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**Mars Landing Simulation with Arduino**

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Final-Year Project

PJE40

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# Abstract

# Acknowledgements

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# 1. Introduction

## 1.1. Background

This research project focuses on simulating the Entry, Descent, and Landing (EDL) process of a Mars landing using an Arduino microcontroller, with the aim of identifying potential errors in the EDL process. The EDL process is the final and most critical stage of a spacecraft’s journey to a planetary surface, and errors in this phase can have catastrophic consequences. To address this challenge, the study utilizes an affordable and accessible technology, the Arduino microcontroller, to collect data during the EDL process. The data collected from the Arduino will be analysed using Python scripts to identify any potential errors that may occur during the landing process. By combining the strengths of both technologies, this study aims to provide valuable insights into the detection and prevention of EDL errors, potentially contributing to the overall success of future Mars missions.

## 1.2. Project Aim and Objectives

The aim of this research project is to identify errors during the Entry, Descent, and Landing (EDL) process of a spacecraft using an Arduino microcontroller. The EDL process is a critical and complex phase of space missions, and identifying potential errors during this stage can significantly improve the chances of mission success. The use of an Arduino microcontroller provides an affordable and accessible platform for simulating the EDL process and collecting data on critical parameters.

To achieve the aim of the project, the following objectives will be pursued:

* To understand the state-of-the-art development in space exploration and Arduino, by reviewing relevant literature and research on the EDL process, space exploration, and the use of Arduino microcontrollers in space applications. This objective will provide a comprehensive understanding of the current state of research and technology in the field, and guide the development of the simulation model and data collection methods.

* To develop a simulation model of the EDL process using the Arduino platform. This will involve programming the Arduino to simulate the various stages of the EDL process, including entry into the Martian atmosphere, parachute deployment, and landing on the Martian surface. The simulation model will collect data on critical parameters such as altitude, velocity, and acceleration.

* To collect data on critical parameters during the EDL process. This will involve running the simulation model on the Arduino and recording data on various parameters using sensors and other data collection tools. The data collected will provide insights into the performance of the simulation model and the accuracy of the data collected.

* To analyse the collected data to identify errors in the EDL process. This will involve processing the collected data using statistical and data analysis tools to identify patterns and anomalies that may indicate errors. The analysis of the data will provide insights into potential errors during the EDL process.

* To evaluate the effectiveness of the Arduino platform in simulating the EDL process and identifying errors. This will involve comparing the results of the simulation model with actual data from previous Mars missions and evaluating the accuracy and reliability of the simulation. The evaluation will provide insights into the potential of the Arduino platform for use in space applications.

By achieving these objectives, this study aims to provide valuable insights into the use of Arduino microcontrollers for simulating the EDL process and identifying errors. The findings of this research could potentially contribute to the success of future Mars missions and advance our understanding of space exploration.

## 1.3. Project Constraints

The project is being conducted as a final year project for a computer science degree, and therefore there may be limitations in the researcher's expertise in physics and mathematics. This may impact their ability to conduct a detailed analysis of the data and write complex mathematical equations for the trajectory of the model during the EDL process. As a result, the scope of the research may be narrower, and the accuracy of the results may be affected.

Furthermore, while Arduino is a suitable microcontroller for a university final-year project, it may not be the best tool available in the industry. The limitations of the Arduino may impact the accuracy of the simulation and may affect the outcomes of the study.

Lastly, it is important to acknowledge that simulating the conditions on Mars is difficult, and it may not be possible to achieve perfect replication. While every effort will be made to replicate the conditions as accurately as possible, the limitations in simulating the conditions on Mars may impact the accuracy of the data collected and the results of the study.

## 1.4. Project Deliverables

The primary goal of this research project is to explore the functionality of the Arduino microcontroller in simulating the EDL process for a spacecraft landing on Mars. To achieve this goal, several deliverables will be produced:

Firstly, a working Arduino-based simulation model of the EDL process will be constructed, which will include the necessary hardware and software components. This simulation model will be designed to accurately replicate the conditions and challenges of a real Mars landing scenario. This tool will be more affordable and accessible for testing Mars landing systems, particularly for academic institutions.

Secondly, a comprehensive analysis of the functionality of the Arduino microcontroller in simulating the EDL process will be conducted. This analysis will consider the strengths and limitations of this approach, as well as potential areas for improvement.

Thirdly, a detailed report documenting the research methodology, experimental setup, results, and conclusions will be produced. This report will provide a comprehensive overview of the project and its findings.

Finally, a set of recommendations for improving the simulation model will be developed. These recommendations may include modifications to the Arduino hardware and software, as well as suggestions for further research in this area.

Together, these deliverables will provide a comprehensive evaluation of the Arduino-based simulation model for the EDL process and its potential for improving the efficiency and accuracy of spacecraft landing on Mars.

## 1.5. Project Significance

## 1.6. Project Structure

# 2. Literature Review

## 2.1. Overview

This section provides an overview of the importance of space exploration and the role of simulations in understanding the Entry, Descent, and Landing (EDL) process for Mars landings. It begins by exploring existing research on space and its significance for humans, followed by a discussion of the tools and research methods needed for simulating EDL.

The section then focuses on past Mars missions and their EDL processes, as well as the future of EDL in space exploration. In addition, it discusses the history and use of Arduino microcontrollers and identifies the commonly used sensors in their applications.

Finally, this section highlights the research gap in the simulations of Mars landings using Arduino microcontrollers, indicating the need for more accessible and affordable tools to test Mars landing systems, especially for smaller organizations and academic institutions.

## 2.2. Space Exploration Through the Years

Space exploration has concerned people since ancient times. However, in the early 20th century, scientists started constructing the first liquid-fuelled rockets. Then World War II paved the way for space exploration by completely changing the field of rocket development, with almost every country taking part in the war researching rocket technology (Launius, 2018). In 1942, Nazi Germany completed the first flight of an artificial object to leave the atmosphere. Then with the end of the war and Germany’s defeat, more than 100 scientists from the German rocket program were recruited for the USA’s program (Kennedy, 2007). That was when both the USA and the Soviet Union started to put satellites into earth’s orbit, humans in outer space and even on the moon’s surface, with the Soviet Union achieving to create functional satellites and put humans in space and the USA sending humans on the Moon.

Undoubtedly, space research plays a significant role in warfare, and its most notable advancements have been achieved in the context of military conflicts. This can be attributed to the potential of space-related technologies, such as rockets and satellites, to serve as crucial defence instruments. The exigencies of war have spurred governments to allocate substantial resources to space research, far exceeding the levels of investment during times of peace. This is demonstrated by the significant funding provided by the US government to NASA for space exploration. During the Space Race era, the budget allocated for space research and exploration had surged to an approximate value of 60 billion dollars for specific years. However, subsequent to the conclusion of the Cold War, the average annual budget for space-related programs has been in the range of 20-30 billion dollars (Society, n.d.).

In the following decades, space exploration continued to advance with the launch of NASA's Space Shuttle program in 1981 and the deployment of the International Space Station in 1998 (Loff, 2017). Numerous robotic missions have been dispatched to investigate the solar system, including the Viking missions aimed at Mars, the Voyager missions directed towards the outer planets, and the rover missions targeted at Mars (NASA, n.d.-a).

Currently, space exploration efforts are focused on sending humans to Mars and beyond, with NASA and SpaceX leading the way. NASA's Artemis program aims to land the first woman and next man on the Moon by 2024 and establish sustainable lunar exploration by the end of the decade. SpaceX's Starship spacecraft is being developed for missions to Mars and other destinations (Smith et al., 2020; SpaceX, 2020)

Overall, the history of space exploration is characterised by a constant drive to push the boundaries of human knowledge and capabilities. This drive is set to continue in the coming years.

## 2.3. Mars Exploration

Mars is one of the most interesting planets in our solar system and has captured humans’ attention since they first observed it. This red-looking object in the sky was first observed with telescopes in the late 19th century, revealing patterns and landforms that made scientists believe the existence of a Martian civilisation which came out to be untrue; however, it is known that 3.5 billion years ago, the planet might have been liveable just like the earth (Drake, 2020).

Mars is one of the closest planets to Earth in our solar system and the most similar. That is why more than 40 explorations have occurred on the red planet since the 1960s. The first mission to Mars was the Soviet Union's Mars 1 in 1962, but it failed before it reached the planet. The first successful mission was NASA's Mariner 4 in 1965, which returned the first close-up images of the Martian surface. Since then, multiple missions have been conducted by NASA, the Soviet Union/Russia, the European Space Agency (ESA), and India. These missions have included orbiters, landers, and rovers and have greatly expanded our understanding of Mars. Orbiters have played an essential role in Mars exploration by providing detailed information about the planet's surface and atmosphere. These spacecraft have mapped the surface, studied the planet's geology, and searched for evidence of water (Carr, 2007). Mars’ land area is very close to earth’s, and water has been found in ice form at the planet's poles; however, the climate is very inhospitable since 96% of its thin atmosphere is carbon dioxide (Jet Propulsion Laboratory, 2020).

One of Mars exploration's main goals is searching for signs of the past or present life. The Viking missions in the 1970s were the first missions to search for life on Mars specifically, but they were inconclusive. However, recent missions such as the Mars Exploration Rovers (Spirit and Opportunity) and the Mars Science Laboratory (Curiosity) have provided strong evidence for a past habitable environment on Mars.

### 2.3.1. Entry, Descent, Landing (EDL)

The EDL phase of a space mission is crucial for the success of a mission, particularly when it comes to Mars exploration. The EDL system must enable a spacecraft to land safely on the planet's surface and deploy its scientific instruments without damage. There are several vital reasons why EDL is so important for Mars exploration, as well as several challenges that must be overcome in order to make it successful.

One of the primary reasons EDL is so important is that Mars has a thin atmosphere, making it difficult to slow down a spacecraft during its descent. This means that EDL systems must use techniques, such as heat shields, parachutes, and retro-rockets, to decelerate the spacecraft and land it safely on the planet's surface. The EDL system must also be able to operate autonomously, as there is a significant time delay between Earth and Mars, which makes it difficult to control the spacecraft in real-time. (Sostaric, 2010)

Another critical challenge of EDL for Mars missions is the need to land in a precise location. This is particularly important for rovers and other scientific instruments, which must be deployed in areas where they can conduct meaningful scientific research. The EDL system must be able to accurately target the landing site, despite the planet's uneven terrain and unpredictable weather patterns. (Braun & Manning, 2007).

Overall, EDL is a critical component of any Mars mission, and its success depends on overcoming numerous technical, logistical, and operational challenges. However, the potential benefits of EDL for Mars exploration are significant, and continued research and development in this area will be essential for enabling future exploration of the Red Planet.

#### 2.3.1.1. Viking 1 & Viking 2 (1976)

The Viking 1 and 2 landers were the first spacecraft to land on the Martian surface successfully. These identical landers provided the first close-up images and measurements of the Martian environment, as well as conducting experiments to search for signs of life on the planet. The landers used a parachute and retrorocket system for descent and landing, which proved to be a reliable and effective method for landing on Mars (Laboratory, 1975).

#### 2.3.1.2. Mars Pathfinder (1996)

The Mars Pathfinder spacecraft, which was also referred to as the Mars Surface Rover, was the first human-made object to successfully land on Mars. NASA launched the mission in 1996 with the objective of demonstrating a cost-effective approach for delivering scientific instruments to the Martian surface. The Entry, Descent, and Landing (EDL) process employed the use of airbags as a means of cushioning the impact and allowing the lander to come to a stop on the Martian surface. (Golombek et al., 1997). Overall the mission was a success.

2.3.1.3. Spirit Rover & Opportunity Rover (2004)

The Spirit and Opportunity rovers were the first robotic missions to successfully land on Mars using airbags. These missions provided unprecedented insights into the geology and history of Mars, as well as the planet's potential to support life. The rovers carried a suite of scientific instruments to study the Martian environment and also performed extensive exploration of the planet's surface, greatly expanding our knowledge of the Red Planet (Deshmukh & Karlgaard, 2021).

#### 2.3.1.4. Phoenix (2007)

The Phoenix mission, launched by NASA in 2007 and successfully landed in 2008, aimed to study the history of water on Mars by studying the soil and ice in the Martian Arctic. The mission used a combination of a parachute and rocket engines to slow the spacecraft down before landing. The EDL process allowed the Phoenix lander to reach the Martian surface and operate for about 5 months, gathering valuable data and images. However, the lander stopped responding due to the severe cold after 5 months and the method was not used again for any similar mission (Oberhettinger et al., 2011).

#### 2.3.1.5. Mars Science Laboratory (2011)

The Mars Science Laboratory (MSL) mission, also known as the Curiosity mission, was launched by NASA in 2011. It aimed to explore and study the Gale Crater to determine if the area has ever had the potential to support microbial life and to study the planet's climate and geology. The EDL process, known as the "Sky Crane" manoeuvre, used a descent stage equipped with rocket engines to lower the rover to the surface on a tether, allowing the rover to land in a more precise location. The mission has been successful, with the rover still active and continues to explore the Martian surface, sending valuable data and images back to Earth. This method is considered as a more advanced and precise way of landing on Mars and has been used in other missions such as Perseverance (Steltzner et al., 2006).

2.3.1.6. InSight Lander (2018)

The Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) lander successfully landed on the surface of Mars on November 2018. Themission was designed to study the interior of Mars, using a suite of instruments to measure seismic activity and heat flow on the planet. The lander used retrorockets for a precise landing and also deployed a suite of scientific instruments, including a seismometer and a heat flow probe. The mission has already made important discoveries, including detecting the first Marsquakes and providing new insights into the structure and evolution of the Red Planet (Maddock et al., 2021).

#### 2.3.1.7. Perseverance (2020)

The Perseverance mission, also known as the Mars 2020 mission, was launched by NASA in July 2020. It aims to investigate the past habitability of Mars, search for signs of ancient microbial life, and collect rock and soil samples for future return to Earth. The mission carries a helicopter called Ingenuity, the first aircraft to fly on another planet. The EDL process for Perseverance mission was similar to the one used in the previous MSL mission, known as the "Sky Crane" manoeuvre. This method allows for a more precise landing location and can be used for larger landers. The mission landed successfully on February 18, 2021, and has been sending valuable data and images ever since (Farley et al., 2020).

2.3.2. Future of Entry, Descent, Landing Systems

Over the years, numerous entry, descent, and landing (EDL) methods have been developed for Mars missions, each aiming to improve safety, speed, cost-effectiveness, and reliability. Recently, SpaceX proposed a new EDL method for their Starship spacecraft, which is planned for use in Mars landings. The proposed method involves reorienting the spacecraft horizontally before landing, using the "Skydiver" technique, with the aim of reducing fuel consumption and improving mission efficiency. The Starship will also utilize retractable landing legs to provide a stable landing platform and absorb impact upon touchdown, thereby minimizing the risk of damage to the spacecraft or payload. Overall, the proposed EDL method for the Starship includes several innovative features, including the use of aerodynamic lift, Raptor engines, and advanced entry guidance technology, which aim to make the landing process safer, more efficient, and more cost-effective (SpaceX, 2020).

## 2.4. Arduino

Arduino is an Italy-based company that designs and sells circuit boards and makes microcontrollers easy to use. They call these circuit boards Arduinos, and there are many different types of Arduinos (Badamasi, 2014). For example, simple Arduino boards like the Arduino Uno are cheap and good enough for more projects. Arduino Uno can be used to control motors, lighting, and cameras or even build a simple robot. Then there are more Arduinos with more powerful processors, Wi-Fi, Ethernet, and more. The company Arduino open sources all of its hardware designs, which means that countless third-party companies build their own Arduino hardware designs. Although they cannot be called Arduino, they functionally are the same. The Arduino “shields” circuit boards also plug into the main Arduino circuit board and add more functionalities. For example, Adafruits is a small controller shield that controls motors and servos without having to design motor control circuitry if it is programmed accordingly. One more very known shield is Sparkfun which can turn an Arduino into a simple mobile phone or an MP3 player (Igloe et al., 2014). There are variations of Arduino with similar and different functionality.

### 2.4.1. Arduino Mega 2560

The purpose of this research project is to simulate a spacecraft's Entry, Descent, and Landing (EDL) process on Mars using an Arduino. The Arduino model selected for this project is the Mega 2560, which is a microcontroller board equipped with the ATMega2560 chip. The Mega 2560 is capable of supporting large-scale projects, boasting 54 input/output (I/O) pins, 15 analogue inputs, and four serial ports. It operates at 5V, with 256 KB of ROM, 4KB of EEPROM, and 8 KB of RAM. While the Mega 2560 has limited RAM compared to regular computers and may not be suitable for industrial applications (Badamasi, 2014; Tazi et al., 2016), it is the ideal device for this project due to its simplicity and ability to execute all aspects of the EDL process under consideration.

### 2.4.2. Arduino Shields and Parts

#### 2.4.2.1. Light Sensor

The light sensor will be used for light collection. NASA uses three ways to power its spacecraft: solar energy, chemical energy (batteries), and nuclear energy (unstable atoms). Using unstable atoms is impossible because it is dangerous and challenging to implement such a technique for this project. Then there is the option of batteries, which is a possible solution, but for this project, solar power is the best way to represent energy collection (NASA, n.d.). That is why a light sensor will be used. The sensor will collect light and measure how much power it has.

#### 2.4.*2*.2. LED and RGB lights

Multiple LED and RGB lights will be used for the EDL phases in different colours. Moreover, messages will be sent back to Earth with colour, just like NASA’s Deep Space Network (DSN), where the data are converted to binary code and transmitted as light back to Earth, where they are read from giant satellite dishes.

#### 2.4.*2*.3. Ultrasonic Sensor Shield

Ultrasonic sensor module HC-SR04 is the shield that will measure the distance to the ground. The output of this measurement will determine what steps are needed to be taken depending on the length. For example, the LED lights' colour will change for different distances.

#### 2.4.2.4. Passive Buzzer

A passive buzzer will send messages in morse code back to earth with information about the mission’s progress, such as the start of the EDL or after the successful landing.

## 2.5. Gaps in Literature

While numerous simulation tools are available for the development and testing of spacecraft and their subsystems, there is a lack of research on the use of Arduino microcontrollers for simulating the landing of spacecraft on Mars. Arduino microcontrollers are one of the popular options in the field of aerospace engineering due to their versatility, affordability, and ease of use. However, they have not yet been extensively utilized in the development of Mars landing simulations.

Simulations are essential for testing the functionality and safety of spacecraft landing systems. These simulations provide valuable insight into the performance of the systems and help identify potential issues that may arise during the actual landing. Currently, most Mars landing simulations are developed using high-end simulation software and hardware, which can be costly and require significant computational resources. This limits the accessibility of such simulations to smaller organizations and academic institutions.

The use of Arduino microcontrollers for Mars landing simulations has several potential advantages. First, they are significantly more affordable than high-end simulation software and hardware, making them more accessible to smaller organizations and academic institutions. Second, they can be easily programmed and modified to simulate various scenarios and test different landing strategies. Finally, Arduino microcontrollers can be used to create realistic physical interfaces, such as control panels, that can be used to train astronauts and mission controllers.

This project aims to fill this gap in the literature by developing a Mars landing simulation using Arduino microcontrollers. By doing so, this project will provide a more accessible and affordable tool for testing Mars landing systems, especially for smaller organizations and academic institutions. Additionally, this project will contribute to the growing body of research on the use of Arduino microcontrollers in aerospace engineering, specifically in the area of Mars landing simulations.

## 2.6. Summary

The literature reviewed in this study highlights the significant advancements made in the field of space exploration and the importance of Mars landing simulations in achieving successful missions. The research gap identified in the existing literature is the lack of accessible and affordable tools for testing Mars landing systems, especially for smaller organizations and academic institutions. The use of Arduino microcontrollers is a unique approach to simulating Mars Landing systems that has not been explored in previous research . The results of this study have the potential to inform future research in this area and provide valuable insights for organisations working on Mars missions.

# 3. Project Management

## 3.1 Overview

## 3.2. Gantt Chart

## 3.3 CRISP DM

|  |  |  |
| --- | --- | --- |
| **Phase** | **CRISP DM** | **Corresponding Chapter** |
| 1 | Business Understanding | Introduction – LitRev |
| 2 | Data Understanding | Methodology |
| 3 | Data Preparation | Methodology |
| 4 | Modelling | Methodology – Results |
| 5 | Evaluation | Evaluation |
| 6 | Deployment | Evaluation - Conclusion |

## 3.4 Summary

# 4. Methodology

## 4.1. Overview

This section of the research paper outlines the methodology employed in the Mars Landing Simulation with Arduino project. It details the development of the Arduino model, data collection, and data analysis. The Arduino model is designed to simulate the Entry, Descent, and Landing (EDL) stage of a spacecraft on Mars, using various sensors and components to obtain data and represent different stages of the EDL process. The data collected from the Arduino model is subsequently analysed using Python to calculate critical information about the spacecraft's condition during the simulation.

## 4.2. Development of The Arduino Model

### 4.2.1. Components and Setup

The Arduino model consists of several components that work together to simulate the EDL stage of a Mars mission. These components include the HC-SR04 (Fig. 1) ultrasonic sensor module, an RGB Light (Fig. 3), a GY-521 (Fig. 2) accelerometer module, an active buzzer (Fig. 4), and a photoresistor (Fig. 5).

The HC-SR04 ultrasonic sensor measures the distance between the Arduino model and the ground (Mars surface) during the descent. The RGB LED indicates the different stages of the EDL process based on the distance from the ground, with each stage corresponding to a specific distance and colour. This is the list of the EDL stages the distances used to replicate real-life data given by NASA and the colours indicated for each stage:

1. Parachute Deploy (200cm, BLUE)

2. Heat Shield Separation (170cm, GREEN)

3. Radar Lock (123cm,  YELLOW)

4. Terrain Relative (62cm, WHITE)

5. Backshell Separation (33cm, RED)

6. Rover Separation (10cm, iterate through colours.

The GY-521 accelerometer module calculates the acceleration in the X, Y, and Z axes, as well as the model’s temperature. An active buzzer is included to indicate when the model has landed. Finally, a photoresistor measures light intensity, which calculates the amount of solar energy collected during the simulation.

Diagram

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*Figure 1 HC-SR04           Figure 2 GY-521*

A shadow of a person

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*Figure 3 RGB Light           Figure 4 Active Buzzer       Figure 5 Photoresistor*

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Figure 6 SD Card Reader

### 4.2.2. Programming the Arduino

The Arduino code provided for this project integrates the various components to create the Mars landing simulation. The necessary libraries are imported, including the MPU6050\_tockn library for the GY-521 accelerometer module, the NewPing library for the HC-SR04 ultrasonic sensor, and the Wire library for I2C communication which is an asynchronous serial communication protocol that used two bidirectional open-drain lines, the Serial Data Line and the Serial Clock Line, to establish efficient and reliable communication between multiple devices (Valdez & Becker, 2015).

Then the pins are defined for each component and constants for distance thresholds corresponding to different stages of the EDL process. The NewPing object is instantiated with the trigger and echo pins of the HC-SR04 sensor.

In the *setup()* function, the pins are configured for each component and communications are initialised for the accelerometer module. The *loop()* function runs continuously to measure distance, light intensity, acceleration, and temperature and to control the RGB LED and buzzer based on the current EDL stage

The code also includes a setColor() function to simplify the process of setting the RGB LED colour and comments throughout to provide a clear understanding of the code's operation.

## 4.3. Data Collection

#### 4.3.1. Acquiring Data from Arduino

The Arduino collects data from each sensor and component, including distance, light intensity, acceleration, and temperature as well as the current and next stage of the EDL process. These values are printed to the Arduino Serial Monitor alongside informative labels, providing real-time feedback during the simulation. These are the data that appear on the serial monitor in the following format:

00:00:00  
Light Level: 000 Ohms | Distance: 00.00cm | Temperature: 00.00°C

Acceleration X: 0.00g | Acceleration Y: 0.00g | Acceleration Z: -0.00g

Completed Stage: Terrain Relative Navigation

Next Stage: Backshell Separation

===========================================================================

The data are being displayed on the serial monitor so that specific values can be extracted from the text using regular expressions in Python. The text contains information about light levels, distance, temperature, acceleration, and details regarding the current and next stages of the Entry, Descent and Landing (EDL) process.

### 4.3.2. Data Extraction

To analyse the data, the Python script provided below is utilized to capture the output from the Arduino Serial Monitor through the USB port. The script employs regular expressions to identify each value by detecting the preceding label and the unit of measurement that follows, allowing for the extraction of relevant information for further processing.

# Set up the regular expressions to extract the data from each line

distance\_regex = re.compile(r"Distance:\s+(\d+)\.\d+\s+cm")

light\_regex = re.compile(r"Light\s+Level:\s+(\d+)\s+Ohms")

acceleration\_regex = re.compile(

    r"Acceleration X:\s+(-?\d+\.\d+)\s+g\s+\|\s+Acceleration Y:\s+(-?\d+\.\d+)\s+g\s+\|\s+Acceleration Z:\s+(-?\d+\.\d+)\s+g")

### 4.3.3. Data Analysis

After extracting all needed data through the serial port and separating each value with regular expressions and assigning them to new variable the data analysis starts.

#### 4.3.3.1. Calculating Solar Energy

The data collected from the photoresistor are used to calculate the solar energy collected from solar panels. With a solar panel efficiency approximately 20% and a solar panel area 1 m2  is possible to do this calculation with the equation 1.

E=L\*0.20\*1\*h (Eq. 1)

Where *E* is the energy collected measured in Wh (watt-hours), L is the light intensity value collected from the photoresistor and measure in Ω (Ohms) and h is the duration measured in hours. The estimation of the solar energy collected

## 4.5. Summary

# 5. Results

## 5.1. Overview

In the results section, the findings obtained from the execution of the simulation model and data collection on critical parameters during the Entry, Descent, and Landing (EDL) process are presented. The successful replication of key aspects of the EDL process by the Arduino-based simulation is highlighted, along with the correlation between the simulated data and actual data from previous Mars missions. This comparison emphasizes the potential of the Arduino platform for Mars EDL simulations.

## 5.2. Replication of key Entry, Descent, and Landing aspects

Asdf

## 5.3. Summary

# 6. Evaluation

## 6.1. Overview

The evaluation section delves into the assessment of the Arduino platform's effectiveness in simulating the Entry, Descent, Landing (EDL) process and identifying errors. By analysing the collected data, patterns and anomalies are identified, indicating potential errors in the simulated EDL process. These insights are utilized to refine the simulation model and improve its accuracy. Moreover, the comparison of the simulation results with real data from previous Mars missions allows for a measurement of the Arduino-based simulation's accuracy and reliability.

## 6.2. Identification of Patterns and Anomalies

Adsf

## 6.3. Refinement of the simulation mode

Asdf

## 6.4. Comparison with real Mars mission data.

Asdf

## 6.5. Summary

Asdf

# 7. Conclusion

## 7.1. Overview

Asdf

## 7.2. Synthesis of research findings

Asdf

## 7.3. Potential of affordable platforms for space mission simulations

Asdf

## 7.4. Future work

Asdf

## 7.5. Recommendation

Asdf

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