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Design & Manufacturing of rocker-Bogie

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ABSTRACT

Taking six-wheeled rocker-bogie lunar rover as an object, on the basis of force analysis between the wheels and lunar soil, its obstacle-climbing force model on loose soil was established in this paper, and the wheel sinkages were obtained. Based on the method of solving the wheel's driving torque solution space feasible regions, this paper analyzed the forward obstacle-climbing capability of six-wheeled rocker-bogie lunar rover on loose soil, including single-wheel obstacle-climbing and two wheels obstacle-climbing simultaneously. Simulations show that under the loose soil environment, the wheels have different obstacle-climbing capability, i.e. the rear wheel is the best, the middle one is the worst and the front one is moderate

Keywords— Mars Rover, Rocker, Bogie, MSL.

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I. INTRODUCTION

The Rocker-Bogie system is the suspension arrangement used in the Mars rovers (mechanical robot) introduced for the Mars Pathfinder and also used on the Mars Exploration Rover (MER) and Mars Science Laboratory (MSL) missions. It is currently NASA's favored design.

The term "rocker" comes from the rocking aspect of the larger links on each side of the suspension system. These rockers are connected to each other and the vehicle chassis through a differential. Relative to the chassis, when one rocker goes up, the other goes down. The chassis maintains the average pitch angle of both rockers. One end of a rocker is fitted with a drive wheel and the other end is pivoted to a bogie.

The term "bogie" refers to the links that have a drive wheel at each end. Bogies were commonly used as load wheels in the tracks of army tanks as idlers distributing the load over the terrain. Bogies were also quite commonly used on the trailers of semi trailer trucks. Both applications now prefer trailing arm suspensions.

NASA recently started an ambitious exploration program of Mars .Pathfinder is the first rover explorer in this program. Future rovers will need to travel several kilometers over periods of months and manipulate rock and soil samples. They will also need to be somewhat autonomous. Rocker-bogie based rovers are likely candidates for these missions The physics of these rovers is quite complex.

To design and control these, analytical models of how the rover interacts with its environment are essential. Models are also needed for rover action planning. Simple mobility analysis of rocker-bogie vehicles have been developed and used for design evaluation. In the available published works, the rocker-bogie configuration is modeled as a planar system.

Improving the performances of a simpler four wheel rover has also been explored .In this work, actuator redundancy and the position of the center of mass of a vehicle (the Gophor) is exploited to improve traction. The method relies on real-time measurements of wheel/ground contact forces, which are difficult to measure in practice. Traction can also be improved by monitoring the skidding of the rover wheels on the ground .However; detailed models of the full 3-D mechanics of rocker-bogie rovers have not been developed. Further models including the manipulator's influence are also required to effectively planning and controlling the actions of these rovers. For example it is important for a planner to be able to predict if a rover can successfully negotiate a given terrain obstacles, such as a ditch, without being trapped..

This was the first planetary mission which has been wide public interest after first man on the moon. Small rover "Sojourner" conducted scientific experiments for 83 Sols (Mars Days) and took hundreds of photographs [1]. Roving on another planet came from dream to real by the help of science and patient ambitious research. This successful mission encouraged the scientists and NASA to continue the Mars exploration with new rovers.

Figure 1: Sojourner examining the rock named "Yogi" (Courtesy of NASA/JPL-Caltech)

Many rovers developed after Sojourner with different features and scientific objectives. In early days of January 2004, second and third rovers landed different locations on Mars named Spirit (MER1) and Opportunity (MER2). Scientific results of these powerful vehicles are bigger than their physical dimensions. All of the three rovers' success and scientific results show that space agencies will continue robotic geologists frequently in future.

It is obvious that rovers are important vehicles of today's solar system exploration. Most of the rover designs have been developed for Mars and Moon surface in order to understand the geological history of the soil and rocks. Exploration operations need high speed and long distance traversal in a short mission period due to environmental effects, climate and communication restrictions. Several mechanisms have been suggested in recent years for suspensions of rovers on rough terrain. Although their different mechanisms have found a widespread usage in mobile robotics, their low operation speed is still a challenging problem. In this research, a new suspension mechanism has been designed and its kinematic analysis results were discussed. Standard rocker-bogie suspension mechanism, which has been developed in

The late 1990's, has excellent weight distribution for different positions on rough terrain. New design, mostly similar to rocker-bogie suspension system, has a natural advantage with linear bogie motion which protects the whole system from getting rollover during high speed operations. This improvement increases the reliability of structure on field operations and also enables the higher speed exploration with same obstacle height capacity as rocker-bogie.

In this thesis study, new bogie mechanism consisted of double-lambda mechanisms, which has been firstly presented by Pafnuty Lvovich Chebyshev in 1869, is solved by analytically to define the positions and singular configurations. A new structural synthesis formula also has been introduced for such suspension mechanisms with lower and higher kinematic pairs. By using structural synthesis methods, a suspension mechanism has been designed with double-lambda mechanism. Equivalent force and moment functions were also derived with equation of motion method. The results are confirmed with the computer analysis made by Visual Nastran 4D. For this purpose, a computer model has been constructed and assembled with the same design parameters of NASA Mars Exploration Rovers (MER1 and MER2)

The Rocker-Bogie design has no springs and stub axles for each wheel, allowing the rover to climb over obstacles, such as rocks, that are up to twice the wheel's diameter in size while keeping all six wheels on the ground. As with any suspension system, the tilt stability is limited by the height of the center of gravity. Systems using springs tend to tip more easily as the loaded side yields. Based on the center of mass, the Curiosity rover of the Mars Science Laboratory mission can withstand a tilt of at least 50 degrees in any direction without overturning, but automatic sensors limit the rover from exceeding 30-degree tilts.[5] The system is designed to be used at slow speed of around 10 cm/s, so as to minimize dynamic shocks and consequential damage to the vehicle when surmounting sizable obstacles.

Each of the rover's six wheels has an independent motor. The two front and two rear wheels have individual steering motors which allow the vehicle to turn in place. Each wheel also has cleats, providing grip for climbing in soft sand and scrambling over rocks. The maximum speed of the robots operated in this way is limited to eliminate as many dynamic effects as possible so that the motors can be geared down, thus enabling each wheel to individually lift a large portion of the entire vehicle's mass.

In order to go over a vertical obstacle face, the front wheels are forced against the obstacle by the center and rear wheels. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle. The middle wheel is then pressed against the obstacle by the rear wheels and pulled against the obstacle by the front until it is lifted up and over. Finally, the rear wheel is pulled over the obstacle by the front two wheels. During each wheel's traversal of the obstacle, forward progress of the vehicle is slowed or completely halted. This is not an issue for the operational speeds at which these vehicles have been operated to date.

II.PROBLEM STATEMENT

he progression of society has always depended on the intellectual growth of mankind. Along with this intellectual growth comes the desire to explore and discover the unknowns of the universe. The National Aeronautics and Space Administration (NASA) is an agency dedicated to the exploration of the universe's mysteries. In the 1960's the agency was able to send man to the moon and revolutionize space exploration for the entire world. Today's focus has shifted somewhat from the moon towards exploration of the planet Mars. This passion is something that must be cultivated in young adults to encourage their imagination. The robots will operate on a terrain that is meant to simulate a lunar environment. This presents many difficulties and constraints regarding the design of the rover.

III.OBJECTIVES & SCOPE

- To contribute evidence in favor of using a track system as opposed to the traditional wheel system
- To use of track system in future rover designs
- To design an efficient rover involves the communication system
- To decrease the cost or increasing the life cycle of the lunar rovers
  SCOPE

The Rocker-Bogie Mobility system was designed to be used at slow speeds. It is capable of overcoming obstacles that are on the order of the size of a wheel. However, when surmounting a sizable obstacle, the vehicles motion effectively stops while the front wheel climbs the obstacle. When operating at low speed (greater than 10cm/second), dynamic shocks are minimized when this happens. For many future planetary missions, rovers will have to operate at human level speeds (~1m/second). Shocks resulting from the impact of the front wheel against an obstacle could damage the payload or the vehicle.

While there are many reasons to explore the moon and Mars, few have had enough economic potential to gain direct interest from the private sector. Due to the high cost of space exploration, most missions to date have been conducted by NASA and other government-supported organizations. However, the continually decreasing cost of technology and economic potential in natural resources has led some private companies to pursue space transportation and exploration as a core business. Existing rocker-bogie rovers cannot move at these higher speeds for several reasons.

1. The motors and gear boxes are inadequate to drive the vehicles at these
Speeds
3. The way rocker-bogies climb obstacles would cause the robot to be damaged
or flipped if it ran into an obstacle at these speeds..

The need to develop specialized high-fidelity systems capable of operating in harsh earth environments typically leads to longer development timelines and greater expenditures. While specific applications will always require unique designs, there are many commonalities in planetary rovers. Issues such as mobility, navigation, and vision, may differ slightly between missions but are largely the same in most scenarios. Given these fundamental characteristics of many planetary rovers we believe that a modular and ruggedized system meeting these basic requirements would aid in the process of developing space-ready technology. There are currently many mobile research platforms available, yet few are designed to operate in the harsh earth environments that are often used for planetary surface rover testing. By creating a rover that is suitable for these types of environments, our goal is to facilitate the development of rovers and their related technologies, in addition to lowering development costs. We also hope that the platform developed can be tested and improved upon, to potentially serve as a model for a rover that could go to the moon or Mars in the future. Our mission is to design, develop, and test a rover to serve as a research platform, suitable for testing planetary surface exploration technologies in harsh earth environments. The design will focus on incorporating features that are believed to be essential for most planetary exploration missions including:

1. Mobility and basic navigation
2. Tele-operation and intuitive user controls
3. Low mass and small form-factor

The rover will also aim to be low cost, ruggedized, and modular to allow for easy additions of custom or Commercial-Off-The-Shelf (COTS) hardware components. It will also have sufficient computing power and standard I/O ports to support a variety of additional payloads. The goal is to provide a platform that can be easily used for the development, testing, and validation of space exploration technology, both hardware and software.

IV.METHODOLOGY

DESIGN CONSIDERATION

Like all other design matters in engineering, robots are designed according to its working environment and purpose. Generally, wheeled robots have advantages on rough, sandy surface with carrying large bodies. Moreover, wheeled robots can rotate even on a spot without any skidding.

SUSPENTION

Wheeled locomotion's main component is its suspension mechanism which connects the wheels to the main body or platform. This connection can be in several ways like springs, elastic rods or rigid mechanisms. Most of the heavy vehicles like trucks and train wagons use leaf springs. For comfortable driving, cars use a complex spring, damping and mechanism combination. Generally, exploration robots are driven on the rough surface which consists of different sized stones and soft sand. For this reason, car suspensions are not applicable for rovers. The requirements of a rover suspension are;

• As simple and lightweight as possible
• Connections should be without spring to maintain equal traction force on
wheels.
• Distribute load equally to each wheel for most of the orientationpossibilities to prevent from slipping.

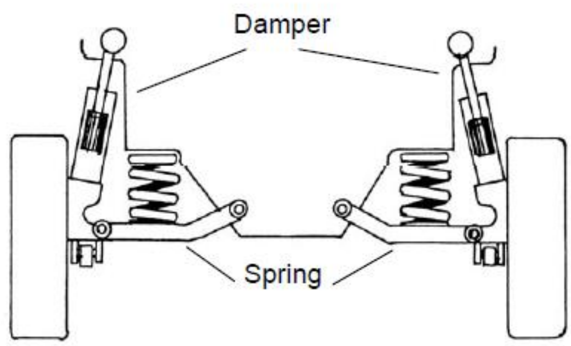

Figure 2: Independent car suspension system with damper and spring

Soft suspension systems with spring reduce vibrations and effects of impacts between wheel and ground. However, reaction force of pressed spring increases the force that transmits from wheel to ground. When climbing over an obstacle, higher wheel's traction force is more than the lover one which causes slippage.

OBSTACLE CAPACITY

A rover's obstacle limit generally compared with robot's wheel size. In four wheel drive off-road vehicles, limit is nearly half of their wheel diameter. It is possible to pass over more than this height by pushing driving wheel to obstacle which can be called as *climbing*. Step or stair climbing is the maximum limit of obstacles. The contact point of wheel and obstacle is at the same height with wheel center for this condition.

Field tests show that Mars mobile robots should be able to overcome at least 1.5 times height of its wheel diameter. This limitation narrows the mobile robot selection alternatives and forces scientists to improve their current designs and study on new rovers.

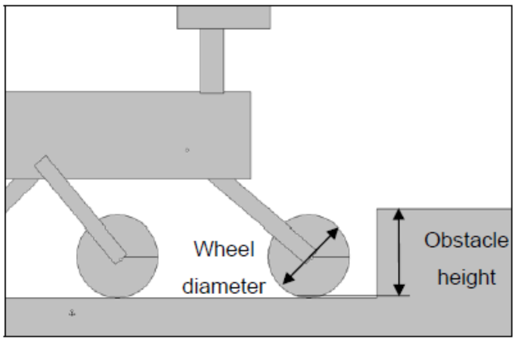

Figure 3: Definition of capacity

Former rover designs have different capacities. The rocker-bogie suspension which has been used on NASA Sojourner, Spirit and Opportunity rover can pass over 1.5 wheel diameter obstacles. The "Shrimp III" rover has extensive ability with a climbing wheel connected by rhombic four-bar has 2 wheel diameter height step obstacle capacity Although powerful climbing characteristics, rover's stability loses its advantage while driving down slope.
All these researches show that most of the rover designs have a climbing capacity between 1.5 diameters and 2 diameters of wheel. To reach higher capacities, active climbing methods are required.

ROCKER-BOGIE SUSPENTION

Rocker-Bogie suspension has been developed for first Mars rover Sojourner by NASA – JPL .This suspension has 6 wheels with symmetric structure for both sides. Each side has 3 wheels which are connected to each other with two links. Main linkage called *rocker* has two joints. While first joint connected to front wheel, other joint assembled to another linkage called *bogie*, which is similar to train wagon suspension member. In later design of articulated suspension system, called rocker-bogie with small changes.

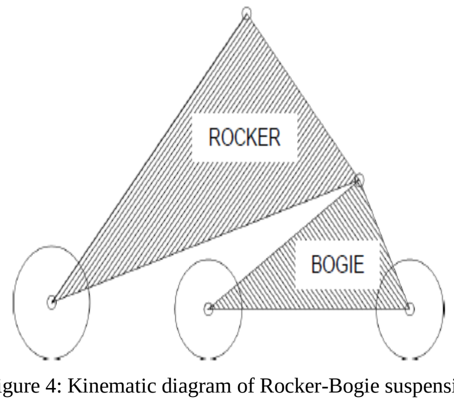

Figure 4: Kinematic diagram of Rocker-Bogie suspension

The main advantage of the rocker bogie suspension is load on each wheel isnearly identical. On different positions, wheels' normal force equally distributes contrary to 4 wheel drive soft suspensions . The connection between symmetrical lateral mechanisms is provided by a differential mechanism which is located inside the body. Rotation of axles which are connected two rockers are averaged, thus, vehicle body pitch angle always adapted even if one side steps over obstacle.

WHEEL MOTION

While driving on a flat surface, if there is no slipping, wheel center will move on a line parallel to the surface with constant velocity. Although, obstacle geometries can be different, most difficult geometry which be can climbed by wheel is stair type rectangular obstacle.

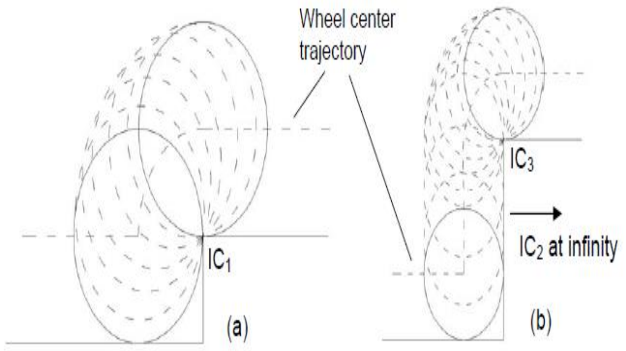

Figure 5: Wheel passing over same wheel diameter (a) and more than half wheel diameter (b) height obstacle

In figure 5(a), height of the obstacle is same or less than the half diameter of the wheel. For this condition, the wheel's instant center of rotation (IC1) is located at the contact point of the obstacle and wheel. Trajectory of the wheel centers' during motion generates a soft curve, thus, horizontal motion of the wheel center does not break.
Since in figure 5(b), height of the obstacle is more than the half diameter of wheel, this condition can be classified as *climbing*. Climbing motion consist of two sub motions. First one is a vertical motion, which causes a horizontal reaction force on wheel center . This vertical motion's instant center (IC2) is at infinity. Second one is a soft rotation similar to figure 5(a) with instant center of rotation (IC3) at the corner.

V. ADVANTAGES OF LINEAR MOTION

Although, load distribution advantage of rocker-bogie, a critical problem can occur when climbing over an obstacle. Wheel forces on opposite direction of motion produce a moment about pivot joint to rotate bogie.

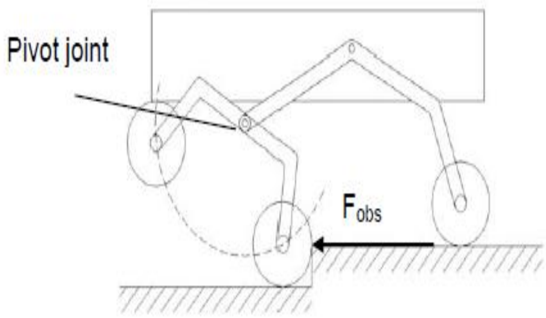

Figure 6: Bogie overturn problem

As we discuss in wheel forces, there are several forces act on wheel on x axis. If the surface friction of an obstacle is not enough to climb, obstacle force (Fobs) can reach high values. This problem can also occur while middle wheel actuator failure. Driving velocity is also restricted by bogie overturn problem. Bogie pitch angle can be adjusted by active control methods.

An easy solution method for this problem can be a linear motion suspension usage where obstacle reaction force cannot create any moment.

VI.CONCLUSION

In this thesis study, rover suspension mechanisms have been discussed. Linear motion mechanism of Chebyshev has been improved and applied for a Mars rover suspension mechanism. Results of the simulations and position analysis show that linear motion bogie has good performance during field operations. On the other hand, different designs should be discussed to improve the capacity of suspension.
This research also shows that it is possible to construct useful mechanisms by arranging classical four-bar mechanisms. These design possibilities can be discussed with new structural synthesis formula, which has been introduced and applied on rover suspension design.
Future studies may continue to discuss dynamic behaviour of the suspension mechanism. Anyone can see that planetary exploration will be the future robotics topic with unusual mobility and high stamina robots.

The purpose of this study is to put another stone on the pyramid of scientific knowledge. Although the art of mechanism design seems like it has lost its popularity due to the powerful control algorithms, there is no doubt that future robotics study will continue to search for new mechanisms.

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