassis:

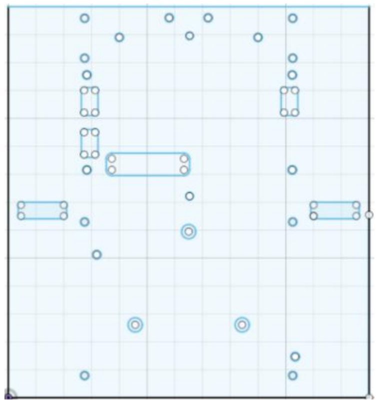


Figure 5.7: Version 1 of chassis 'bottom layer' CAD

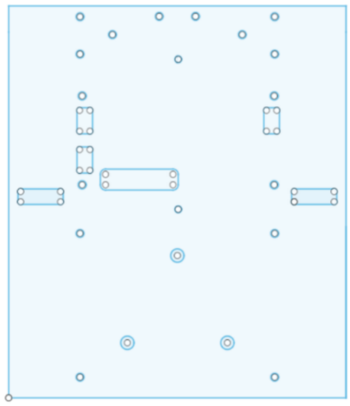


Figure 5.8: Version 2 of chassis 'bottom layer' CAD

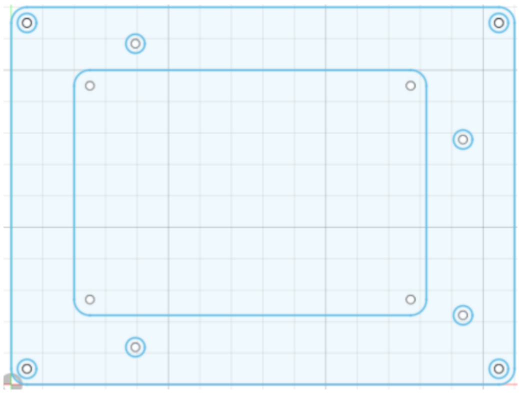


Figure 5.9: Chassis 'top layer' CAD

After deciding how the chassis would be arranged, the team moved to its design. The minimum width of the chassis was limited by the width of the battery pack and the motor mounts. In the interest of minimising chassis size, a width of 130mm and a length of 140mm was chosen. The original design is shown in Figure .5.7. There were a few issues, as the parts were unable to fit as easily as originally intended. Therefore, a new design was made that extended the chassis to a length of 150mm, this allowed for enough space to fit all the required elements and accommodate the castor. This final design can be seen in figure 5.8.

When designing the chassis, it was important to consider that all the holes were in the correct place. Moreover, there must be holes in the chassis that allowed the wires underneath it to pass through and be connected to the circuit on the top. Due to design changes after the final chassis had been printed, a few problems arose. In the interest of time, design decisions were made to work around the existing holes. If there was more time, then the design could have been made more optimal.

When testing the 2mm acrylic, the team found it had some flex. However, it was decided that this was not a problem as it was unlikely that the rover would experience any large external forces.

<u>Motor mounts:</u>

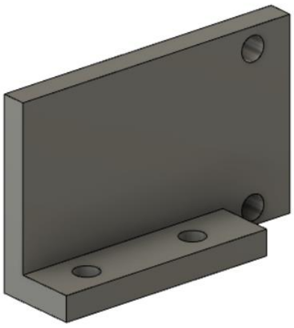


Figure 5.10: Motor mount CAD

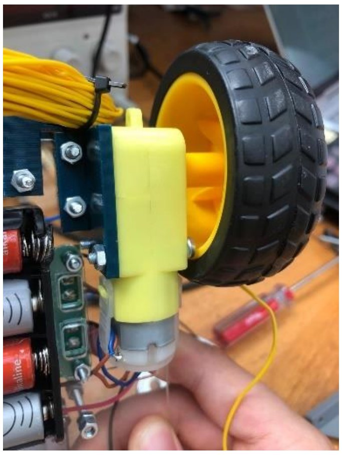


Figure 5.11: Motor mount attached to chassis

The team decided to 3D print an alternative to the existing right-angle brackets. The design was required to hold motors securely underneath the chassis. The final design was a L shape bracket that attaches to the side of the motor and underside of the chassis with screws, as seen in figure 5.10 and 5.11.

This design worked well, the first prototype had to be redesigned slightly to move the hole positions, but was then adjusted and reprinted, along with the mirrored version for the other side. In testing, the team found that the mounts held the motors securely, serving their purpose as required.

Mounting the antenna:

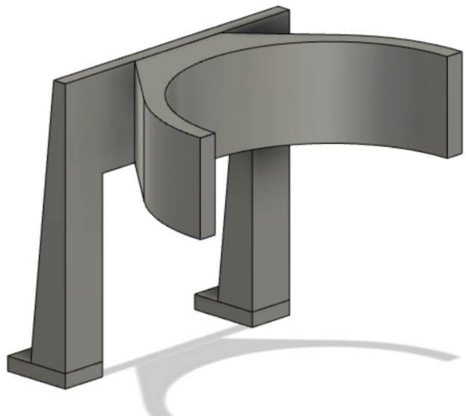


Figure 5.12: Initial antenna mount CAD

The antenna for the radio sensor was 11.5cm in diameter, so posed a challenge to mount in a way that could still pick up the signal from the alien. The initial design was to mount it in a 'halo' design above the head of the alien, using the tallest alien's height as a standard. The initial prototype for the mount can be seen in Figure 5.12.

The problem with this was not all the aliens were the same height, meaning that we would be able to get closer to some aliens than others. The mount would also be largely overhanging, which could cause weight distribution problems and it caused problems when mounting other sensors.

Figure 5.13: Final antenna mount CAD

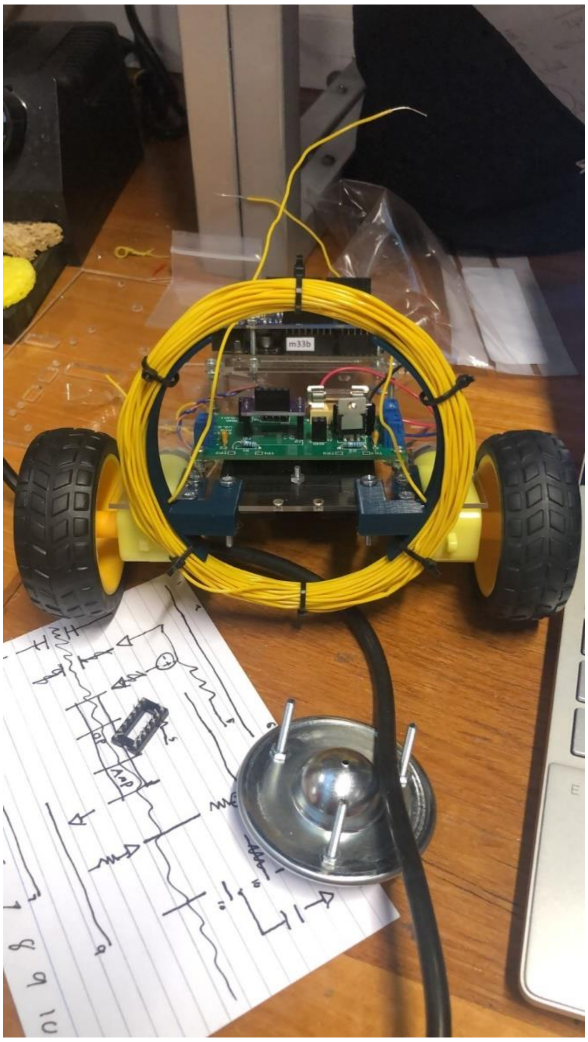


Figure 5.14: Antenna mount attached to chassis

When testing the final iteration of the radio sensor antenna it was found that the sensor worked equally well parallel to the alien. Thus, it was decided by the team that it would be mounted this way, to avoid the issues stated above. Figure 5.13 shows this final design. The mount was designed to grip around the front of the acrylic and be secured on both sides. This prevented any spinning which could have been a problem due to it being connected at one point of contact. The coil was attached with zip ties as shown in figure 5.14 zip ties were chosen as they were readily available and held the coil securely.

This design worked well, and it was found in testing that it had minimal effect on the output of the sensor.

<u>Mounting the other sensors:</u>

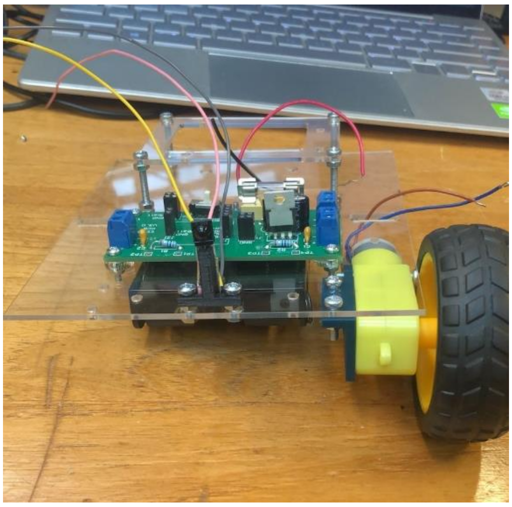


Figure 5.15: Initial IR receiver mount attached to chassis

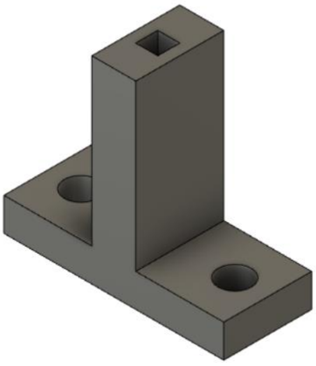


Figure 5.16: Initial IR receiver mount CAD

The initial plan to mount the IR and Hall Effect sensor was to 3D print mounts. The first design can be seen in figure 5.16. This worked well and could be easily attached to the chassis as seen in figure 5.15. This provided a good solution for the IR sensor, however there was no space for the Hall Effect sensor, and as printing times had increased in the lab, the team looked for an alternative solution.

Figure 5.17: Mounting of IR and Hall Effect sensors

Therefore, it was decided to use a small part of a stripboard, attached with screws to the chassis. The sensors would be securely soldered onto the board along with wires that could be connected to the overall circuit. This was a good solution and secured the sensors well. This stripboard could then be moved about and mounted in the most optimal position to get the best range. This can be seen in figure 5.17.

<u>The third wheel:</u>

Figure 5.18: Ball Caster

For the third wheel, the team initially decided to use a ball castor. However, when researching ball castors from provided suppliers, smaller components were hard to find and were intended for industrial use. The team ordered a ball castor pictured in Figure 5.18. This appeared to be an optimal solution, however it was 61mm across in diameter and weighed 0.087kg. It was decided by the team that it was too bulky for the purpose and that it shouldn't be used.

It was decided to revert to the support used by the EEEBug, a plastic dome nut attached to a M4 bolt, until a suitable replacement could be sourced. The team believed that friction wouldn't cause a large problem as the arena is smooth and the dome nut provides the stability needed by the rover. This was confirmed in testing.

Figure 5.19: Initial castor mount CAD

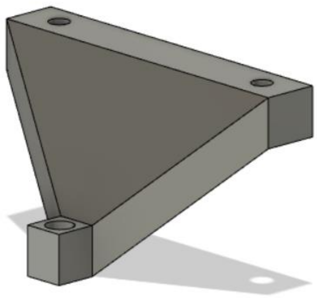


Figure 5.20: Castor mount CAD

In order to attach this to the rover a mount had to be 3D printed. This was a simple design that attached to the original castor holes, and positioned the bolt at the correct position to keep the rover level. The first iteration can be seen in figure 5.19. This design was printed with minimal material to reduce printing time, however it was found to be too weak and broke when attached. The second version was reinforced and can be seen in Figure 5.20.

The team then managed to source an appropriately sized orientable wheel. It weighed around 0.055 KG, with a height of 46mm.

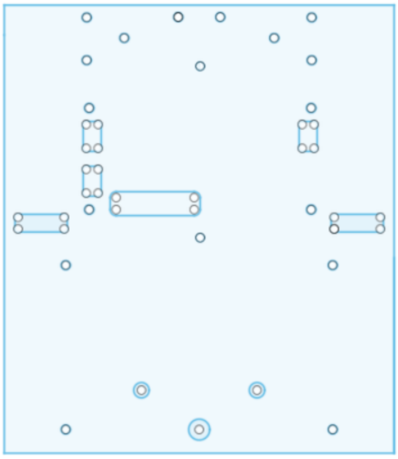


Figure 5.21: Final bottom layer chassis design

In order to attach it to the chassis, an M6 screw and bolt was needed. New holes to match the new wheel were added to the back of the chassis. This can be seen in Figure 5.21. By adding this castor, it would ensure a minimum amount of friction and would keep the rover level whilst also providing support to manoeuvrability.

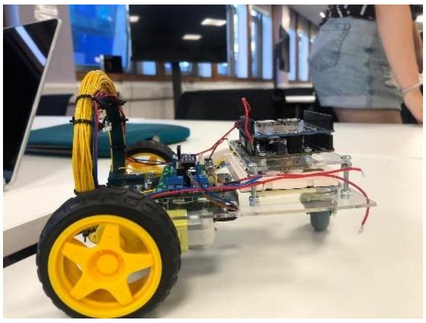


Figure 5.22: Castor attached to chassis

The engineering diagrams for these designs can be seen below.

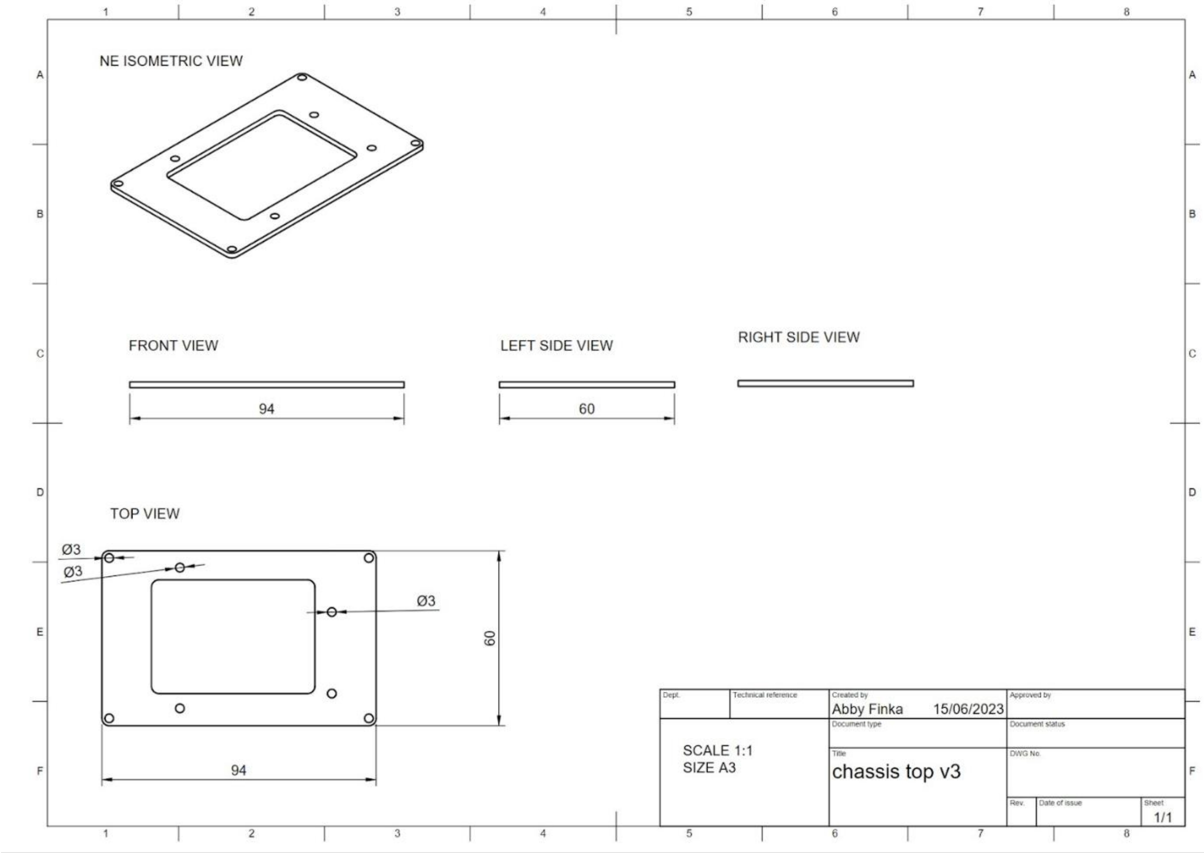


Figure 5.23: 'Top layer' engineering diagram

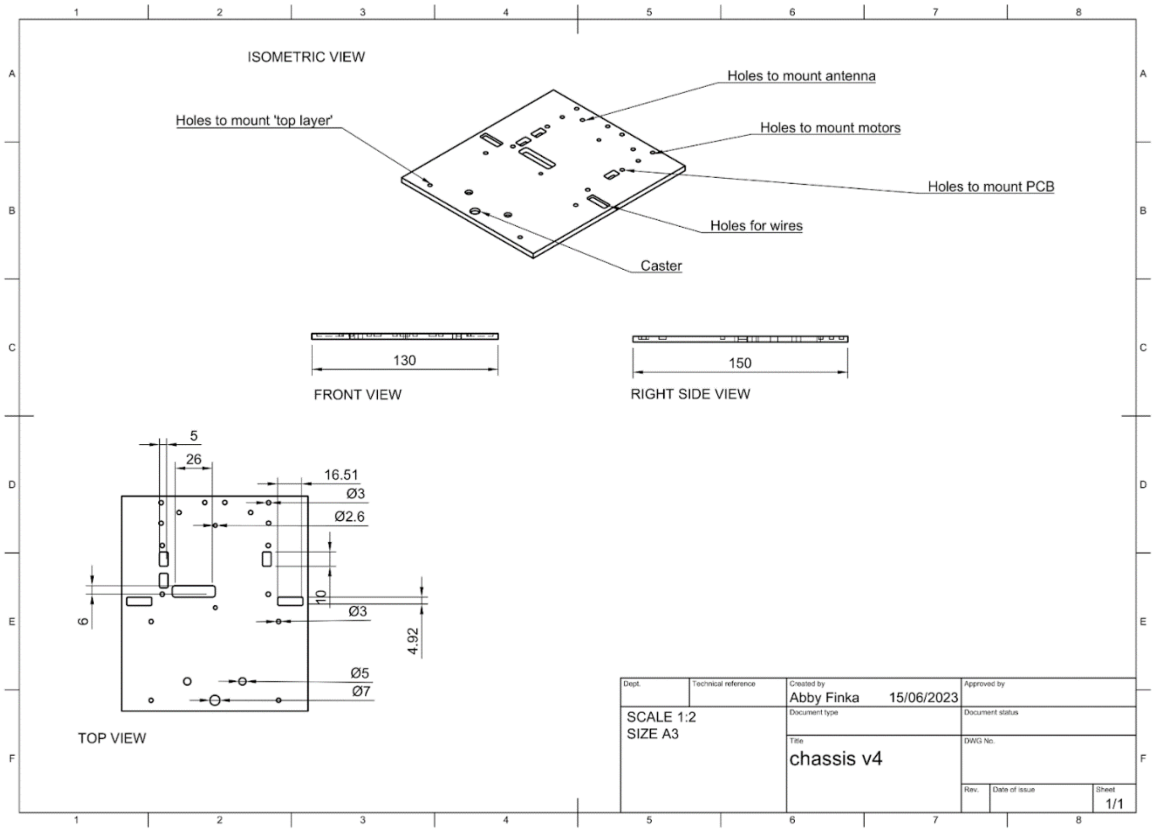


Figure 5.24: 'Bottom layer' engineering diagram

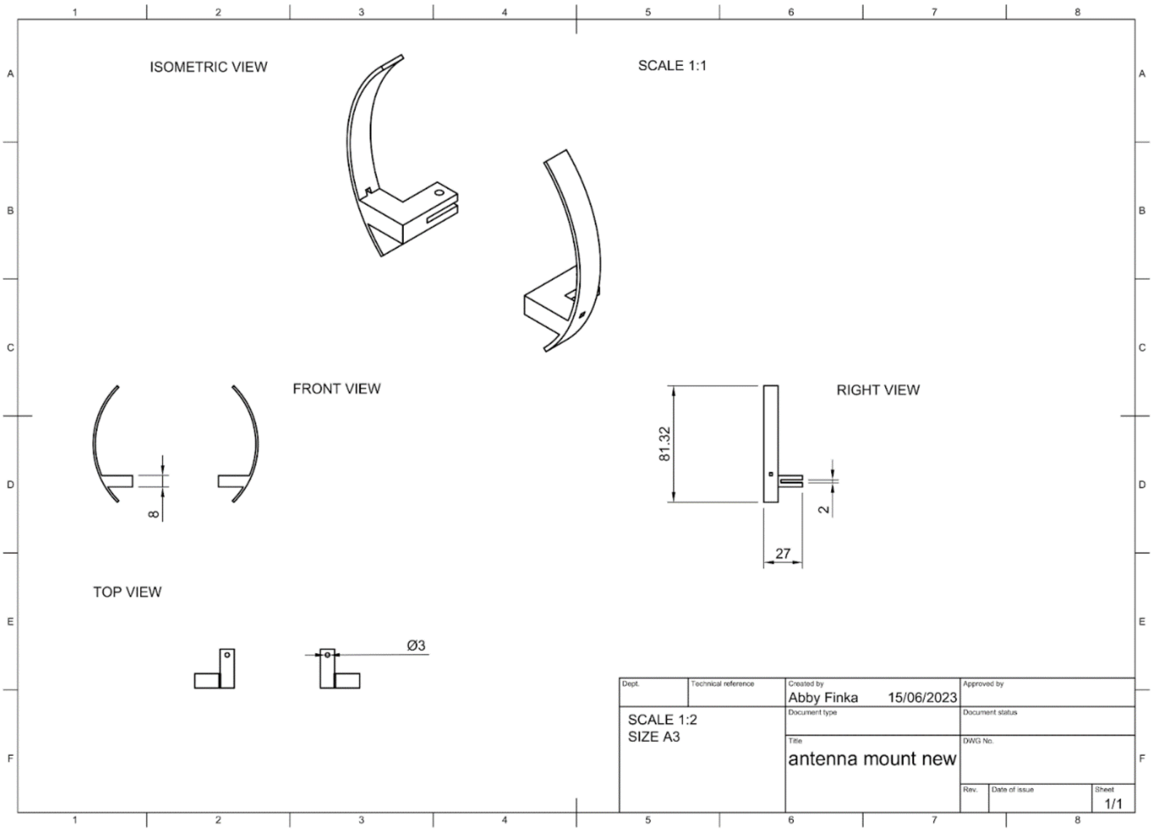


Figure 2.25: Antenna mount engineering diagram

Conclusion

In conclusion, team Soltrax were able to build and test a successful rover. Evidently, all three alien characteristics can be received.
First sensor: the alien's name, which was encoded within a radio signal, was received, then demodulated, and finally decoded.
Second sensor: the alien's age was found by calculating the period of their optical pulse detected using an infrared sensor.
Third sensor: the alien's magnetic polarity was determined using a hall effect sensor.
The name, age and magnetic polarity of all aliens were displayed on the website's interface.

Movement: with the aid of lightweight wheels, a castor and two motors, the rover moves swiftly and in a controlled manner. This is important as the range of the sensors is not large so fine control is necessary when approaching the alien.

Each design choice was made to ensure the rover met all the requirements. With an overall expenditure of £43.21, the rover was within the budget of £60.

Furthermore, its compact lightweight structure ensured the rover was well below the weight limit.

In the future we would acquire better sensors to increase the range of our data gathering especially regarding the magnetic sensor which proved to be the limiting factor in our data gathering range. However, this is an unfortunate property innate to the sensor so would require a completely different sensor and method for detecting the magnetic field such as collecting the data while moving.

Overall, the success of the project was a result of good teamwork and time management. The team thoroughly enjoyed the task they were set and completed it in a creative yet simplistic and efficient manner.

Appendix

1. Budget

This section will outline how the team spent the allocated funds and why each purchase was made, all with the aim of being as cost effective as possible. There were many parts that the team had to order but it was important to stay within the £60 limit so whenever possible the cheaper option was chosen. However sometimes a more expensive part was needed to fit our purposes such as ordering a more expensive infrared detector rather than use the free phototransistors to increase our range and reliability.

Purchases

two Hall effect sensors: £2 total cost
two Infrared sensors: £2.24 total cost
three OP amps: £5.67 total cost
four Stripboards: £0.96
one 1.144km copper wire: £10.80
three Castors: £11.50
one Acrylic sheet: £8.07
five Tape pads: £0.15
four 8-pin Solder socket: £1.64
Assorted Screws/Nuts: £0.18

Total expenditure was £43.21.
This was within our budget with over a quarter left spare. At the start the team agreed to split the budget into £45 of money to be spent freely and £15 to be withheld for emergency issues. While there were some issues such as Castors not working as intended requiring replacements or Op amps breaking during

soldering, we still managed to stay below our £45 free spend budget. Most of the money was well spent and can be seen on our final Rover, notable exceptions to this are the wire and stripboards as these were not fit for the team's purposes upon testing. The money spent on sensors and acrylic was vital as although pricey without them the rover would not be able to function and having backups of these key components was vital in case of any problems during testing.

2. Product Design Specification

Version: 02 Date: 15/06/2023

1. Performance

The rover should be able to navigate the terrain of a remote planet and survey the alien creatures that live there. It should be able to capture the following alien characteristics:

a. Name - transmitted as radio waves.

b. Age - transmitted as infrared radiation.

c. Magnetic field - transmitted via the detection and analysis of a magnetic field.

2. Environment:

The rover should have a high mobility to avoid obstacles as well as traverse the flat environment with speed and efficiency.

3. Life in Service:

The rover should remain operational within the time of the project.

4. Maintenance:

This element does not appear to apply to our product as it is designed for a single use purpose.

5. Target Product Cost:

This product will not be on the market, the target product cost is not specified.

6. Competition:

This product will not be on the market, competition is not relevant.

7. Shipping:

This element does not apply to our product as it will be manufactured and used in the lab.

8. Packing:

This element does not apply to our product as it will be manufactured and used in the lab.

9. Quantity:

The product is made one-off, only one unit will be produced.

10. Manufacturing Facilities:

The product will be assembled in the lab, it will not require outsourcing external manufacturing facilities.

11. Size:

The rover will be small so that it maintains a light profile. This ensures high mobility and speed.

12. Weight:

The rover's weight must be kept under 1kg to maintain effective communication with the aliens. Once the weight exceeds 1kg, the aliens in the environment became shy, and will stop communicating. Adhering to the weight restriction will ensure the rover captures all the aliens' characteristics.

13. Aesthetics:

The product prioritizes functionality over aesthetics, so this is not relevant.

14. Appearance and Finish:

The product prioritised functionality over aesthetics so this is not relevant.

15. Materials:

Acrylic, 3D printer filament and Copper wire were all used to make the rover chassis and other components such as the inductor.

16. Product Life Span:

This is not relevant as the product is not for sale.

17. Standards and Specifications:

The rover is up to the standards laid out by the specification and passes all relevant requirements.

18. Ergonomics:

Ergonomic design was used when designing the website for ease of use but is not relevant to the rover as it is intended for remote operation.

19. Customer:

The rover is not for sale, so this is not relevant.

20. Quality and Reliability:

The rover is reliable enough for the required purpose, but the quality is not relevant beyond the rover working as intended as it is not for sale.

21. Shelf Life:

This is not relevant as the rover is not for sale.

22. Processes:

3D printing, laser cutting, soldering and breadboard circuit design were all used and incredibly helpful in actualising the rover.

23. Time Scale:

The team has worked to the given timeframe very well and accomplished everything necessary before the deadline.

24. Testing:

Testing has been done constantly throughout designing the rover and was vital to the design process allowing rapid design changes to be implemented where necessary.

25. Safety:

Safety has been respected throughout the project. Fuses are used to prevent large current draw and prevent fires. Also, minimal power draw is used so there are very low levels of risk.

26. Company Constraints:

There is no relevant company and such no constraints other than requests from college regarding privacy of code repositories which have all been complied with.

27. Market Constraints:

The rover is not to be sold so this is not relevant.

28. Patents, Literature and Product Data:

The team has respected all patents and licences involved in the product such as the software licence for some of the code used, also as it is not for sale there is no Product data.

29. Political and Social Implications:

There are no likely political or social implications from the rover as it is quite mundane.

30. Legal:

There is no relevance for Legal issues as the rover is not breaking any laws and there are no legal challenges with its use.

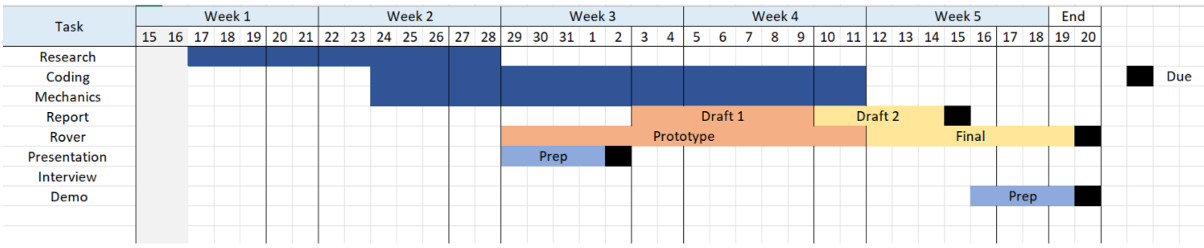
31. Installation:

The rover is not to be installed or permanently fixed to anything, so this is not relevant.

32. Documentation:

The report documents the design process for the rover and lists any relevant information pertaining to it.

3. Gantt Chart



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