Design and Development of High-Performance Rocker Bogie Mechanism for Industrial Applications

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ABSTRACT

The Rocker Bogie system plays a crucial role in enabling in-situ scientific analysis of targets located at considerable distances, ranging from meters to kilometers apart. In contrast to complex mobility designs involving multiple wheels or legs, the Rocker Bogie design provides a reliable solution that minimizes mechanical failures in Mars' harsh environment. This design features a six-wheeled rover equipped with an efficient and highly mobile suspension system, enabling it to navigate challenging terrains with ease. A significant advantage of the Rocker Bogie design is its streamlined drive train. By utilizing only two motors for mobility, strategically positioned within the rover's body, the design achieves simplicity and efficiency. Insulating the motors from extreme thermal variations enhances their reliability and optimizes overall performance. Furthermore, the use of six wheels is justified by the infrequent occurrence of obstacles in Mars' natural terrain that require simultaneous climbing by both front wheels. Extensive mobility experiments conducted in diverse environments, including agricultural land, rough roads, inclines, stairs, and surfaces with obstacles, have verified the effectiveness of the Rocker Bogie design. These experiments have demonstrated the rover's capability to traverse significant distances across various types of terrain.

Keywords: - *Microcontroller, DC motors, Robotics, Telecommunications engineering, Batteries.*

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1. Introduction

NASA has recently embarked on an ambitious Mars exploration program, with the Pathfinder rover being the inaugural explorer in this endeavor. As future missions will require rovers to travel long distances spanning several kilometers over months, as well as perform tasks like manipulating rock and soil samples, there is a growing need for semi-autonomous capabilities. Rocker-bogie based rovers have emerged as strong candidates for these missions, although their physics present a complex challenge [1].

To design and effectively control these rovers, it is essential to develop analytical models that capture how the rover interacts with its environment. Additionally, models are necessary for rover action planning. Simple mobility analyses have been conducted on rocker-bogie vehicles to evaluate their design. However, the existing literature treats the rocker-bogie configuration as a planar system [2].

Efforts have also been made to enhance the performance of simpler four-wheel rovers. For instance, a vehicle called the Gophor explores the utilization of actuator redundancy and the manipulation of the center of mass to improve traction. This approach relies on real-time measurements of wheel/ground contact forces, which can be challenging to obtain. Another avenue for improving traction involves monitoring the skidding of rover wheels on the ground. Nonetheless, comprehensive models that account for the full three-dimensional mechanics of rocker-bogie rovers are yet to be developed. Furthermore, incorporating the influence of the manipulator in these models is crucial for effective planning and control of rover actions. Planners should be able to predict whether a given rover can successfully navigate obstacles, such as ditches, without becoming trapped [3]. Aluminum alloys are commonly used for the rover's structural components, including the body frame, chassis, and suspension arms [4]–[13]. Aluminum is lightweight, corrosion-resistant, and offers good strength-to-weight ratio, making it suitable for reducing the overall weight of the rover. Also, Titanium and titanium alloys find applications in critical components that require high strength, such as wheel hubs and drive shafts. Titanium offers excellent strength-to-weight ratio, corrosion resistance, and can withstand the harsh conditions on Mars. Composite materials are often employed in Rocker Bogie systems due to their excellent strength-to-weight ratio and specific mechanical properties [14]–[18]. FRP composites, also known as glass fiber composites, consist of glass fibers embedded in a polymer matrix. They provide good strength and are relatively cost-effective compared to CFRP [19]–[23]. FRP composites are commonly used in non-structural components of Rocker Bogie rovers. Sandwich panels consist of lightweight core materials (e.g., foam or honeycomb) sandwiched between layers of composite skins. These panels provide exceptional strength and stiffness while minimizing weight. They are often used in structural components of Rocker Bogie systems, such as the rover's body panels or load-bearing elements. Composite materials offer several advantages for Rocker Bogie rovers, including weight reduction, enhanced structural integrity, and improved performance in demanding terrains [24]–[29]. The specific choice of composite material depends on factors such as the mission requirements, desired mechanical properties, and the trade-off between weight and durability[30]–[35].

This paper presents a physical model of a rocker-bogie rover. It outlines an efficient approach to solving the rover's inverse kinematics and quasi-static force analysis, accounting for factors such as the manipulator, actuator saturation, and tire-slip. Additionally, a graphical interface is described, enhancing the understanding of the model's physics.

2. Literature Survey

In India, the Indian Space Research Organisation (ISRO) has been actively involved in space exploration and rover missions. While ISRO has primarily focused on lunar exploration with missions like Chandrayaan-1 and Chandrayaan-2, the Rocker Bogie system has not been extensively mentioned in the context of Indian rover missions. It's worth noting that the Rocker Bogie system is a well-established mobility concept used by various space agencies worldwide, including NASA's Mars rovers. However, the specific application and development of Rocker Bogie systems in the Indian space program might not have received significant attention or publication in the literature. In line with the future principle of cost-effective space exploration, there is a growing need for rover designs that offer enhanced flexibility during field operations. While obstacle detection and avoidance algorithms contribute to increased safety, the overall speed of a rover is often limited by its suspension design. For instance, existing Mars Exploration Rovers have a maximum speed of 5 centimeters per second on flat, solid ground. However, to prioritize drive safety, these rovers are equipped with hazard avoidance software that prompts them to periodically halt and reassess their position. Consequently, the average speed during field operations is typically around 1 centimeter per second due to the implementation of these safety protocols.

Nonetheless, it is inevitable that future rovers, benefiting from advancements in software improvements and suspension design, will be capable of achieving higher speeds compared to current capabilities. This shift towards higher speeds will be driven by the continuous refinement of software algorithms and the development of more robust suspension systems, ultimately enhancing the overall efficiency and productivity of future rover missions.

The "Lunakhod" rover was chosen as the pioneering geological exploration vehicle for planetary missions. It was deployed on the Moon twice as part of the Luna missions conducted by the USSR. The primary objectives of the Lunakhod missions were to collect valuable information and capture images of the lunar environment. The Lunakhod rover operated under real-time guidance from a dedicated team of five individuals stationed at the Deep Space Center near Moscow, USSR. One of the most remarkable achievements of the Lunakhod missions was the successful exploration of the lunar Mare Imbrium, also known as the Sea of Rains, by the Lunakhod-2 rover. This mission lasted for an impressive eleven months, during which the rover covered a remarkable distance of 37 kilometers across the lunar terrain. The Lunakhod-2 mission stands as one of the notable triumphs in lunar exploration.

The Shrimp rover, developed by the Swiss Federal Institute of Technology - EPFL, offers a distinct design with its six-wheeled configuration. It incorporates a unique front four-bar mechanism that enables it to efficiently climb obstacles of up to two times the wheel diameter without compromising stability. In the middle section, four wheels are arranged in a parallelogram bogie formation, which effectively balances the reaction forces exerted by the wheels during climbing maneuvers. To enhance its climbing capability, the Shrimp rover features direct connections between the single back and front wheels and the main body. These wheels are driven by motors, further augmenting the rover's ability to tackle challenging terrains and obstacles. The Shrimp rover's design showcases a focus on optimizing climbing capacity while maintaining stability and efficiency during its exploration missions.

In addition to exploration, the Rocker Bogie rover holds potential for applications in military and civil domains, emphasizing the need for cost efficiency and speed. Our primary objective in developing the rover will be to optimize its speed, ensuring it maintains stability and avoids flipping while enabling faster travel. Simultaneously, we aim to enhance cost efficiency by maximizing rigidity and robustness in the rover's design. To achieve these goals, we are actively exploring the incorporation of solar energy as a power source for the rover. By harnessing the sun's energy, we aim to reduce dependence on traditional fuel sources, enhancing sustainability and minimizing operational costs. Additionally, we are diligently working on modifying the rover's structure to enhance its capabilities in rugged terrains, enabling it to traverse challenging landscapes with ease. Through these combined efforts, our objective is to create a Rocker Bogie rover that excels in terms of speed, cost efficiency, and adaptability, allowing for versatile applications in various sectors while prioritizing sustainability and performance in demanding environments.

3. Proposed System

The rocker-bogie mechanism is a widely utilized suspension system employed in rovers and various vehicles to enhance their maneuverability over uneven and challenging terrains. This mechanism has gained prominence through its successful implementation in NASA's Mars rovers, including Sojourner, Spirit, Opportunity, and Curiosity. By employing the rocker-bogie system, these rovers have achieved remarkable stability and adaptability while navigating the rough and rocky landscapes of Mars. Here is an overview of the proposed luffing bogie mechanism system:

Seesaw Mechanism: The rocker-bogie system incorporates a seesaw mechanism that allows the rover to maintain stability while traversing uneven surfaces. It achieves this by distributing the weight of the vehicle evenly across its wheels, preventing tipping and maintaining equilibrium during movements.

Bogie Mechanism: The bogie mechanism forms a critical component of the rocker-bogie system. It provides the necessary flexibility and articulation to adapt to changes in the terrain, ensuring that all wheels maintain contact with the ground even on uneven surfaces. This enables the rover to navigate obstacles and rough terrain more effectively.

Steering and Controls: The rocker-bogie mechanism includes steering and control systems that enable precise maneuvering of the rover. These systems allow for efficient turning and navigation, enhancing the overall agility and responsiveness of the vehicle.

Determining the dimensions of the rocker and bogie linkages, as well as the angles between them, is a crucial aspect of manufacturing the rocker bogie mechanism. These dimensions and angles can be adjusted based on specific requirements. The objective of this work is to fabricate a rocker bogie mechanism capable of overcoming obstacles with a height of 150 mm (such as stones or wooden blocks) and ascending stairs with a height of 150 mm. Additionally, the mechanism should be able to climb surfaces at a 45-degree angle. To achieve these objectives, a rocker-bogie model was designed with an assumed stair height of 150 mm and length of 370 mm. By applying the Pythagorean theorem, the dimensions of the model were determined. The linkages in the model have angles of 90 degrees and 45 degrees. Designed rocker-bogie is shown in Fig. 1.

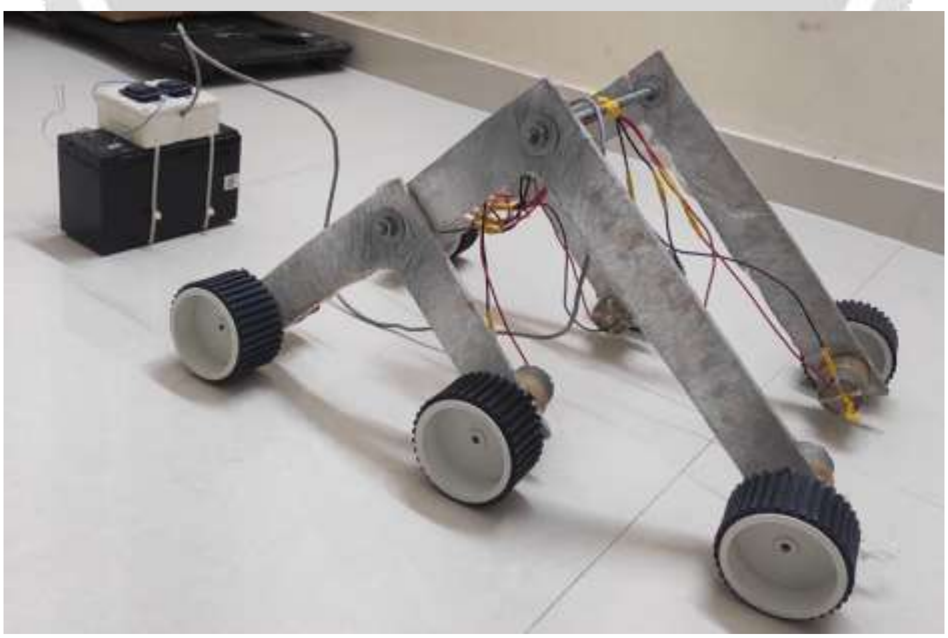

Fig 1: Photographs of the designed rocker-bogie mechanism.

4. Performance at Different Conditions

Based on the ground-level experiments conducted using the manufactured rocker bogie mechanism, satisfactory performance has been observed. The results of these tests are illustrated in Fig. 2(a-b), showcasing the performance of the rover on various obstacles and surfaces.

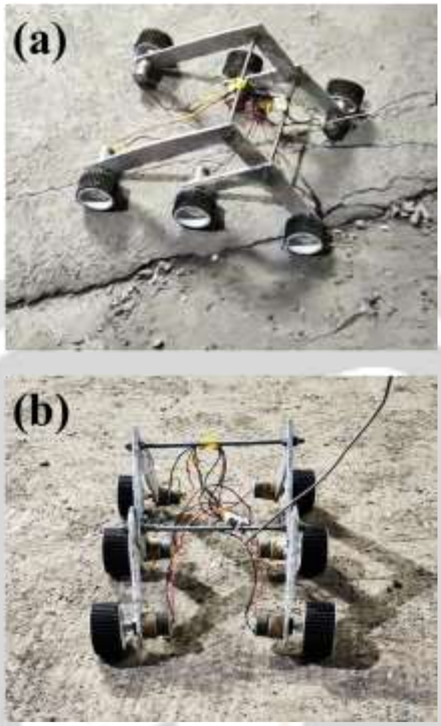

Fig 2: Photographs of field testing on (a) Inclined Road, and (b) Flat road.

5. Future Scope

The modular research platform developed as part of this project is designed to serve as a versatile foundation for future applications. Through advancements in technology, the rover can be utilized for reconnaissance purposes by integrating cameras and reducing its size. Additionally, by incorporating additional features such as robotic arms, it can be employed effectively in bomb diffusing operations, enabling the cutting of wires for bomb disposal.

Expanding on the concept, a larger model can be developed to transport both humans and materials across challenging terrains and obstacle-ridden areas like stairs. Furthermore, there is potential to adapt the rover into a wheelchair, providing mobility assistance to individuals in need. It can be deployed in valleys, jungles, or other hazardous locations where human presence may pose risks.

Moreover, the rover holds the potential to serve as a low-cost exploration vehicle, gathering valuable information about the environmental conditions of celestial bodies. By further refining its capabilities, it can be deployed for cost-effective exploration missions, contributing to our understanding of distant celestial bodies.

6. Conclusion

This research highlights the potential of utilizing classical four-bar mechanisms in constructing valuable mechanisms. These design possibilities can be explored using a new structural synthesis formula, which has been introduced and applied in the design of rover suspensions. Future studies can delve into the dynamic behavior of the suspension mechanism. It is evident that planetary exploration will remain a focal point in robotics, requiring unconventional mobility and robust robots. We hope that this study will contribute to the advancement of scientific knowledge in this field, adding another valuable piece to the growing body of research in industries, planetary exploration and robotics.

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