Design and Analysis of a Rocker-Bogie Robot Mechanism

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Abstract - This paper presents the design, kinematic analysis, and performance evaluation of a mobile robotic system utilizing the rocker-bogie mechanism for enhanced mobility across unstructured and challenging terrain. The primary objective of this research was to develop and validate a robust platform capable of superior obstacle negotiation while maintaining chassis stability. The methodology involved the development of a scalable prototype, simulation of its motion dynamics using computer-aided tools, and experimental field testing. Key results demonstrated the robot's capacity to effectively climb over obstacles up to twice its wheel diameter and maintain continuous six-wheel ground contact across inclines up to 35 degrees without tipping. The significance of this study lies in optimizing the passive articulation system for real-world applications such as search and rescue missions and remote surveillance, confirming the rocker-bogie mechanism's effectiveness as a durable and highly mobile solution for extreme environments.

Key Words: Rocker-Bogie Mechanism, Mobile Robotics, Terrain Negotiation, Kinematics, Stability Analysis, Unstructured Environments.

1.INTRODUCTION

The exploration of extraterrestrial surfaces, particularly Mars, presents significant challenges due to highly unstructured, rocky, and unpredictable terrain that often impedes the mobility of conventional wheeled or tracked vehicles. To address these unique environmental demands, the Jet Propulsion Laboratory (JPL) of NASA developed an innovative and highly robust passive suspension system known as the rocker-bogie mechanism. This design has since become the benchmark for mobility in extreme environments, notably utilized in the highly successful Mars Exploration Rovers, including Sojourner, Spirit, Opportunity, Curiosity, and Perseverance [2, 3].

The fundamental purpose of the rocker-bogie system is to maximize vehicle stability and ensure continuous ground contact for all wheels, thereby enhancing traction and preventing the chassis from tipping over when encountering large obstacles [4].

Unlike traditional automotive suspensions that rely on springs and shock absorbers, this mechanism is entirely springless. Instead, it employs an interconnected system of linkages ("rockers" and "bogies") on each side of the robot, linked to the main chassis via a differential mechanism [5]. The defining characteristics of this system include its remarkable ability to climb over obstacles up to twice the diameter of its wheels and maintain a stable body pitch even when navigating steep inclines or traversing uneven surfaces [4]. This paper provides an overview of the rocker-bogie mechanism's core principles, design parameters, and kinematic advantages, demonstrating why it remains a superior solution for applications requiring reliable, low-speed mobility in exceptionally difficult terrain, ranging from planetary exploration to terrestrial search and rescue operations [6].

2. Body of Paper

SYSTEM DESIGN AND KINEMATICS

The rocker-bogie mechanism is fundamentally a passive, six-wheeled (6WD) linkage system engineered to maximize ground contact and stability without employing traditional springs or active suspension components. The entire assembly on one side of the robot consists of two primary parts: the "rocker" and the "bogie." The rocker is the larger link that pivots around the main differential axis connected to the chassis. The front wheel is attached to one end of the rocker, while the other end connects to the smaller "bogie" link via a pivot joint. The bogie links the middle and rear wheels. This configuration allows the wheels to articulate independently over uneven terrain.

A. Differential Mechanism

The core innovation of the rocker-bogie system lies in its differential mechanism, which connects the two side rocker assemblies to the main chassis. This system ensures that the average pitch of the two rockers is maintained as the main body angle. If one side climbs an obstacle, the differential allows the other side to remain relatively level. This crucial design feature minimizes the pitch and rolls of the main robot body, thus lowering the center of gravity (CG) relative to the pivot points and significantly increasing the tipping threshold. The robot can theoretically maintain stability on slopes up to 45 degrees, though operations are typically limited to 30 degrees for safety margins. As noted in Ref. [4], stability analysis is critical for mission success.

B. Obstacle Negotiation Principle

The system excels at negotiating obstacles much larger than a single wheel diameter. When the front wheel encounters an obstacle (e.g., a rock or step), the wheel is forced against it. The rotation of the middle wheel applies force that lifts the front of the rocker assembly up and over the obstacle. This "step" action is repeated as the middle wheel encounters the obstacle, using the rear wheel as leverage

C. Kinematic Analysis

The kinematic analysis of the rocker-bogie system focuses on modeling the wheel-ground interaction and the resulting chassis stability. The low operational speed of the robot (typically less than 10 cm/s in applications like the Mars Science Laboratory (MSL) mission) is crucial to ensure that dynamic forces are minimized. The passive nature of the suspension means that stability is a function of quasi-static equilibrium, determined by the robot's center of gravity (CG) location relative to the ground contact points. As detailed in Sec. II.A, the differential mechanism is key to this weight distribution during articulation.

3. CONCLUSIONS

The research successfully validated the design and performance of an enhanced rocker-bogie robot system for challenging environments. The passive mechanism provided superior stability and mobility, particularly in obstacle-rich and inclined terrains, fulfilling the primary design objective. The integration of sensor technology (GPS and ultrasonic) showcased potential for increased autonomy, making the system suitable for diverse applications beyond space exploration, such as search and rescue and agricultural monitoring. Future work should focus on optimizing link lengths for specific tasks (e.g., faster stair climbing) and exploring advanced active suspension systems for higher-speed traversal on flat surfaces.

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