Design &Development of a Lunar Rover (chandrayan type) for Indian Space Applications

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Abstract

The Moon has captivated human curiosity throughout history as it holds valuable insights into the early evolution of the solar system and our own planet. India's space exploration program, initiated with the Chandrayaan-1 orbiter mission in 2008, aimed to unravel the mysteries of the Moon. Building upon this success, India launched Chandrayaan-2, its most technologically advanced mission, to study the unexplored South Polar Region. This region poses numerous challenges due to extreme cold and perpetual darkness, making it a risky endeavor. The entire world was eagerly awaiting the outcome of this ambitious mission. Chandrayaan-1 made significant discoveries using remote-sensing instruments, including the detection of water signatures, identification of spinel minerals, and evidence of recent volcanism. Chandrayaan-2, consisting of an orbiter, lander, and rover, was launched in 2019. Although the Orbiter successfully reached lunar orbit, communication was lost with the Lander, resulting in an unfortunate crash with the Pragyan rover and scientific equipment. Despite the challenges faced, the Chandrayaan missions have contributed valuable knowledge about the Moon and have been a testament to India's achievements in space exploration. The work done & presented in this paper is the result of the final year one year project work that has been done by the final year engineering students of the college and as such there is little novelty in it and the references are being taken from various sources from the internet, the paper is being written by the students to test their writing skills in the final stages of their engineering career and also to test the presentation skills during their final year project presentation and the work done & presented in this paper is the report of the undergraduate project work done by the students.

Keywords Planetary Exploration, Lunar Orbit Insertion, Orbiter Craft, Lander Craft, Lunar Rover, Soft Landing, Landing Sites, Craters.

1. Introduction

The Moon, the largest and brightest celestial object in the night sky, has been a focus of scientific exploration for many years. Various missions have been launched to study the Moon's surface and orbit. In 1959, the Soviet Union's Luna missions made significant advancements, with Luna 2 being the first spacecraft to impact the lunar surface and Luna 9 achieving a controlled soft landing. India joined the lunar exploration race with the launch of Chandrayaan-1 in October 2008, marking its first planetary exploration mission. Building on this success, Chandrayaan-2 was launched in July 2019, consisting of an Orbiter, Lander, and Rover. The GSLV MK-III M1 was used to carry the spacecraft to the Moon, with the Orbiter and combined stack being inserted into a lunar orbit. The Lander and Rover were planned for a soft landing near the Moon's south polar surface. These missions represent significant milestones in lunar exploration and demonstrate India's growing capabilities in space exploration.

2. Objective or the project work

Chandrayaan-2 aims to expand on the achievements of the Chandrayaan-1 mission by introducing new technologies and conducting experiments on the lunar surface. The rover will collect samples and perform on-site analysis, transmitting data back to Earth through the orbiter. The orbiter, on the other hand, will conduct comprehensive mapping of the lunar surface, study the lunar exosphere, and delve into the origin and evolution of the Moon. The mission's primary objective was to successfully soft-land the lander (Vikram) and operate the rover in the Moon's South Polar Region. Scientific goals include studying topography, seismography, mineral identification, surface composition, soil characteristics, and the lunar atmosphere. Unfortunately, during the landing attempt, the lander deviated from its intended trajectory and communication was lost. Chandrayaan-2 presents an opportunity for ISRO to showcase its advanced systems and technologies, attempting controlled landing maneuvers and successful rover deployment, thereby pushing the boundaries of Indian space technology.

3. Literature reviews / surveys

A brief review of the literature follows in this section [1]-[17].

- "Spacecraft command and data system simulator for the payload chaste in Chandrayaan-2 mission" by Aneesh, Dinakaran et.al. [2017]: This paper discusses the bus structure of the Orbiter Craft Module, which is a three-ton category structure created by HAL and delivered to ISAC for the Chandrayaan-2 mission. The paper also describes the modules of the Chandrayaan-2 mission, including the Orbiter, Lander, and Rover, and their propulsion and landing mechanisms [9].
- "Next generation rover for lunar exploration" by Harrison & et.al. [2008]: This paper discusses the design and development of a lunar rover with six identical, independent wheel components. The paper explains the suspension, drive, and steering systems included in each wheel module and the advantages of the vehicle's ability to "level" and "belly" on the ground [10].
- "Analyzing and Designing of Lunar Rover Motion Controller" by Jiang Huiping [2016]: This paper addresses the problem of lunar rover motion control and presents a motion control strategy that simplifies the complicated kinematics and classifies the lunar rover's motion control problem into Path following and point Stabilization [11].
- "Retrieval of Lunar Surface Dielectric Constant Using Chandrayaan-2 Full-Polarimetric SAR Data" by Kochars et.al. [2022]: This paper focuses on the use of high-resolution full-polarimetric synthetic aperture radar datasets for the retrieval of the dielectric constant of the lunar surface from the Fresnel reflection coefficients. The paper also shows that it is possible to retrieve the lunar dielectric constant via the classical Freeman-Furden decomposition (FDD) [12].
- "A Memorable Mission Conducted by ISRO" by Buddhadev Sarkar, Pabitra Kumar Mani [2020]: This paper discusses the significance of the Chandrayaan-2 mission, which aimed to wave the Indian flag on the dark side (South Pole) of the Moon, gather more scientific information about the Moon, and conduct a soft landing of the Lander and Rover modules [13].
- "Possible Landing site for Chandrayaan-2 Rover" [2016] by Callas et.al.: This paper discusses the selection of landing sites for the Chandrayaan-2 mission's Rover module based on communication, the shape of the landing area, the topography, and lightning requirements. The paper describes the primary and backup landing sites chosen by ISRO at the Lunar South Pole, where it is hypothesized that ice may form in areas that are permanently in shadow [14].

4. Problems to be solved in the project work

- To successfully perform a soft landing on the lunar surface and operate a robotic rover.
- To develop and demonstrate key technologies required for a complete lunar mission.
- To utilize the Orbiter for observing the lunar surface and facilitating communication between the Earth Station and Lander.
- To create detailed maps of the lunar surface, including 3D representations.
- To conduct extensive studies on the lunar topology, mineralogy, surface chemical composition, elemental abundance, and employ image processing techniques for lunar exploration.
- To develop an application for the analysis of data obtained from the Rover.

5. Highlights of chandrayaan-2

- To build upon the discoveries of Chandrayaan-1, as reported by the ISRO.
- To specifically target the unexplored "South Polar region" of the Moon.
- To conduct extensive mapping of the lunar surface in order to study variations in composition and gain insights into the origin and evolution of the Moon.
- To undertake a challenging mission by venturing into the previously unexplored South Polar Region, which no other space agency had reached before.

6. Challenge of moon landingss

Moon landing poses several challenges, including trajectory accuracy, communication with the deep space network, extreme temperature variations, lunar dust, lumpy gravity, and achieving a soft landing. Communication with the deep space network is crucial for controlling the satellite during the mission, providing commands and updates, determining the satellite's location and trajectory, and firing rocket engines and thrusters. India's deep space network, located near Bangalore (Karnataka) at Byalalu, plays a vital role in maintaining communication. Lack of communication can significantly impact mission success. Soft landing was a significant challenge in this mission, marking India's first attempt at a soft landing on the lunar surface. It required precise execution of rough braking and fine braking maneuvers by firing the onboard engines while ensuring the lander could absorb shock impacts without damaging its payload and systems. Another challenge is the extreme temperature variation on the Moon due to the lack of atmosphere. With a rotation period of 27.5 days, one side of the Moon experiences 13.6 days of continuous sunlight (lunar day) and the other side remains in darkness for 13.6 days (lunar night). During the lunar day, temperatures can reach up to 260°F, while during the lunar night, they can drop to as low as -280°F. These extreme temperature conditions need to be considered during mission planning and spacecraft design to ensure proper functioning (ISRO, 2019a).

7. Operations

Wheel module - According to the Daniel A. Harrison [7], in his paper "Next Generation Rover for Lunar Exploration", The Rover has six identical, independent wheel components. Systems for suspension, drive, and steering are included in each wheel module. Rover's suspension system enables a comfortable ride, as well as the capacity to "level" the vehicle, raise individual wheels, and place the bottom of the frame, commonly known as the "belly," on the ground. Chariot's capacity to put its "belly" on the ground is advantageous for a number of reasons, including making it easier for astronauts to board and exit the lunar truck, significantly lowering ground pressure when Rover is stationary, and requiring less maintenance work in many circumstances. The ability to "level" the vehicle has various advantages, including allowing the Rover to be levelled on uneven terrain, allowing the truck to "lean" into a slope, and enabling the positioning of tools at specific angles and heights.

The ability of Chariot to lift wheels independently has additional advantages, particularly with the six-wheel design: it enables Chariot to adjust the ground pressure at each wheel; increases the likelihood of escaping from "sticky" situations; offers a simple "work-around" of lifting a wheel off the ground if a wheel module fails; and, in many cases, lowers the maintenance effort. The dual-arm suspension on the Chariot has inboard active and passive components and is load-sensing. Figure 6 illustrates how the specially created arms make the most of Chariot's capacity to alter the wheel height and locate the majority of the suspension components inside the car for safety. The upper arm is controlled by the sequence of the active and passive parts. The wheel module can be individually lifted or lowered with a range of more than 20 inches thanks to the active element. To do this, a linear actuator and guide rails are used to modify the passive suspension's lower pivot point. A low-frequency system called the active suspension may go through its whole range of motion in less than ten seconds.

Many off-road vehicles use a twin coil-over-shock layout for the passive element. With this more conventional design, Chariot has a wide range of choices to stiffen or soften the ride as well as change the mid-range of the suspension for different payloads [7].

8. Power distribution unit

By using CAN bus connectivity, the Power Distribution Unit (PDU), shown in Figure 1, allows for the control and distribution of battery power as well as regulated low-voltage DC power to Rover subsystems. Three layers of bus voltage monitoring will be used. The Battery Management System will keep an eye on the battery bank (BMS). The PDU Controllers will receive the individual cell health information from this system. The PDU system will take preventative action to guard against the batteries' voltages falling below their minimum levels. The response will involve alerting the driver to the issue and the requirement for a recharge within a predefined window of time, turning off some optional features, and finally shutting down the car. Recognizing that the batteries could be damaged beyond repair. An electronic power supply sequencer will keep track of the output voltage of each converter. If the output of a converter veers outside of a predetermined window, this device will stop all converters. As a last resort, this will safeguard the electronics against disastrous occurrences. The PDU control software will keep track of the supply for each sub-assembly.

As part of a health package, the voltage measurement will be transmitted to the chassis off chassis processor. The PDU control software will flag and alert the operator if the voltage is outside of a predefined window. Two layers of bus current monitoring will be used. The PDU control software will keep track of each converter's output current. As part of a health package, the current readings will be transmitted to the vehicle's off-chassis processor. The off-chassis processor may be located at a teleoperator station or on the crew housing system. In the event that the converter's output exceeds a predetermined value, the PDU control software will shut down the converter. As a last resort, this will safeguard the electronics against disastrous occurrences. The Fig. 1 gives the overview of the battery system.

9. Battery system

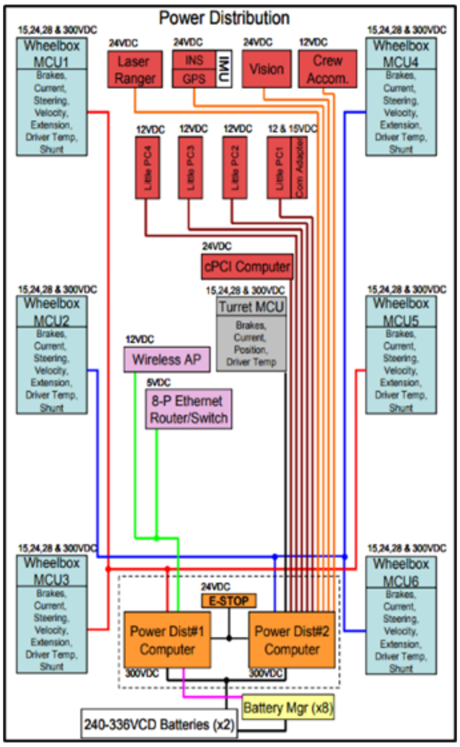

Fig. 1 : Power distribution unit

Since the batteries are connected in series, it is crucial that the "state of charge" of each battery always matches [7]. A BMS, also from Lithium Technology, is utilized by the Rover to keep track of each battery pack's temperature and cell voltage. If any cell voltage drops too low or if the temperature limit is reached, the BMS will cut off vehicle power. The BMS additionally keeps an eye on the battery system when it's charging, which might be risky if done incorrectly. Overcharging has the potential to cause lithium metal to plate out, which is a very dangerous condition [7].

10. System software

The software on the Rover system is extremely basic for its initial release. An embedded PowerPC running the vxWorksTM operating system in a small PCI chassis function as the brains of the system. Three CAN devices operating at 1 MBit/s are the Rovers's only sources of input and output (I/O). The power system, left and right side of the car, and CAN devices are all under its control. The network traffic was divided to increase the system's throughput. The power distribution system regulates the power distribution system and keeps an eye on the batteries. A module that handles low-level control, sequencing, safety features, and I/O is at the center of the

Rover program. The low-level safety and sequencing operations act as a simple system manager. The inverse kinematics solution of the vehicle points all wheels at the same location in space using the instantaneous centers method. The wheels are then turned at the correct speeds to propel the car at the desired linear and angular rates. The output of a visualization tool used to test the driving kinematics of the Chariot is shown in Fig. 2. The six wheels of the car are represented by the arrows in the tool.

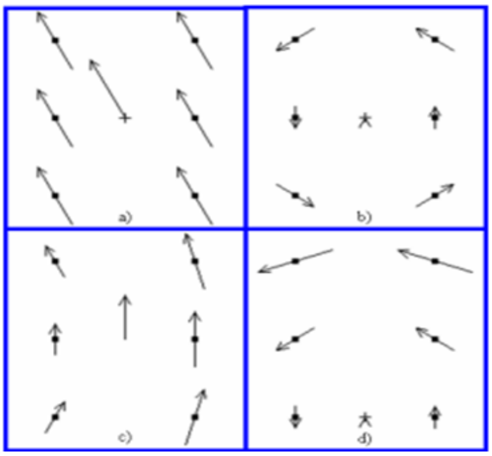

Fig. 2: a) driving in a general direction; b) zero turn radius;
c) double Ackerman driving; d) turning about a general position.

The direction the wheel points in is indicated by the angle of the arrow. The size of the arrow indicates the wheel's drive velocity. An application programmer's interface allows an off-chassis processor to operate the system (API). This API is a clear interface for requesting data and status from the car as well as giving it driving and mode instructions. With the help of this API, the core motion system is able to handle commands consistently regardless of who is issuing them: an on-board driver, a teleoperator operating the vehicle across time delay from line-of-sight or inside a habitat, a semi-autonomous waypoint generator, or an Earth-based driver.

11. Timing Analysis

The system was created using two micro controllers. The synchronization of the two microcontrollers was crucial to the system's overall success. This is an important step in putting these kinds of systems into place. These two micro controllers receive the tasks from the systems in a time multiplexed fashion. [3]. Programs are created using timer control. A BDH controller timer is used to start the program for reading BDH data, and another timer is used to synchronously serially communicate with the spacecraft system. The data from the BDH is received using one of the timers in the spacecraft command and data system simulator, and UART communication is accomplished using the other timer. To create a time strategy to efficiently operate the system, timing analysis is carried out. Different timer counts are used for the timing analysis at various clock frequencies. Visual Basic software was created to calculate the timer count for various clock frequencies. Two different types of errors are seen to occur at random in synchronous serial communication. The Bit missing error - This error happens when bits are not received at a specific clock period. Bit duplication error - This error happens when the same bit is received more than once at various clock periods. Both errors are detrimental to system operations and are the result of improper synchronization between these systems [3][6].

12. Lunar rover control

Jiang Huiping addresses the challenge of motion control for lunar rovers. To tackle this problem, a motion control strategy is proposed, simplifying the complex kinematics and categorizing the lunar rover's motion control into two types: path following and point stabilization. Path following involves generating control inputs to guide the lunar rover along a predetermined reference path. On the other hand, point stabilization focuses on stabilizing the lunar rover from any initial position to a specified target position. The point stabilization problem is determined based on two conditions, namely the heading constraint condition at the target position. This means that point stabilization can be achieved either with a target heading position angle constraint or without a target heading constraint. By addressing these aspects of motion control, the challenges associated with lunar rover movement can be effectively tackled (Jiang Huiping)..

13. Proposed methodology

The block diagram of the project, consists of 3 parts Lander/Orbiter, Rover, and Base Station as shwon in the Fig. 3.

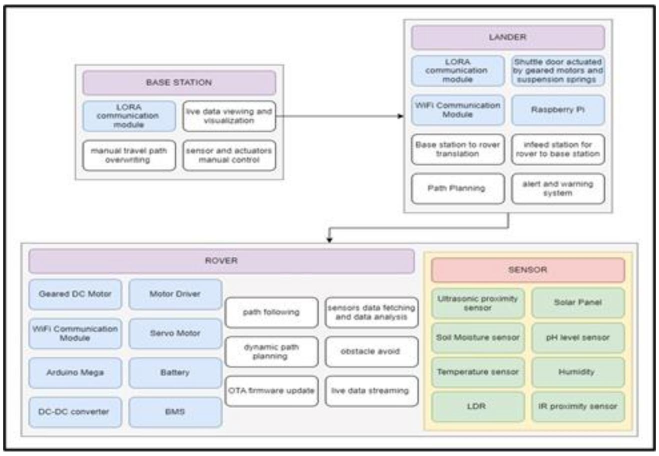

Fig. 3: Block Diagram

1. Orbiter/Lander: The Orbiter revolves around the moon and collects samples from the rover and then then transmits it to the Earth Station. When the Lander lands, the sensors connected to the wheels of the lander sends the signal to the motor which in turn rotates and slowly the door opens. Once the door is opened, it'll send a signal to the rover that the door is opened.
2. Rover: Once it receives the signal from the lander, it'll get ready to come out. When it moves to the surface of the moon, it will capture the images and sends to the Earth Station via orbiter.
3. Base Station: Here, the received signals from the lander are analyzed for further applications like Image processing and etc. Which is linked to a Mobile application or Website and Base station has control over all the process of the system.

14. Future advancement

In November 2019, ISRO officials announced their plans for a new lunar mission called Chandrayaan-3, which is being studied for a launch in November 2020. This mission aims to reattempt a landing on the lunar surface and enhance the landing capabilities of the spacecraft. Chandrayaan-3 is a collaborative project between India and Japan, scheduled for 2024. Unlike previous missions, this Lunar Polar Exploration Mission will not include an orbiter launched into lunar orbit. Instead, the proposed spacecraft will consist of a detachable propulsion system, a lander, and a rover, focusing on exploring the lunar polar region.

15. Conclusions

The mission to reach the South Pole of the moon was a matter of great national pride for India, marking the first-ever attempt by a country to explore that region. Although the landing of the VIKRAM rover on the moon was not successful, the project was considered a 95% success in terms of achieving its objectives, as stated by ISRO. Building on this achievement, ISRO has now set its sights on a new landing mission called Chandrayaan-3, which aims to land successfully on the lunar surface.

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