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Mars Landing Simulation with Arduino

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# Abstract

# Acknowledgements

Contents

[Abstract 2](#_Toc132907998)

[Acknowledgements 3](#_Toc132907999)

[Contents 4](#_Toc132908000)

[1. Introduction 6](#_Toc132908001)

[1.1. Background 6](#_Toc132908002)

[1.2. Project Aim and Objectives 6](#_Toc132908003)

[1.3. Project Constraints 7](#_Toc132908004)

[1.4. Project Deliverables 7](#_Toc132908005)

[1.5. Project Significance 8](#_Toc132908006)

[1.6. Project Structure 8](#_Toc132908007)

[2. Literature Review 10](#_Toc132908008)

[2.1. Overview 10](#_Toc132908009)

[2.2. Space Exploration Through the Years 10](#_Toc132908010)

[2.3. Mars Exploration 11](#_Toc132908011)

[2.3.1. Entry, Descent, Landing (EDL) 11](#_Toc132908012)

[2.3.2. Future of Entry, Descent, Landing (EDL) Systems 13](#_Toc132908013)

[2.4. Arduino 14](#_Toc132908014)

[2.4.1. Arduino Mega 2560 14](#_Toc132908015)

[2.4.2. Arduino Shields and Parts 14](#_Toc132908016)

[2.5. Gaps in Literature 15](#_Toc132908017)

[2.6. Summary 15](#_Toc132908018)

[3. Project Management 17](#_Toc132908019)

[3.1. Overview 17](#_Toc132908020)

[3.2. Gantt Chart 17](#_Toc132908021)

[3.3. CRISP-DM 18](#_Toc132908022)

[3.4 Summary 19](#_Toc132908023)

[4. Methodology 20](#_Toc132908024)

[4.1. Overview 20](#_Toc132908025)

[4.2. Development of The Arduino Model 20](#_Toc132908026)

[4.2.1. Components and Setup 20](#_Toc132908027)

[4.2.2. Programming the Arduino 21](#_Toc132908028)

[4.3. Data Collection 22](#_Toc132908029)

[4.3.2. Data Extraction 22](#_Toc132908030)

[4.3.3. Data Analysis 23](#_Toc132908031)

[4.5. Summary 23](#_Toc132908032)

[5. Results 24](#_Toc132908033)

[5.1. Overview 24](#_Toc132908034)

[5.2. Replication of key Entry, Descent, and Landing aspects 24](#_Toc132908035)

[5.3. Summary 24](#_Toc132908036)

[6. Evaluation 25](#_Toc132908037)

[6.1. Overview 25](#_Toc132908038)

[6.2. Identification of Patterns and Anomalies 25](#_Toc132908039)

[6.3. Refinement of the simulation mode 25](#_Toc132908040)

[6.4. Comparison with real Mars mission data. 25](#_Toc132908041)

[6.5. Summary 25](#_Toc132908042)

[7. Conclusion 26](#_Toc132908043)

[7.1. Overview 26](#_Toc132908044)

[7.2. Synthesis of research findings 26](#_Toc132908045)

[7.3. Potential of affordable platforms for space mission simulations 26](#_Toc132908046)

[7.4. Future work 26](#_Toc132908047)

[7.5. Recommendation 26](#_Toc132908048)

[References 27](#_Toc132908049)

[A. PID Document 29](#_Toc132908050)

[B. Ethics Certificate 30](#_Toc132908051)

# 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

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 a perfect replication. 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 analyse the data collected from the Arduino during the EDL process. The code will use statistical and data analysis tools to 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 Entry, Descent, and Landing (EDL) 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.

The Methodology chapter 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 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 simulations play in understanding the Entry, Descent, and Landing (EDL) process for Mars landings. Initially, the discussion involves a thorough analysis of existing research on space and its implications for humanity, scrutinizing 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 emphasizes the research gap in Mars landing simulations using Arduino microcontrollers, underlining the need for more accessible and cost-effective tools, particularly for smaller organizations 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 German rocket program joined the USA's program (Kennedy, 2007), 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 realized 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 and SpaceX at the forefront. NASA's Artemis program aspires to land the first woman and the next man 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 and international collaborations in space exploration has broadened the scope of research and innovation in this field. The democratization 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 characterized 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, one of the most fascinating planets in our solar system, has captivated human 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 civilization. Although this idea was later disproven, it is now understood that 3.5 billion years ago, the planet might have been habitable, 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 40 explorations have been conducted on the red planet since the 1960s. The first mission to Mars, the Soviet Union's Mars 1 in 1962, 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. 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 spacecraft 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 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 (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 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

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

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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.

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

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 is 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.

The third stage, Data Preparation, involved cleaning, transforming, and structuring the collected data to prepare it for modelling. This stage is also covered in the Methodology chapter, where the process of cleaning and processing the collected data was outlined. The collected data required no cleaning, but it was structured in a way that could be easily processed in the next stage.

The fourth stage, Modelling, involved developing models to gain insights into the research problem. This stage is covered in the Methodology and Results chapters of the report, where the simulation model of the EDL process is developed and evaluated using the collected data. The model was developed by programming the Arduino MEGA2560 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 collected data on critical parameters such as altitude, temperature, and acceleration, which were then analysed using Python scripts to identify potential errors in the EDL process.

The fifth stage, Evaluation, involved evaluating the models developed in the previous stage to determine their effectiveness in addressing the research problem. This stage is covered in the Evaluation chapter, where the simulation model is evaluated by comparing its results with actual data from previous Mars missions. The evaluation provided 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 summarized, 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 deviated from the initial plan. The chapter highlights these deviations and provides explanations for the delays.

The chapter then introduces the CRISP DM methodology, which was used to guide the research process. The methodology involved six stages: Business Understanding, Data Understanding, Data Preparation, Modelling, Evaluation, and Deployment. The chapter explains how each stage was applied to the project and provides examples of the tools and techniques used.

Finally, the chapter evaluates the effectiveness of the project management methodologies used. 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

### 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:

|  |  |  |  |
| --- | --- | --- | --- |
| Stage Number | Stage | Distance (cm) | Colour |
| 1 | Parachute Deploy | 200 | BLUE |
| 2 | Heat Shield Separation | 170 | GREEN |
| 3 | Radar Lock | 123 | YELLOW |
| 4 | Terrain Relative | 62 | WHITE |
| 5 | Backshell Separation | 33 | RED |
| 6 | Rover Separation | 10 | MULTICOLOUR |

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

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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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# 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

# 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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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**