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Implementation of a Robotic Rocker-Bogie Prototype

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ABSTRACT

Currently, many small Army ground robots have mobility configurations containing tracks with sets of dual or quad flipper configurations. Many of these robots include the iRobot PackBot, Talon, and Dragon Runner. While the preceding robotic designs have allowed these robots to navigate over obstacles and across low traction environments, an increasing need for agile robotic platforms in complex environments involving subterranean and urban structure missions will be critical in the future. Therefore, a new mobility system for dismounted ground robots is being researched to aid in the exploration, mapping, and identification by targets of interest for dense urban environments. This paper discusses one possibility for a new small CRS-I sized ground robot mobility system that is inspired by the rocker-bogie designs of the Mars rover systems.

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1. INTRODUCTION

Many of the small ground robots available to the Army consist of sets of tracks and flippers, used in combination to navigate over obstacles. However, this current mobility configuration presents problems for system performance in challenging environments, by reduced mobility in dense urban and subterranean terrain environments. Therefore, a potential solution to this problem is the adaptation of a rocker-bogie mobility system to a small robotic CRS-I size platform, that would demonstrate an increase in the current all-terrain capabilities for robotics within the Army. The inspiration to adapt a rocker-bogie mechanism onto a small robotic platform was due to research conducted by NASA for the first Mars rover Sojourner in 1997 [1].

None of the current ground robotic platforms for the Army utilize a rocker-bogie mobility system for terrain management and navigation, making this a unique problem to solve, develop, implement, test & evaluate. While the goal of this project was to develop, implement, and test a prototype, the robotic platform has not been fully tested and evaluated to determine with enough information that the system is an improvement over current Army mobility robotic technologies. Later studies will be conducted in comparison to a similar size iRobot PackBot system for terrain navigation and management.

For achieving a greater stability platform in future Army ground robotic configurations, a dynamic rocker-bogie suspension system is introduced in this paper in comparison to many current robotic systems. The remaining parts of the paper cover the design and implementation of the robotic prototype built. With the final goal of this prototype to be tested and evaluated in comparison with current CRS-I comparable robotic designs. Future evaluations will involve urban structure and subterranean test comparing: slope grades climbing 45%, surpassing vertical faces 2 times wheel height, simulated NIST rubble test track, and ascending descending stairs.

2. Current Army Small Ground Robots

Most available small robots for the Army utilize the same dimension for terrain management and mobility designs. Many of these robotic designs contain tracks, with and without flippers to assist the robot over obstacles and correct orientation figures (1-3). While the addition of flippers on many small ground robots provide a reliable system for navigating over obstacles and correcting orientation, the system is not designed for unstructured terrain within its environment. Many of these unstructured terrain environments are encountered on the battlefield and in dense urban environments where debris, rubble, and vertical faces are common. To combat these new and dynamic environments a rocker-bogie mobility system has been created for implementation on a robotic platform.

Figure 1: iRobot PackBot 510 [2]

Figure 2: Talon Robot [3]

Figure 3: Dragon Runner [4]

3. Robotic Rocker-Bogie System

The rocker-bogie mechanism has been studied in detail since the first introduction seen in the Mars rover Sojourner in 1997. Because of its robust capabilities to deal with obstacles, the rocker-bogie suspension system is successfully used in the Sojourner Mars Rover, MER (Mars Exploration Rover), and the latest MSL (Mars Science Laboratory) [5]. The purpose of the rocker-bogie designed mobility system for the first Mars rover Sojourner was to provide a stable platform for scientific instruments while still being able to navigate the rugged landscape of Mars, away from any human contact. This purpose presents a similar challenge to the current problems of navigating dense urban and subterranean environments where human contact is dangerous or limited.

However, the rocker-bogie suspension system still shows some shortcoming design features that will need to be considered. Average speed of operation is slow making the rocker-bogie system not ideal for situations where high-speed traversal over flat surfaces is needed to cover large areas in short periods of time [5]. For this reason, key design aspects can be used to help mitigate this shortcoming. With several design considerations, the following prototype of the robotic platform was completed as shown in figure (4).

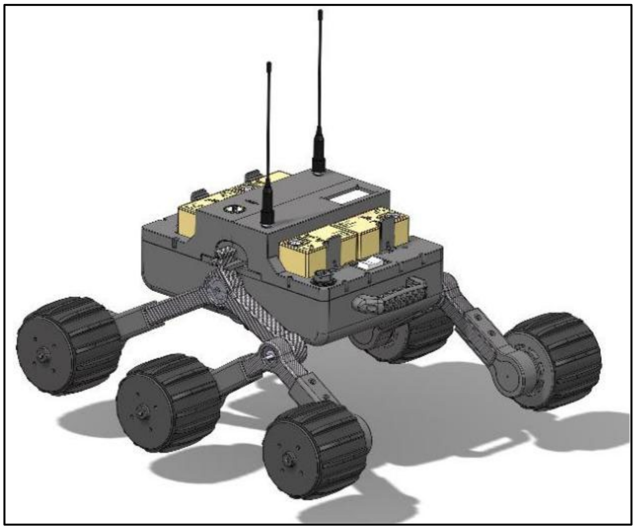

Figure 4: Prototyped Rocker-Bogie Robot

4. Implementation

To account for these design considerations to increase the stability of the rover across hard-flat surfaces. The first consideration was the mechanical design of how the suspension system was going to be integrated into a robotic platform. To minimize the slow traverse speed the prototype developed was designed to reduce the center of gravity by increasing wheel stability and averaging the body motion between suspension arms.

To reduce the center of gravity to allow for improved traverse speeds, the first consideration in the design was to reduce the forked arm height to the body of the robot between the rocker and bogie mechanisms, as seen in figure (5).

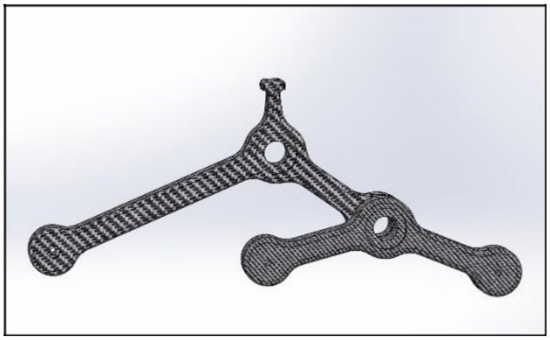

Figure 5: Rocker-Bogie Mechanism

By reducing the height of the rocker and bogie arms the center of gravity can be lowered to increase stability at higher speeds. However, considerations must be made in note to the wheel diameter being used. The purpose of many rocker-bogie systems is to allow the vehicle to climb an obstacle twice the diameter of the wheel [6]. Therefore, to have a successful rock-bogie suspension system navigate over an obstacle or vertical face equation (1) must be considered.

$$Height = 2 \times D \tag{1}$$

From equation (1) to have the vehicle chassis overcome an obstacle, the wheel diameter represented as D will have to be multiplied twice to get the clearance height for the rocker-bogie system. Allowing the height of the chassis to be less than the twice the wheel diameters increases the chance of the body snagging or bumping on an obstacle. Unanticipated body impediments are counterproductive to the purpose of a rocker-bogie system by providing the opportunity for body instability. To minimize impediments the total rocker and bogie arm heights shall be at least twice the wheel diameters chosen. However, design considerations for forked arm angles can impact mobility in turning by increasing the spacing between wheels.

Another factor was to account for wheel stability and improve the simplicity of a prototype design. Unlike the Mars rover such as Curiosity that has wheels that can independently turn [6], the rocker-bogie prototype discussed in this paper utilizes differential kinematics. This increases the simplicity of the prototype construction and the control by the user. The wheels were also widened, and rubber features were added to the 3D printed model to provide stability and traction.

Lastly, the most important key factor when addressing the design of the rocker-bogie suspension system is the need for the averaging of the chassis between the two rocker-bogie mechanisms. Providing an average body dynamic across both rocker and bogie suspension systems is critical in maintaining stability, allowing the body to maintain a rough average of the current terrain. This is achieved in the robotic design by the addition of an inverse cross brace to dynamically change with the rocker and bogie mechanisms figure (6). Without an average mechanism the robotic chassis will stay level to the current terrain causing dynamic changes in body pitch.

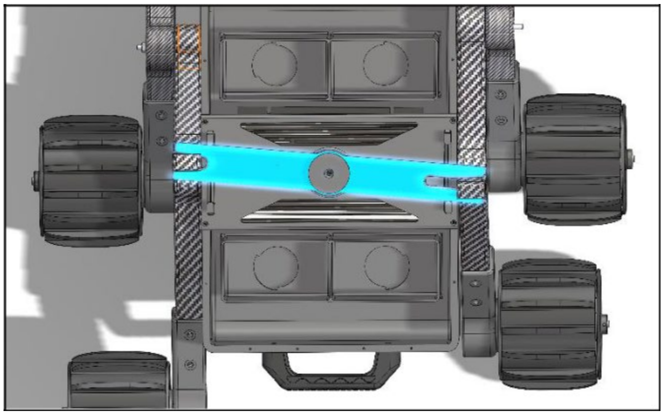

Figure 6: Averaging Mechanism

4.1. Kinematics

The kinematics for the prototype robotic rocker-bogie robot consist of 3 pairs of differential drive systems. Each differential pair works to control one axle to independently control specific wheel speeds [7]. On the robotic prototype shown in figure (4), each wheel has an independent motor controller where the motor is embedded in the wheel body, providing the rover with a reduced center of gravity. One differential pair equation has control over both right and left wheel speeds, then the same equations can be applied to the other differential drive pairs. The differential drive kinematics equations (2) are calculated using the wheel size and distance between pairs of wheels. Equation (2) shows the wheel speeds solved for both right and left wheels in terms of velocity values in the differential equations (2) [8].

$$\omega_r = \frac{1}{r}\left(v + \frac{w\lambda}{2}\right),\ \omega_l = \frac{1}{r}\left(v - \frac{w\lambda}{2}\right) \qquad (2)$$

Equation (2) shows that the velocity in the X direction is added to the width *w* and multiplied by the yaw rate λ. The same equation is taken into consideration for the left wheel speed just subtracted, and where each wheel speed is multiplied by the inverse of the radius *r* for the wheel speed. Finally, this equation can be adapted to each differential pair to provide the rover mobility in both the X and yaw directions figure (7).

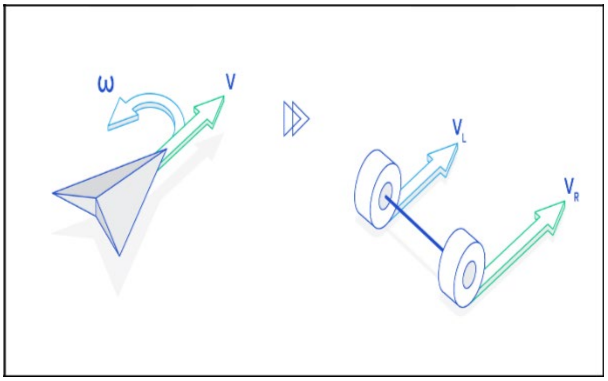

Figure 7: Differential Drive Representation in Velocity and Yaw Rate [9]

From the graphic shown in figure (7) a pair of differential drive wheels act independently, where left and right wheels will have changing velocities. Together, both wheels work to create a forward velocity of the robot or provide a yaw rate for left or right movement. Forward velocity is controlled by both forward wheel speeds, the same is true for reverse directions. While changing yaw rates for left orientation, the right wheel speed increases and left wheel speeds increase to change yaw rates for right orientation.

4.2. Electrical Subsystem

Much of the electrical subsystem for the rocker-bogie robot is designed to be modular with commercial parts, to rapidly increase development and reduce developmental cost. The electrical subsystem is divided into two main parts, power distribution, and data communication. For the power distribution portion of the robot, a series of BB 2590 military batteries are used to get a combined system voltage of around 34V. Battery voltage is then utilized to distribute the main power to all of the smaller power consumption modules such as processors, data hubs, motor drivers, and electric motors figure (8). To supply power to all modules within the robot battery voltage was divided into 12V and 24V subsystems by buck converters.

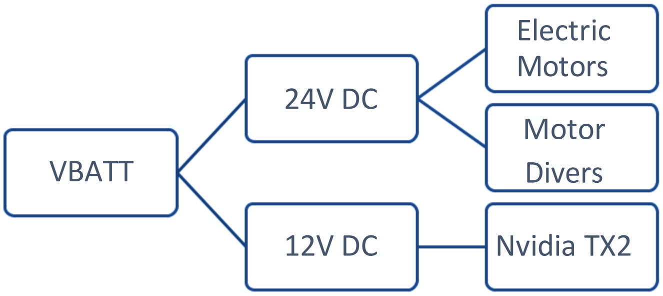

Figure 8: Power Distribution Subsystems

For the communication and data subsystem of the rocker-bogie robot the main processor is the Nvidia TX2 developer module. The TX2 developer module was chosen due to its small form factor, power, processing capabilities, cost, and ease of development. Whereas other embedded microprocessors of similar cost and size offer fewer advantages in processing, cost, and development. The data and communication system architecture are divided into 3 main parts one for each of the differential mobility drivers. With a Nvidia TX2 processor sending velocity commands over USB to UART (Universal Asynchronous Receiver-Transmitter) to each of the motor drivers shown in figure (9).

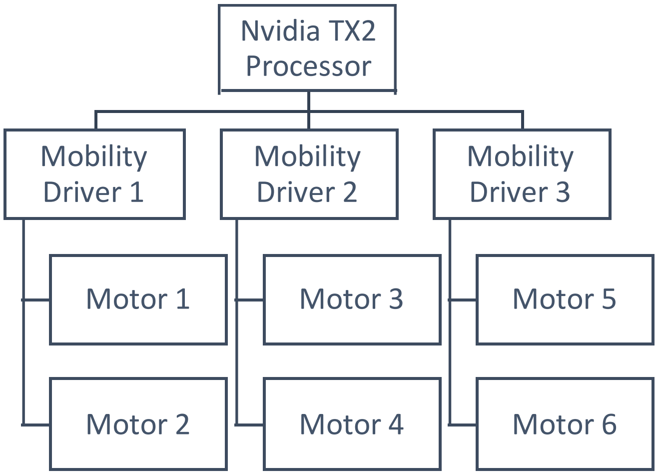

Figure 9: Hardware Architecture

The mobility drivers used in the prototyped design are Sabertooth 2x12 Dual 12A motor drivers. These motor drivers were chosen due to the high power and ease of integration, in many applications covering robotics or R/C control. Each Sabertooth 2x12 motor driver used in the rocker-bogie prototype has a unique address and can be controlled independently from the other motor drivers connected in series. The microprocessor embedded in the Sabertooth 2x12 motor driver allows the control of each motor velocity and direction based on the address, command, data, and checksum. Where the command signal controls the direction of rotation of the electric motors, and the data signal dictates the speed of the motors.

6. Software Subsystem

The software subsystem utilizes ROS (Robotic Operating System) to communicate to both OCU (Operation Control Unit) and embedded logic controllers. In detail, ROS acts as the network communication along with the low-level controller for motor actuation.

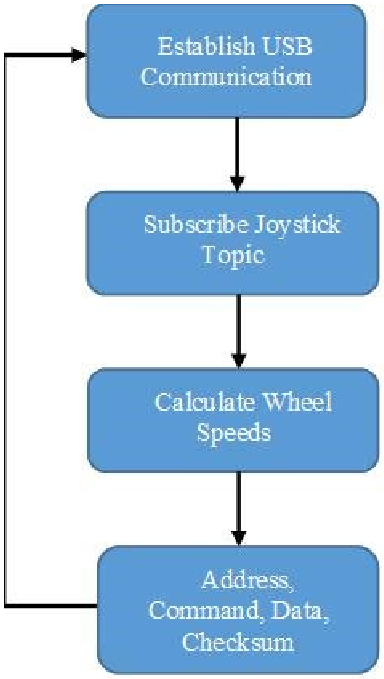

Figure 10: Software Flowchart

Much of the software is controlled by ROS nodes where the main mobility node establishes the USB communication, node subscribers, calculation of wheel speeds, and logic level commands. Figure (10) displays the software processes for the main mobility node. Once ROS has established USB communication and subscribed to the OCU controller node, then wheel speeds can be calculated using the differential equations discussed in the kinematics section of the report. Utilizing the information from the Sabertooth 2x12 motor driver, the results of the kinematics equations can be used to send the motor address, command, data, and checksum information over USB.

For the hardware communication over the */dev/ttyACM0* port a USB to UART converter was utilized. However, a static USB defined device is needed for the mobility node to connect low-level motor drivers. To help solve this problem a kernel device is created in the USB rule file for the Nvidia TX2 processor. If ports are not assigned based on connection information two devices being mapped to */dev/ttyACM0* and */dev/ttyACM1*, may switch depending which one was connected first in the system [10]. Therefore, port kernel configuration plays a key role in consistent system setup, by configuring the port, vendor identification number, and simulated link name. This creates a unique connection tree that remembers the device connected to the network. Once a static hardware description is created data can be transmitted to the low-level Sabertooth mobility drivers from the USB converter.

7. Improvements

Throughout the development, design, and implementation of the robotic rocker-bogie platform several improvements were observed. Where many of these improvements involve robust design parts and redesigns. However, some improvements will be adopted in the form of continued research based on many of the Mars rovers NASA has developed. One such design improvements to research is non-pneumatic tires (NPT).

Figure 11: NASA Non-pneumatic Tire [11]

NASA's current MSL rover utilizes the non-pneumatic tires to absorb shock by the utilization of memory alloys figure (11). With shape memory alloys, engineers can make a tire out of arches that support a mesh with no air inside [11]. These memory mesh designs and alloys play a key role in absorbing and balancing forces throughout the wheel from unstructured features. Non-pneumatic tiers can also be used as a suspension system handling 30 times the deformation that conventional spring steel - like car suspensions - can sustain [11]. This reduces the need for traditional suspension involving springs that none of the Mars rover are equipped with. Many other improvements will be discovered with future testing of the rocker-bogie robotic platform in comparison to Army current ground robot technology.

8. Conclusion

Detailed test and evaluations still must be completed to prove improvements over the traditional small Army robotic configurations. Later testing will include the rocker-bogie platform on the NIST (National Institute of Standards and Technology) testing facilities where performance in urban navigation will be tested. Success and failures will be scored in comparison to current small robotic systems. Detailed analysis will be conducted to determine overall performance in specific mobility categories. Each category will be in comparison to CRS-I Packbot robot converted to a GVR-bot platform. Categories will involve urban structure and subterranean test for: ascending slope 45% grades, climbing vertical faces, simulated NIST rubble test track, and navigating stairs.

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