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Mars Landing Simulation with Arduino

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# Abstract

This research project explores the application of an Arduino microcontroller in simulating the Entry, Descent, and Landing (EDL) process of a Mars landing, aiming to measure critical parameters, analyse data, and identify potential errors. The EDL process is a vital and complex stage in space missions, and detecting errors during this phase can significantly improve mission success. Using an affordable and accessible Arduino microcontroller for simulating the EDL process and collecting data is an innovative approach. The research project comprises several objectives, including reviewing relevant literature on space exploration and Arduino, developing a simulation model using the Arduino platform, analysing collected data with Python, and evaluating the Arduino platform's effectiveness in simulating the EDL process. The research’s outcomes may contribute to the success of future Mars missions and advance our understanding of space exploration. Through a comprehensive structure including chapters on introduction, literature review, project management, methodology, results, evaluation, and conclusion, the dissertation provides insights into the performance of the Arduino-based simulation model and its potential for enhancing the efficiency and accuracy of spacecraft landings on Mars.

# 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 taking measurements, store and analyse data and then identify potential errors that occurred during the process. EDL is the final, shortest and most intense stage of a spacecraft’s journey to a planetary surface, and errors in this phase can have catastrophic consequences (NASA, n.d.). To address this challenge, the study utilises 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 the programming language Python 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 measure important parameters during the Entry, Descent, and Landing (EDL) process and identify errors throughout the process, using an Arduino microcontroller and data analysis tools. The EDL process is a critical and complex phase of space missions, and identifying potential errors during this stage can significantly increase the chances of a mission’s 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 and collect data on critical parameters during the process. 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, and then run the simulation model and record data on various parameters like altitude, acceleration, temperature, light level and velocity. The data collected will provide insights into the performance of the simulation model and the accuracy of the data itshelf.

* To analyse the collected data, and design graphs in order to identify errors during the process. This will involve processing the collected data using statistical and data analysis tools like the programming language Python, to identify patterns and anomalies that may indicate errors.
* To evaluate the effectiveness of the Arduino platform in simulating the EDL process and identifying errors. This will involve 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

This research project is being conducted as a final year project for a computer science degree. As such, the researcher's expertise in physics and mathematics may be limited, which could 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. Therefore, the scope of the research may be narrower than what is ideal, and the accuracy of the results may be affected.

Furthermore, while the Arduino microcontroller is a suitable platform for a university final-year project, it may not be the best tool available in the industry. The limitations of the Arduino could impact the accuracy of the simulation and may affect the outcomes of the study. In addition, the process of simulating the conditions on Mars is difficult and complex, and it may not be possible to achieve the most accurate simulation possible. Although 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. These constraints will be taken into account during the development of the simulation model and the data analysis process.

## 1.4. Project Deliverables

The primary goal of this research project is to explore the functionality of the Arduino micro-controller 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. Additionally, a Python code will be developed to extract the data from the Arduino and analyse them. The code will use statistical and data analysis tools to design visualisations and identify patterns and anomalies in the data that may indicate errors during the landing process.

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, including the effectiveness of the Arduino platform in simulating the EDL process and identifying errors. The report will also discuss the potential of the Arduino platform for use in space applications and provide recommendations for improving the simulation model.

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. The Python analysis code will enable the identification of errors and potential areas for improvement during the EDL process, providing valuable insights into the detection and prevention of errors in future space missions.

## 1.5. Project Significance

The study of the Entry, Descent, and Landing (EDL) process is a critical area in space exploration, and identifying errors during this process is crucial to 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. This research project aims to identify potential errors in the EDL process using an Arduino microcontroller and analyse the collected data to develop insights that can be applied to future Mars missions. By achieving the project objectives, this study aims to provide valuable insights into the use of Arduino microcontrollers for simulating the EDL process and identifying errors, potentially contributing to the overall success of future space missions.

## 1.6. Project Structure

The dissertation is structured in a logical and sequential manner, beginning with the Introduction chapter, which provides the background and context of the project, and clearly states the aim and objectives of the research. The Literature Review chapter provides an overview of 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 chapter 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.

In the third chapter, Project Management, is explained how the Gantt Chart and the Crisp DM methodology were utilised to effectively manage and monitor the progress of the project, ensuring completion on time. Additionally, the chapter outlines the issues and challenges faced during the development of the project, providing an explanation of the approaches taken to overcome them. Next is the Methodology chapter, which provides a detailed description of the approach taken in the project, including the development of the simulation model, the data collection process, and the data analysis and visualisation methods. This chapter will also discuss the limitations and challenges faced during the project and the strategies employed to overcome them. The Results chapter presents the findings of the study, including the data collected and analysed, and the insights gained from the analysis.

The Evaluation chapter evaluates the effectiveness of the Arduino platform in simulating the EDL process and identifying errors, by comparing the results of the simulation model with actual data from previous Mars missions and evaluating the accuracy and reliability of the simulation. Finally, the Conclusion chapter summarises the key findings of the project, provides recommendations for future research, and highlights the significance of the study in contributing to the understanding of the EDL process and the use of Arduino microcontrollers in space applications.

# 2. Literature Review

## 2.1. Overview

The following section provides a comprehensive and critical examination of space exploration's importance, and the role that simulations play in understanding the Entry, Descent, and Landing (EDL) process for mission on Mars. Initially, the discussion involves a thorough analysis of existing research on space missions and its implications for humanity, scrutinising the tools and research methods essential for simulating EDL. The focus then shifts to past Mars missions and their EDL processes, as well as the future prospects of EDL in space exploration. Moreover, the history and practical applications of Arduino microcontrollers are explored, highlighting the commonly employed sensors. Ultimately, the section emphasises the research gap in Mars landing simulations using Arduino microcontrollers, underlining the need for more accessible and cost-effective tools, particularly for smaller organisations and academic institutions.

## 2.2. Space Exploration Through the Years

People's fascination with space exploration can be traced back to ancient times. However, it wasn't until the early 20th century that scientists began developing the first liquid-fuelled rockets. World War II served as a catalyst for rocket development, with numerous countries participating in the war conducting cutting-edge rocket technology research (Launius, 2018). In 1942, Nazi Germany achieved a significant milestone by launching the first artificial object to exit the atmosphere. Following the war and Germany's defeat, over 100 scientists from the controversial German rocket program, some with questionable pasts, were recruited to join the USA's program (Kennedy, 2007). This sparked debates and concerns among Americans while marking the beginning of an intense space race between the USA and the Soviet Union.

Remarkably, space research has played a critical role in warfare, with significant advancements realised within the context of military conflicts. The potential of space-related technologies, such as rockets and satellites, to function as essential defence instruments has driven governments to allocate substantial resources to space research during wartime, surpassing investment levels during peaceful periods (Society, n.d.). The impact of political climate on space research funding can be exemplified by the fluctuation of the US government's allocation to NASA over the years.

Space exploration continued to progress in the following decades, with notable milestones such as NASA's Space Shuttle program initiation in 1981 and the establishment of the International Space Station in 1998 (Loff, 2017). The era also saw numerous robotic missions launched to explore the solar system, including Mars-focused Viking missions, outer planet-directed Voyager missions, and Mars rover missions (NASA, n.d.-a).

Currently, space exploration endeavours are cantered on sending humans to Mars and beyond, with NASA, ESA and SpaceX at the forefront. NASA's Artemis program aspires to land the first woman and the first black person on the Moon by 2024 and establish sustainable lunar exploration by the end of the decade. In parallel, SpaceX's Starship spacecraft is under development for missions to Mars and other destinations (Smith et al., 2020; SpaceX, 2020). These ambitious projects exemplify humanity's unwavering determination to push the boundaries of our knowledge and capabilities.

Moreover, the increasing involvement of private companies like SpaceX and international collaborations in space exploration has broadened the scope of research and innovation in this field. The democratisation of space has led to new perspectives and approaches, paving the way for ground-breaking discoveries and technologies.

In conclusion, the history of space exploration is characterised by a persistent drive to expand human knowledge and capabilities. With various ongoing projects and the potential for new international collaborations, the trend of pushing boundaries is expected to continue, shaping the future of space exploration for years to come.

## 2.3. Mars Exploration

Mars is one of the most fascinating planets in our solar system and it has captivated human’s attention since its first observation. Initially observed through telescopes in the late 19th century, Mars displayed patterns and landforms that led scientists to believe in the existence of a Martian civilisation. Although this idea was later disproven, it is now believed that 3.5 billion years ago, the planet might have been habitable, and similar to Earth (Drake, 2020).

Mars is one of the closest planets to Earth in our solar system and bears the most resemblance. As a result, more than 50 explorations have been conducted on the red planet since the 1960s (Jet Propulsion Laboratory, 2020). The first mission to Mars, the Soviet Union's Korabl 4 in 1960, failed before reaching the planet. However, NASA's Mariner 4 in 1965 marked the first successful mission, returning the first close-up images of the Martian surface (Jet Propulsion Laboratory, 2020). Since then, multiple missions have been conducted by NASA, the Soviet Union/Russia, the European Space Agency (ESA), and India. These missions have involved orbiters, landers, and rovers, significantly enhancing our understanding of Mars. Orbiters have played a crucial role in Mars exploration, providing detailed information about the planet's surface and atmosphere. These spacecrafts have mapped the surface, studied the planet's geology, and searched for evidence of water (Carr, 2007). Mars' land area is very similar to Earth's, and water has been found in ice form at the planet's poles. However, the climate is inhospitable due to the thin atmosphere, 96% of which is carbon dioxide (Jet Propulsion Laboratory, 2020).

One of the primary goals of Mars exploration is searching for signs of past or present life. The Viking missions in the 1970s were the first to specifically search for life on Mars, but their results were inconclusive. Nevertheless, 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 Entry, Descent, Landing (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 retrorockets, 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 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 in 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 (EDL) 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 utilise retractable landing legs to provide a stable landing platform and absorb impact upon touchdown, thereby minimising 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

There is a lack of research on the use of Arduino microcontrollers for modelling the landing of spacecraft on Mars, despite the fact that there are many simulation tools accessible for the construction and testing of spacecraft and their subsystems. Due to their adaptability, affordability, and simplicity of use, Arduino microcontrollers are one of the most often used solutions in the field of aeronautical engineering. However, their use in creating simulations of Mars landings has not yet been fully explored.

Testing the efficiency and security of spaceship landing systems requires simulations. These simulations help discover any problems that can occur during the real landing and offer insightful information about how the systems work. Currently, the majority of Mars landing simulations are created using specialised simulation hardware and software, which can be expensive and demand a lot of computational power. Because of this, only smaller businesses and academic institutions may use these simulators.

Utilising Arduino microcontrollers for Mars landing simulations presents several potential benefits. Firstly, they are considerably more cost-effective than high-end simulation software and hardware, making them more accessible to smaller organisations and academic institutions. Secondly, they can be easily programmed and adapted to simulate various situations and assess different landing approaches. Lastly, Arduino microcontrollers can be employed to create realistic physical interfaces, such as control panels, for training astronauts and mission controllers.

This project seeks to address this research gap by developing a Mars landing simulation using Arduino microcontrollers. In doing so, it will provide a more accessible and affordable tool for testing Mars landing systems, particularly for smaller organisations and academic institutions. Furthermore, this project will contribute to the expanding research on Arduino microcontrollers in aerospace engineering, specifically in the realm 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 organisations 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

The Project Management chapter outlines the methodologies used to manage the research project, including the development of a Gantt chart and the application of the CRISP DM methodology. The chapter also provides an analysis of the project progress against the initial plan, highlighting any deviations and the reasons behind them.

## 3.2. Gantt Chart

The initial plan for the project management was to use a Gantt chart to track the progress of the project. The chart was created with the aim of ensuring that each task was completed within the assigned time frame. The Gantt chart was divided into several tasks, with each task assigned a specific start and end date. The tasks included research through past scientific papers, establishing requirements, literature review, model design, programming sensors, testing the model, and writing the report. The project management plan was to begin with research through past scientific papers and establish the requirements, then move on to the literature review, model design, and programming sensors. Testing the model was scheduled to begin in mid-March, with the report writing phase to commence at the start of April.

Timeline, Teams

Description automatically generated

However, due to unforeseen circumstances, the Gantt chart could not be strictly followed. The research through past scientific papers and literature review took longer than initially anticipated due to the extensive amount of material available. As a result, the literature review extended beyond the initial end date. This delay had a knock-on effect on the model design phase, and the programming of the sensors was delayed.

Additionally, the unforeseen circumstances that arose during the project, such as the researcher's illness, a broken laptop, and other university projects, caused further delays. Despite the delays, the project was still completed within the original deadline, but not strictly following the Gantt chart. The programming of the data analysis was completed within the time frame and moved testing the model to an earlier date than initially scheduled.

In summary, although the Gantt chart was created with the aim of ensuring that the project was completed within the deadline, unforeseen circumstances and other delays led to some of the tasks being postponed and rescheduled. This led to the project not following the initial plan strictly. However, by incorporating the delays and obstacles that arose during the project, the project was still completed within the original deadline.

## 3.3. CRISP-DM

The CRISP-DM (Cross-Industry Standard Process for Data Mining) methodology was employed as the framework for project management in this research. The methodology is widely used for data mining projects and offers a structured approach to managing the various stages of a project.



The first stage, Business Understanding, involved defining the research problem and the objectives of the study. This stage was covered in the Introduction and Literature Review chapters of the report, where the background and aims of the research were discussed in detail.

The second stage, Data Understanding, involved gathering and analysing data to gain insights into the problem domain. This stage is covered in the Methodology chapter, where the data collection and analysis process are outlined. In this stage, various sensors were used to collect data on critical parameters such as altitude, temperature, and acceleration during the EDL process. The data was then stored on an SD card for further analysis in the next stage.

In the Data Preparation stage, the third step, the collected data was cleaned, transformed, and structured to ready it for modelling. The Methodology chapter delves into this stage, detailing the cleaning and processing of the data. While no cleaning was needed, the data was structured in a manner that facilitated easy processing in the following stage.

The fourth stage, Modelling, entailed creating models to gain insights into the research problem. Both the Methodology and Results chapters discuss this stage, in which the Entry, Descent, and Landing (EDL) process simulation model is developed and assessed using the collected data. The Arduino MEGA2560 was programmed to simulate various EDL stages, including entry into the Martian atmosphere, parachute deployment, and landing on Mars. The simulation model gathered data on crucial parameters like altitude, temperature, and acceleration, which were then analysed with Python scripts to detect potential EDL errors.

The Evaluation stage, the fifth step, involved assessing the models developed earlier to ascertain their effectiveness in addressing the research problem. The Evaluation chapter covers this stage, where the simulation model is examined by comparing its results to actual data from past Mars missions. This evaluation offered insights into the potential of the Arduino MEGA2560 platform for use in space applications.

The sixth and final stage, Deployment, involved deploying the models and insights gained from the project to solve the original research problem. This stage is covered in the Conclusion chapter, where the findings of the research were summarised, and recommendations were made for improving the simulation model for future research.

Overall, the CRISP-DM methodology provided a structured approach to managing the various stages of the research project, ensuring that each stage was adequately addressed, and the project was completed successfully.

## 3.4 Summary

The chapter begins with a description of the Gantt chart used to plan the project timeline. The chart included several key milestones such as research, requirements gathering, literature review, model design, sensor programming, testing, and report writing. However, due to various unforeseen events, including illness and other university projects, the project timeline strayed from the initial plan. Also, the explanation for the delays is provided.

The CRISP DM technique, which served as a roadmap for the research process, is then introduced in the chapter. There were six steps to the methodology: Business Understanding, Data Understanding, Data Preparation, Modelling, Evaluation, and Deployment. The chapter includes examples of the tools and techniques utilised and describes how each step was applied to the project.

The chapter assesses the efficiency of the employed project management approaches in its last section. The Gantt chart was found to be a useful tool for planning the project timeline and identifying key milestones. However, due to unforeseen events, the project timeline deviated significantly from the initial plan. The CRISP DM methodology was found to be a useful framework for guiding the research process, providing a structured approach to data analysis and model development. Overall, the chapter provides insights into the project management methodologies used in the research project, highlighting both successes and areas for improvement.

# 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

In the Arduino implementation of the project, the code is structured to efficiently collect data from various sensors, store the data on an SD card, and provide real-time feedback through LED indicators and a buzzer.

### 4.2.1. Sensor Description

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), the GY-521 (Fig. 2) which includes a 3-axis gyroscope, a 3-axis accelerometer, a digital motion processor (DMP), and a temperature sensor, an active buzzer (Fig. 4), a photoresistor (Fig. 5) and an SD card reader module (Fig. 6).

Diagram

Description automatically generated     A picture containing icon

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

A shadow of a person

Description automatically generated with low confidence           A picture containing logo

Description automatically generated     Icon

Description automatically generated

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

A picture containing icon

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Figure 6 SD Card Reader

The HC-SR04 ultrasonic sensor measures the distance between the Arduino model and the ground (Mars surface) during the whole process of the landing. The EDL method has been chosen to begin at an initial value of 200 cm for the measurements of the distance from the ground. Based on this initial value, further threshold distances have been determined, offering a framework for the evolution of the EDL phases. The two RGB LED used indicate the different stages of the EDL process based on the distance from the ground, with each stage corresponding to a specific distance and colour. The correlation between stages, distances and colours can be seen in table 2.



The GY-521 module is used to calculate the acceleration in the X, Y, and Z axes, as well as the 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.

### 4.2.2. Main Functions

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 uses 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.

### 4.2.3. Sending Data

The data collected by the Arduino is stored in the SD card and also displayed on the Serial Monitor for real-time observation. To achieve this, specific functions within the Arduino code are employed.

For storing data on the SD card, the Arduino is equipped with an SD card module which is interfaced with the microcontroller. The SD card is initialised, and a file is opened or created using the appropriate functions. The data is then written to the SD card sequentially, with each piece of data separated by a newline character. The stored data can be seen in fig. 8.



In addition to storing the data on the SD card, it is also displayed on the Serial Monitor. The Serial Monitor enables real-time observation of the data being collected. This is achieved by using the ***Serial.println()*** function. These functions output the data to the Serial Monitor as seen in fig. 9., making it easier to monitor the progress and check for any potential issues during the data collection process.



## 4.3. Data Processing and Analysis

### 4.3.1. Acquiring Data from the Model and Pre-Processing

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 stored in a ***.txt*** file in an SD card and printed to the Arduino Serial Monitor alongside informative labels, providing real-time feedback during the simulation testing. Then using the programming language Python, the data are extracted from the SD card and separated into different values using regular expression. The regular expression used to extract the data is shown in the ***extract\_data()*** method of the fig. 10.



Then the data pre-processing is taking place. The data of the acceleration need to be modified as the GY-521 module uses the earth’s gravity (g = 9.8 m/s²) to measure the acceleration. So, it is essential to convert this value to m/s², this happens by multiplying each value in the loop that extracts the patterns with the earth’s gravity value.

### 4.3.2. Energy and Power Calculations

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 , it is possible to do this calculation using the following equations:



Where ***E***is the energy collected measured in Wh, ***L*** is the light intensity value collected from the photoresistor and measured in Ohms and ***h*** is the duration measured in hours.

To calculate the power output of the solar panel, the power in kilowatts (kW) was first calculated using the following equation:



Where ***P*** is the power output of the solar panel measured in kilowatts, ***L*** is the light intensity value collected from the photoresistor and measured in Ohms, and 0.20 is the solar panel efficiency.

Once the power output has been calculated in kW, the energy output in kilowatt-hours (kWh) was calculated over a given period of times using the following equation:



Where E is the energy output measured in kilowatt-hours (kWh), P is the power output measured in kilowatts (kW), and t is the time period measured in hours.

These calculations are performed in the Python code using the ***calculate\_power\_and\_energy()*** function, which takes the light levels and timestamps as inputs and returns the power output and energy output in kilowatts and kilowatt-hours, respectively.



### 4.3.3. Angle of Movement Calculation

The angle of movement of the model can also be calculated setting the acceleration values ***acc\_x*** and ***acc\_y*** in the arctangent function. The ***calculate\_angle()*** function is used to implement the trigonometric function and determine the angle of movement in degrees. The function is clearly shown in Fig. 12.



### 4.3.4. Data Visualisation

After cleaning and processing the extracted data, several graphs were generated using Python to visualise the results and draw insights. The main graphs included light levels, distance, temperature, and acceleration measurements over time, which allowed for trends in the data to be easily identified. Additionally, a correlation matrix was created to identify any correlations between the different measurements and provide insights into the factors affecting the efficiency of the solar panels. The stage chart bars provided an overview of the testing stages, highlighting any potential issues or delays. Overall, these visualisations provided a clear representation of the collected data and allowed for valuable insights to be drawn from the results. The libraries used to generate the graphs were matplotlib for creating various types of graphs and visualisations and seaborn for statistical data visualisations. Here is an example of the code that generates the Energy-Time and Power-Time graphs:



## 4.4. Summary

The methodology outlines the development of the Mars Landing Simulation with Arduino project, including the development of the Arduino model and data analysis. The Arduino model consists of several components, including the HC-SR04 ultrasonic sensor, GY-521 3-axis gyroscope and accelerometer module, RGB Light, active buzzer, and photoresistor. Data collected by the Arduino is stored on an SD card and analysed using Python. Visualisations were generated using matplotlib and seaborn libraries, including graphs for light levels, distance, temperature, and acceleration measurements over time, as well as a correlation matrix and stage chart bars.

# 5. Results

## 5.1. Overview

This chapter presents the results of the Mars Landing Simulation with Arduino project. It begins with an overview of the project and then moves on to describing the Arduino model and its functionalities, which includes a description of the components and sensors used as well as pictures of the model. The section also covers the connections of sensors used in the model.

Subsequently, the data collection and storage process are outlined, with a focus on the SD card data. The chapter then goes on to describe the data processing and cleaning process, followed by the data visualisation results. The visualisation section covers light level, distance, temperature, and acceleration measurements, including corresponding graphs that illustrate trends in the data.

Taken together, this chapter provides a comprehensive summary of the project, including a detailed analysis of the data collected and the visualisations generated.

## 5.2. Arduino Model and Functionalities

The Arduino model was developed to simulate the Entry, Descent, and Landing (EDL) stage of a spacecraft on Mars. The model consists of various sensors and components, including the HC-SR04 ultrasonic sensor module, the GY-521 3-axis gyroscope, accelerometer and thermometer module, an RGB LED, an active buzzer, and a photoresistor.

The sensors and components work together to collect data and represent different stages of the EDL process. For example, the HC-SR04 ultrasonic sensor measures the distance between the Arduino model and the ground, while the RGB LED lights indicates the different stages of the EDL process based on the distance from the ground. The GY-521 module is used to calculate the acceleration in the X, Y, and Z axes, as well as the temperature. The active buzzer indicates when the model has landed, and the photoresistor measures light intensity, which calculates the amount of solar energy collected during the simulation.

Diagram, schematic

Description automatically generated

Figure 15 Arduino Simulation Model Design using wowki.com

The connections between sensors, the breadboard and the Arduino MEGA2560 are depicted in Figure 15 which is an image generated using the [Wowki](https://wokwi.com/) website. In addition to the sensors, the resistors played an important role in the project by regulating the power through the restriction of current flow within the circuits. This can also be observed in figure 15.

## 5.3. Data Collection and Storage

The information gathered from the Arduino model is saved on an SD card and presented on the Serial Monitor for immediate viewing. A .txt file saves the data on the SD card, and it encompasses measurements of distance, light intensity, acceleration, temperature, and the completed and next stage of the EDL procedure as it is shown in fig.16.



## 5.4. Data Processing and Cleaning

After extracting and processing the data, it was carefully cleaned and saved into the "table.csv" file, as illustrated in Figure 17. In order to ensure accuracy, the acceleration values were converted from g to m/s² before being stored. Regular expressions were utilised to extract the data and it was saved in the CSV file for further analysis.

Table

Description automatically generated

Figure 17 Processed & Cleaned Data

## 5.5. Data Visualisations

This section presents the visualisation of the collected data to provide a better understanding of the findings. Visualisations were created using Python libraries, such as Matplotlib for creating various types of graphs and Seaborn for statistical data visualisations like correlation matrices.

### 5.5.1. Main Graphs

The main graphs generated from the collected data include measurements of light level, distance, temperature, and the 3-axis acceleration, over time. They allow easy identification of trends in the data and provide valuable insights into the different parts of the Mars Landing Simulation. As shown in Figure 18, the graphs give a clear representation of the collected data and enable the drawing of important conclusions from the results. The Distances over Time graph illustrates how long it would take for the model to touch the ground since the first value, which represents how far the model is from the ground, is around 200 cm, and the last value, is approximately 10 cm.

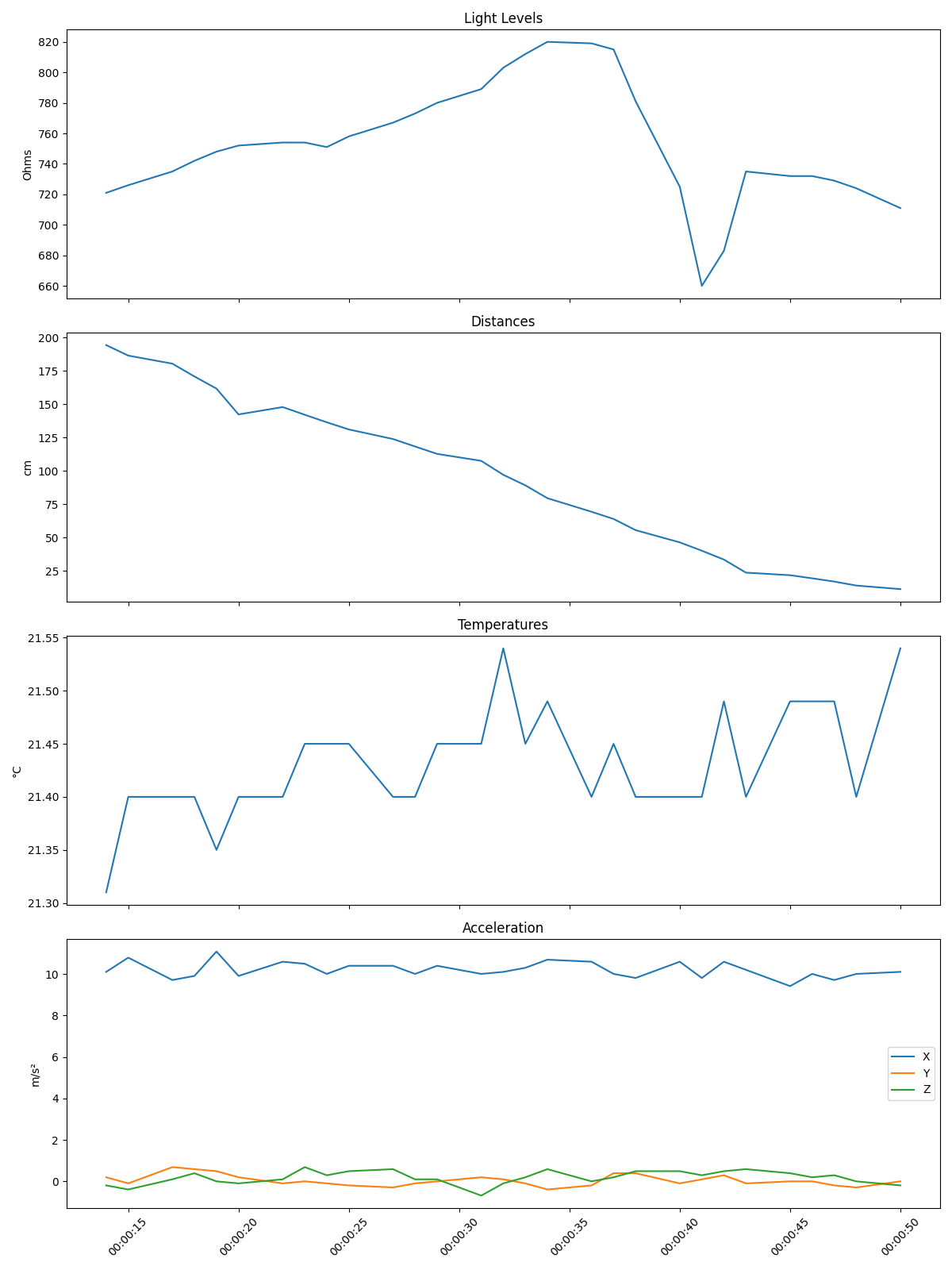


Figure 18 Main Graphs

### 5.5.2. Light Level Measurements

The graphs shown in Figure 19 depict the cumulative energy and power over time. After calculating the two values of energy and power the graphs were generated. By analysing these graphs, we can gain valuable insights into the efficiency of the solar panels and the amount of power generated during the Mars Landing Simulation.

Chart, line chart

Description automatically generated

Figure 19 Cumulative Energy & Power Graphs

### 5.5.3. Acceleration Measurements

The angle of movement graph over time, displayed in figure 20, was generated after calculating the angle of movement of the model using the arctangent function. This graph provides valuable insights into the movement and orientation of the model during the EDL process.

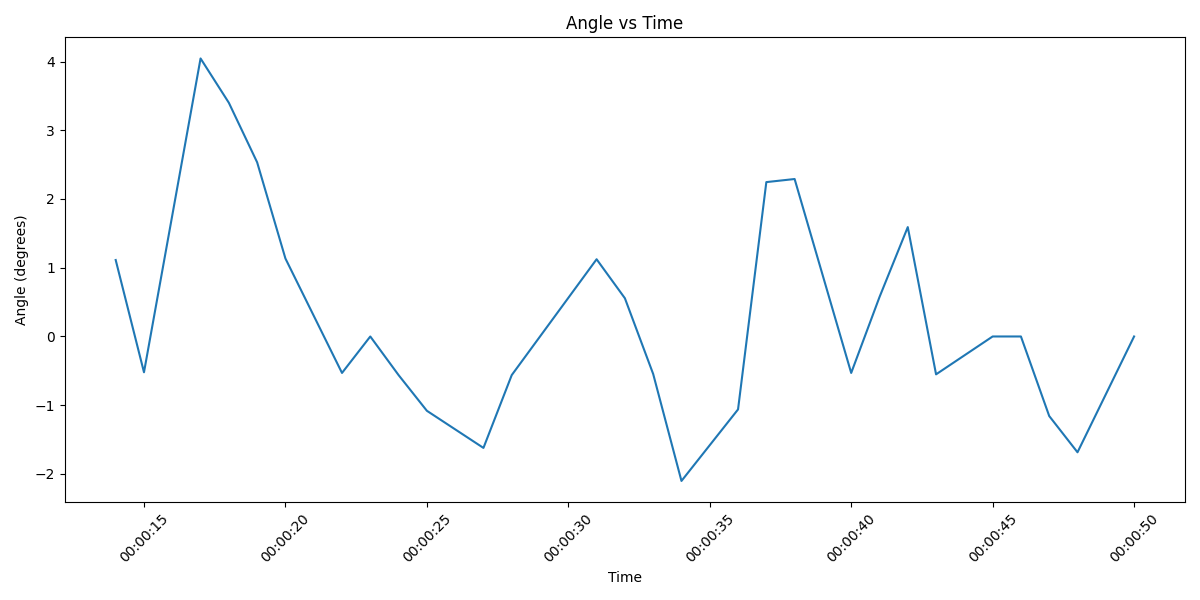


Figure 20 Angle of Movement Graph

### 5.5.4. Other Visualisations

Figure 21 displays the correlation matrix, which identifies any correlations between the different measurements. This matrix helps understand how each variable could affect the other.

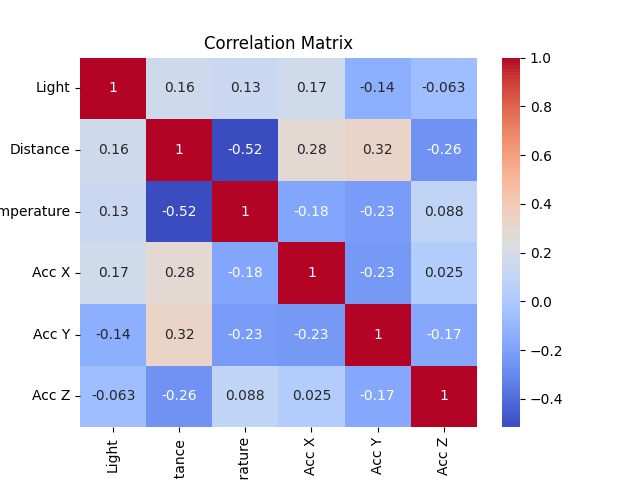


Figure 21 Correlation Matrix

## 5.7. Summary

The results of the Mars Landing Simulation with Arduino project have been presented in this chapter. The Arduino model was developed to simulate the Entry, Descent, and Landing stage of a spacecraft on Mars, and it consists of various sensors and components that collect data and represent different stages of the EDL process.

The data collected from the Arduino model was stored on an SD card and presented on the Serial Monitor for immediate viewing. In order to ensure accuracy, the data were carefully cleaned and saved in the "table.csv" file.

Python packages like Matplotlib and Seaborn were used to build visualisations that helped explain the gathered data. Measurements of light level, distance, temperature, and acceleration over time are included in the primary graphs produced from the data collected, making it simple to spot trends in the data.

Important information on the efficiency of the solar panels and how much electricity was generated during the Mars Landing Simulation can be found in the graphs that display the total energy and power created over time. The angle of movement graph, which was generated using the translated acceleration values, helps to better understand the movement and orientation of the model during the EDL process. Making informed conclusions from the data obtained throughout the simulation is made simpler by the correlation matrix, which displays any correlations between the various metrics.

This chapter concludes with a complete assessment of the study that includes a detailed analysis of the data collected and the visualisations produced, to allow for the essential conclusions to be made from the results.

# 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 utilised 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. Then, the accomplishment of the objectives and the research goal are discussed. The evaluation is summarised at the end, and insightful conclusions are drawn.

## 6.2. Arduino Model and Data Collection

The model was successfully designed and constructed to carry out the EDL process. Two RGB lights and a buzzer were used to indicate the EDL stages. The measurements were taken using several sensors including HC-SR04, GY-521, and photoresistor. These sensors were used to measure the distance from the ground, the 3-axis acceleration, the temperature, and the light level, respectively. However, since the measurements were taken every one second, there is a higher chance of errors occurring.

The data collected from the sensors were successfully stored in the SD card and also printed in the Serial Monitor to test the model during the design. The model could have achieved better accuracy with a larger project budget, as other measurements such as a Parachute Deployment Sensor and a Mars Environmental Dynamics Analyser (MEDA) could have been conducted (Rodriguez-Manfredi et al., 2021), but they were too expensive to be purchased.

Another potential limitation of the model is the use of a single HC-SR04 sensor to measure the distance from the ground. This sensor can be affected by external factors such as wind or dust, which can impact the accuracy of the measurements. To improve the accuracy of the model, multiple sensors could be used to measure the distance from different angles, providing more accurate data and reducing the impact of external factors.

In addition, the GY-521 accelerometer sensor used in the model is only capable of measuring acceleration in three axes. In a real EDL process, there are additional forces that may impact the trajectory of the vehicle, such as wind and gravitational pull. To better capture the complexity of the EDL process, additional sensors that measure other forces and factors may be needed.

Moreover, the model's built quality is not suitable for industrial testing due to the fragile connections between the pins and the Arduino. This could lead to inaccurate measurements or even a failure of the model during the EDL process. To make the model more robust, more durable and secure connections between the sensors and the Arduino could be implemented.

The accuracy of the measurements may be affected by human error as the model is held and guided towards the ground during the simulation. To mitigate this limitation, the model could be mounted on a stable platform or fixture to ensure a more consistent and controlled EDL process. However, it is important to note that the data collected may still not be very accurate as the model does not follow the stages of the EDL in a real environment. As a result, the values obtained for the 3-axis acceleration, temperature, and light levels are only indicative of how the real data would be collected, and not necessarily accurate data themselves.

Overall, while the model has demonstrated the potential of the Arduino platform for simulating the EDL process and taking measurements, there are still several areas for improvement to achieve greater accuracy and reliability.

## 6.3. Data Processing, Calculations and Visualisations

This section focuses on the methods used in the project for data processing, analysis, and visualisation. The section emphasises how using Python modules like Pandas, NumPy, and Matplotlib created a solid framework for manipulating and displaying data. The.txt file's useful data was extracted using a regular expression, and the data was first processed by being cleaned and put into a structured manner. The use of descriptive statistics, visualisations, and the correlation matrix to learn more about the EDL process is covered in this section. The calculations for energy and power as well as the angle of movement were completed successfully. However, due to a lack of information and the impact of outside forces on the object, it was difficult to determine the velocity and trajectory.

### 6.3.1. Data Processing

This project's data processing showed excellent. The utilisation of the regular expression for the segregation of values from the .txt file proved to be highly efficient, enabling meaningful deductions. The initial processing of the data involved cleaning and organising the data into a structured format that was easily readable and accessible and stored in the “table.csv” file. Where from there the data can be stored in a database and used in the future for further analysis.

### 6.3.2. Calculations and Visualisations

A strong basis for the visualisations was provided by the usage of Python libraries Pandas, NumPy, Seaborn and Matplotlib. These libraries were successful at visualising the processed and calculated data because they are widely used for analysis, numerical operations, and graph plotting (Sial et al., 2021). However, the first step after the data processing was the calculation of important values for the plotting of the graphs.

Descriptive statistics were used to provide the data a clear grasp, enabling more thorough analysis and interpretation. The data was presented in this project's visualisations in a clear and concise manner, making it possible to interpret the findings quickly and simply. Time serving as the universal x-axis for all major graphs made it easier to compare all values throughout time, as seen in fig. 17 of chapter 5.

The energy and power calculations were a crucial aspect of the project, and they were executed successfully. The light level data collected from the photoresistor was used to compute the energy and power values for each phase of the EDL process. The energy and power formulas adopted proved to be very efficient, as evidenced by the accuracy of the values obtained, which was confirmed by the plotted graphs. By knowing this information it is possible to calculate the battery level of the rover after the landing for the execution of the next stages of the mission in Mars.

Despite the absence of external factors measurements such as weather and pressure in the experiment, the angle of movement calculation was as precise as possible given the available tools. Although the accuracy of the calculation was not perfect, it still demonstrated the capabilities of the Arduino in this context and the graph angle over time successfully depicts how the angle of movement can change during the process.

Unfortunately, the calculation of the velocity was unsuccessful due to the lack of data. In order to calculate the velocity of the model, the velocities in the X and Y axis were needed and to calculate these two velocities it is necessary to know the initial velocity of the model starts and that is not possible since the experiment starts from a static condition. The formula of the angular velocity can be seen in eq. 4 and the formula of the velocity in X and Y axis is depicted in eq. 5.



Furthermore, it was not feasible to determine the trajectory in this project since the formula for calculating trajectory includes the object's velocity, as shown in equation 6. However, due to the unknown external forces operating on the object, the computation would still be subject to error even if the velocity was known.

The correlation matrix was a great tool for finding patterns and connections between the various variables, giving information on the major variables affecting the EDL process. However, with the data collected from the Arduino, it is not feasible to determine which variable had an impact on the other, but if the data were accurate, a pattern where the decrease of the acceleration in one axis could have an impact on the increase of the decrease of the temperature.

## 6.4. Overall Evaluation

The project's overall evaluation will be covered in this section. The methods used to accomplish the goals as well as potential areas for improvement will be the main points of discussion. It will be possible to learn how to optimise future initiatives and raise the quality and dependability of the data acquired by reviewing the project's strengths and flaws.

### 6.4.1. State-of-the-Art Development in Space Exploration and Arduino

A thorough grasp of the most recent advancements in space research and the usage of Arduino microcontrollers in space applications, specifically for mimicking the EDL process of spacecraft on Mars, is provided through the literature review. The assessment emphasises the value of simulating Mars landings for successful missions and the research gap caused by the shortage of easily available and reasonably priced instruments for testing Mars landing systems, particularly for smaller businesses and academic institutions.

A summary of the EDL process and the difficulties in simulating it are given in the review. It talks about the limits of the currently available simulation tools and proposes Arduino microcontrollers as a novel method for simulating Mars landing systems that hasn't been investigated in prior studies. The characteristics of Arduino microcontrollers are also discussed, including the several varieties of Arduinos and their functionalities, the usage of shields to add additional functionality, and the open-source hardware designs.

The review also covers the Arduino Mega 2560, the exact model used for the simulation project, and its features, such as the quantity of input/output pins, analogue inputs, and serial ports. It lists all of the many Arduino shields and components that will be utilised for the simulation, including the light sensor, LED and RGB lights, ultrasonic sensor shield, and passive buzzer. The analysis describes how these elements will be utilised to gather information and offer feedback during the simulation.

Overall, the literature analysis offers insightful information about the status of science, technology, and space exploration, as well as the application of Arduino microcontrollers to the simulation of Mars landing systems. The assessment points out the research gap caused by the absence of easily usable and cost-effective simulation tools and suggests the usage of Arduino microcontrollers as a potential fix. Future study in this field will be influenced by the review, which lays the groundwork for the creation of the simulation model and data gathering techniques.

### 6.4.2. Development of the Simulation Model and Data Collection

The development of the simulation model was successful. The model was developed using the Arduino MEGA2560 which ended up being the correct decision, since it completed the requirements and run the given code without any computational problem.

Various sensors were utilised for data collection in this study. The ultrasonic sensor, HC-SR04, was used to estimate the distance from the ground, enabling the calculation of altitude and stage completion. However, a single sensor may not provide accurate measurements due to potential interference from external factors such as winds or obstacles, necessitating the use of multiple sensors to enhance measurement accuracy. The GY-521 module provided information on 3-axis acceleration and temperature, with the latter enabling the measurement of other critical variables like the angle of movement. Calibration of the module was required, and a stable start was essential for accurate measurements, meaning that a delay of 8 seconds was incurred before data collection. The temperature of the model was monitored during the process with the same sensor (GY-521) to better understand how altitude, acceleration, and light level affect it. The light level was measured using a photoresistor, and this information was utilised to calculate the energy and power collected by the model for future use post-landing. All measurements are collected by the Arduino model, which then stores them on an SD card in a format suitable for later analysis. However, because a velocity sensor was not available, the model was unable to measure velocity, one of the parameters listed in the project's objectives. The velocity had to be determined as a result during the data analysis phase.

Ideally, the model could be tested in an existing EDL spacecraft that undergoes testing and function as a data measurement tool during the process, but this was not possible to be executing, since the nature of the project is a final year project, and it is not common to conduct this experiment. This drawback has affected the accuracy of the data, however, the rest of the project continued unaffected, and the analysis was conducted successfully.

Overall, the goal of using the Arduino platform to create a simulation model of the EDL process was accomplished. The Arduino MEGA2560 microcontroller was the right choice since it met the requirement, the employed sensors functioned well with data as accurate as possible, and then recorded them correctly on the SD card.

### 6.4.3. Data Extraction, Analysis and Visualisations

The third objective of the project, to analyse the collected data and identify errors during the EDL process was partially achieved as the data were successfully analysed, but their accuracy was not sufficient enough to observe errors, however, if the data were more accurate, the existing analysis and visualisations that was programmed with Python would be enough to identify errors.

Firstly, the data were extracted successfully from the SD card and then cleaned and stored in a .csv file for further analysis. Then the calculation of the angle of movement, and the energy and power collection were successful and the only value that could not be calculated was the velocity because of the data provided before the start of the EDL and the external forces that cannot be determined. Furthermore, the visualisations were insightful, with the main graphs explaining the measurements of the Arduino’s readings over time, which helped in comparing each value at specific timestamps. Then, a few more visualisations were generated to understand the angle of movement over time, the cumulative energy and power over time and the correlation matrix.

Overall, the objective was sufficiently achieved even if there were a few drawbacks during the process.

### 6.4.4. Effectiveness of the Arduino Platform for EDL Simulations

The effectiveness of the Arduino platform in simulating the EDL process was evaluated based on the data collected and the simulation model developed in this research project.

Although the model could not measure the velocity directly due to the unavailability of a velocity sensor, and the rest of the measurements are not very accurate, but they provided a comprehensive understanding of the EDL process. Also, it is possible to store these data effectively and further analysis can then be conducted. So, in a better testing environment with more accurate conditions, the Arduino could effectively complete the EDL simulation by measuring certain parameters.

Overall, the Arduino platform showed promising potential in simulating the EDL process, and further research and development could enhance its effectiveness for future space applications.

## 6.5. Summary

In conclusion, the goal of this research project was to measure crucial parameters during the Entry, Descent, and Landing (EDL) process and identify errors throughout the process using an Arduino microcontroller and data analysis tools like Python. It was successfully carried out as shown in this chapter. The usefulness of the Arduino platform in emulating the EDL process and detecting mistakes was evaluated in the evaluation part.

It was successfully created and built for the Arduino model to execute the EDL procedure. The use of a single sensor to measure distance and the absence of sensors to monitor other forces and conditions that have an influence on the EDL process are only a few of the limitations. Successful SD card storage and analysis of the sensor data were accomplished using Pandas, NumPy, and Matplotlib, three Python packages. The calculations for energy and power as well as the angle of movement were successful, but the absence of data made it impossible to calculate velocity and trajectory.

The literature research emphasised the use of Arduino microcontrollers in space applications and their potential for mimicking Mars landing technologies. The Arduino MEGA2560 microcontroller and the used sensors were successfully used to construct a simulation model that produced data that was as accurate as possible. The examination of the Arduino platform's efficacy in recreating the EDL process revealed encouraging possibilities, and more research and development might increase its usefulness for upcoming space applications.

Overall, despite its flaws and room for development, the project was successful in achieving its objectives. The experiment showed the Arduino platform's capability for measuring and modelling the EDL process, and the results may be used to improve the simulation model's accuracy.

# 7. Conclusion

## 7.1. Overview

Overall, the project was successfully completed and the findings provided important insights about the utility of the Arduino platform in simulations in the space sector. The main aim was approached correctly and achieved as planned with only a few parts of the objectives not possible to be executed, like the measurement of the velocity and the trajectory of the object.

## 7.2. Synthesis of research findings

The findings of this project were numerous. First of all, the Arduino model was developed using the Arduino MEGA2560 and different sensors, resistors and cables and it measured valuable information about the Entry, Descent and Landing (EDL) process with indications of the stages during the process. Then the data were stored from the Arduino in an SD card and then they were extracted using the programming language Python, and further analysis was conducted after the pre-processing and cleaning of the data. Visualisations were designed, using the pre-processed data. The main graphs provided a good understanding of every measurement that the Arduino conducted over the same time frame and various other visualisations like a correlation matrix and more graphs about cumulative energy and power and angle of movement over time provided further understanding of the process.

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

Although the limitations of the Arduino platform are unavoidable it can still be an efficient way to simulate various measurements of an EDL process. That shows that affordable platforms like Arduino can complete these processes. There is more potential for these platforms, as it is possible to carry out more simulations for space missions. For example, models for simulating functionalities of satellites could be designed to test altitude and light level calculations. There are more affordable platforms that can be used for these simulations, one of them is Raspberry Pi (Upton, Halfacree, 2016) which can complete every stage that the Arduino model did by using the same exact sensors, however, the price of the Raspberry Pi is a bit higher than the Arduino (Nguyen et al., 2015) and that is why it was not selected for this project.

## 7.4. Future work

The Mars Landing Simulation project has identified several areas that warrant further investigation. One important topic is the development of more cost-effective large-scale space mission simulators. While this project focused on a specific simulation platform, there are numerous other affordable options, such as the Raspberry Pi, which could be evaluated and compared due to its greater computational power compared to any Arduino platform.

Another area of interest is the integration of virtual reality (VR) and augmented reality (AR) technologies in space mission simulations (Liu, et al., 2010). These advancements have the potential to create more realistic and immersive simulations, which could enhance user engagement and offer new perspectives on the planning and execution of space missions.

Lastly, exploring the use of space mission simulations across different educational levels would be valuable. Although this research focused on university-level courses, simulations could be applied to K-12 education or public outreach initiatives. Investigating the most effective ways to utilise simulations in these contexts could help educate and inspire future generations of space enthusiasts and provide insights into their effectiveness under various conditions.

## 7.5. Recommendation

Several recommendations can be made to enhance this project further. Firstly, improvements can be made to the Arduino's design. The model's instability and the ease with which cables can become disconnected are two significant current issues. Increasing the model's robustness by strengthening the connections and designing an external enclosure to protect the model from accidental drops would be a good starting point.

Another recommendation is to enhance the software used for data analysis and visualisation. By employing more advanced data analytics tools and techniques, the project could gain deeper insights into the EDL process and its performance under different conditions.

Integrating real-time communication capabilities between the Arduino system and a remote monitoring station could allow researchers to oversee and control the simulation while it runs. This would permit on-the-fly adjustments, leading to more efficient testing and iteration of the EDL process.

Broadening the project's scope to test various landing strategies and technologies, including different parachute types or propulsion systems, could yield valuable information on their efficacy for Mars landings. This would help in the development of more dependable and efficient EDL systems.

Furthermore, conducting tests under simulated Martian environmental conditions, such as fluctuating temperature, pressure, and atmospheric composition, would assist in evaluating the EDL system's performance in a more realistic setting. This would offer a better understanding of potential challenges and the system's effectiveness under actual Mars landing conditions.

Lastly, partnering with other research institutions, academic organisations, or industry collaborators could facilitate the exchange of knowledge, resources, and expertise. This collaboration could expedite the project's development and contribute to a wider comprehension of Mars landing technologies and their potential uses.

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# PID Document

## Basic details

|  |  |
| --- | --- |
| Student name: | Aristeidis Karalis |
| Draft project title: | Mars Landing Simulation with Arduino |
| Course and year: | Computer Science, 3rd Year, Level 6 |
| Project supervisor: | Dr Taiwo Adedeji |
| Client organisation: |  |
| Client contact name: |  |

## Degree suitability

As Computer Science students we learn how to solve problems using programming languages and embedded systems. In this engineering project, I will use an embedded system device called Arduino and Python to simulate a spacecraft’s Entry, Descent, and Landing on Mars (EDL).

## Outline of the project environment and problem to be solved

The distance between Earth and Mars is so long that it needs 7 minutes for a message to be sent from one planet to the other. (Jet Propulsion Laboratory, 2021. para. 3) This delay makes the EDL process more difficult because the mission team on Earth will know that the process has started when on Mars it has already been completed. That is why it is very important to program every single step of the process before the spaceship has taken off from the earth.

## Project aim and objectives

The aim of this project is to create an Arduino model that will go through the process of EDL and point out the difficulties of this kind of mission and understand and counter the physical and technical problems these missions face. First, we need to figure out what caused these issues in the first place by researching past missions and analysing them step by step and then figuring out what is needed to fix them and prevent future problems. Meanwhile, it is possible to spot problems that have not occurred yet and fix them.

# 

## Project constraints

Due to the unique nature of Mars, it is impossible to test the model in real-life situations, that is why most of the tests will be done in the best possible environment and will take in account as many variables as possible but there will always be cases that cannot be tested properly.

## Facilities and resources

The most important tool for this project is Elegoo’s MEGA 2560 Project starter kit which includes all the sensors and tools needed for the design and functionality of the model. Some of the sensors that are going to be used are MEGA 2560 Controller Board, Ultrasonic sensor, LED lights and active Buzzers. Then a laptop with Windows 10 will be used to program the Arduino kit in Python with the use of Arduino’s IDE. In addition, GitHub and Jira will be used for code and plan management.

## Log of risks

|  |  |  |
| --- | --- | --- |
| **Description** | **Impact** | **Mitigation/Avoidance** |
| Sensors that malfunction | False data will affect the functionality of the model. | Constantly test if all the sensors work and if one breaks, buy another one as soon as possible. |
| Laptop problems | Not possible to connect the controller board and program the model. | Try to fix my laptop or complete the project through the university’s laptops. |
| Supervisor unable to work for a long period. | Not being able to get feedback from the supervisor. | Find lecturers that supervise a few projects and ask them for their feedback if and only if they have time available. |

## Project deliverables

A small-sized physical model will be designed that will implement the process of EDL 1.20m over the ground. A project report which will include a user guide explaining how to do the demonstration and what are the expected results, a literature review and the requirements of the project. Finally, snippets from the code will be provided.

## Project approach

First, research needs to be done on existing scientific papers about Mars, space landings and a lot more aspects of engineering that are needed for this project to be completed. Since it is only one person that works on this project I chose the Waterfall model for the Software Development Life Cycle (SDLC) because it suits better with the nature of this project as I can go through all the development stages again and again when I occur problems.

## Project plan

* Abstract
* Introduction
* Research through past scientific papers
* Establish requirements
* Literature Review
* Design Model
* Program sensors
* Test model
* Write Report

## 11. Supervisor Meetings

It is decided that a meeting will be held every other week on Fridays. The progress of the project will be discussed and feedback and suggestions will be done by the supervisor.

References

*Code a Mars Landing*. (2021, February 9). https://www.jpl.nasa.gov/edu/learn/project/code-a-mars-landing/

# Ethics Certificate

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Description automatically generated

Certificate of Ethics Review

**Project title:** Mars Landing Simulation with Arduino

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name**: | Aristeidis Karalis | **User ID**: | 958669 | **Application date**: | 14/10/2022  11:33:10 | **ER Number**: | TETHIC-2022-103753 |

The FEC representative(s) for the **School of Computing** is/are [**Haythem Nakkas**](https://www.port.ac.uk/about-us/structure-and-governance/our-people/our-staff/haythem-nakkas)**,** [**Dalin Zhou**](https://www.port.ac.uk/about-us/structure-and-governance/our-people/our-staff/dalin-zhou)

It is your responsibility to follow the University Code of Practice on Ethical Standards and any Department/School or professional guidelines in the conduct of your study including relevant guidelines regarding health and safety of researchers including the following:

* [University Policy](https://staff.port.ac.uk/departments/services/corporategovernance/healthandsafety/healthandsafetypolicy/)
* [Safety on Geological Fieldwork](http://www.southampton.ac.uk/~imw/safety.htm)

It is also your responsibility to follow University guidance on Data Protection Policy:

* [General guidance for all data protection issues](https://www.port.ac.uk/about-us/structure-and-governance/legal/data-protection-and-gdpr)
* [University Data Protection Policy](http://policies.docstore.port.ac.uk/policy-022.pdf)

Which school/department do you belong to?: **School of Computing**

What is your primary role at the University?: **Undergraduate Student**

What is the name of the member of staff who is responsible for supervising your project?: **Dr Taiwo Adedeji**

Is the study likely to involve human subjects (observation) or participants?: No

Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?: No

Are there risks of significant damage to physical and/or ecological environmental features?: No Are there risks of significant damage to features of historical or cultural heritage (e.g. impacts of study techniques, taking of samples)?: No

Does the project involve animals in any way?: No

Could the research outputs potentially be harmful to third parties?: No

Could your research/artefact be adapted and be misused?: No

Will your project or project deliverables be relevant to defence, the military, police or other security organisations and/or in addition, could it be used by others to threaten UK security?: No

# Supervisor Review

As supervisor, I will ensure that this work will be conducted in an ethical manner in line with the University Ethics Policy.

Supervisor comments

Supervisor’s Digital Signature**: ** Date**: 20/10/2022**