High-Speed Traversal of Rough Terrain Using a Rocker-Bogie Mobility System

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Abstract:
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. This paper describes a method of driving a rocker-bogie vehicle so that it can effectively step over most obstacles rather than impacting and climbing over them. Most of the benefits of this method can be achieved without any mechanical modification to existing designs – only a change in control strategy. Some mechanical changes are suggested to gather the maximum benefit and to greatly increase the effective operational speed of future rovers.

The Rocker-Bogie System:

One of the major shortcomings of current planetary rovers is that they are slow. In order to be able to overcome significantly rough terrain (i.e., obstacles more than a few percent of wheel radius) without significant risk of flipping the vehicle or damaging the suspension, these robots move slowly and climb over the obstacles by having wheels lift each piece of the suspension over the obstacle one portion at a time. NASA's currently favored design, the rocker-bogie [1,2], uses a two wheeled rocker arm on a passive pivot attached to a main bogie that is connected differentially to the main bogie on the other side (see Figure 1). The body of the rover is attached

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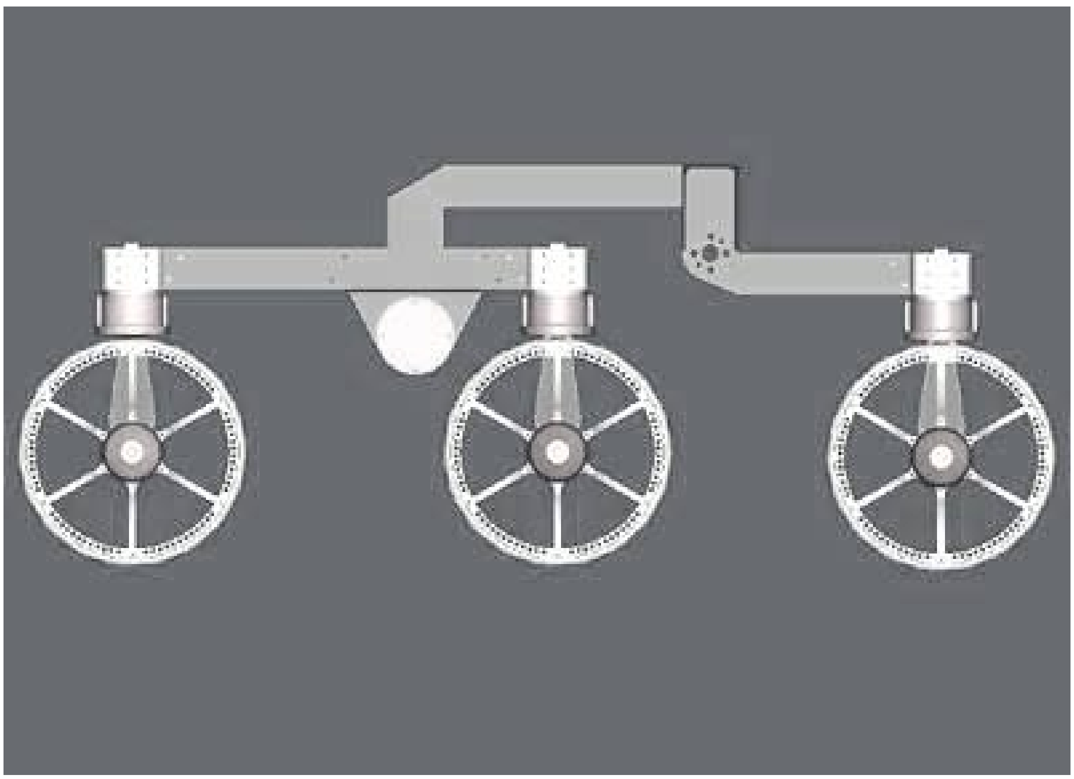
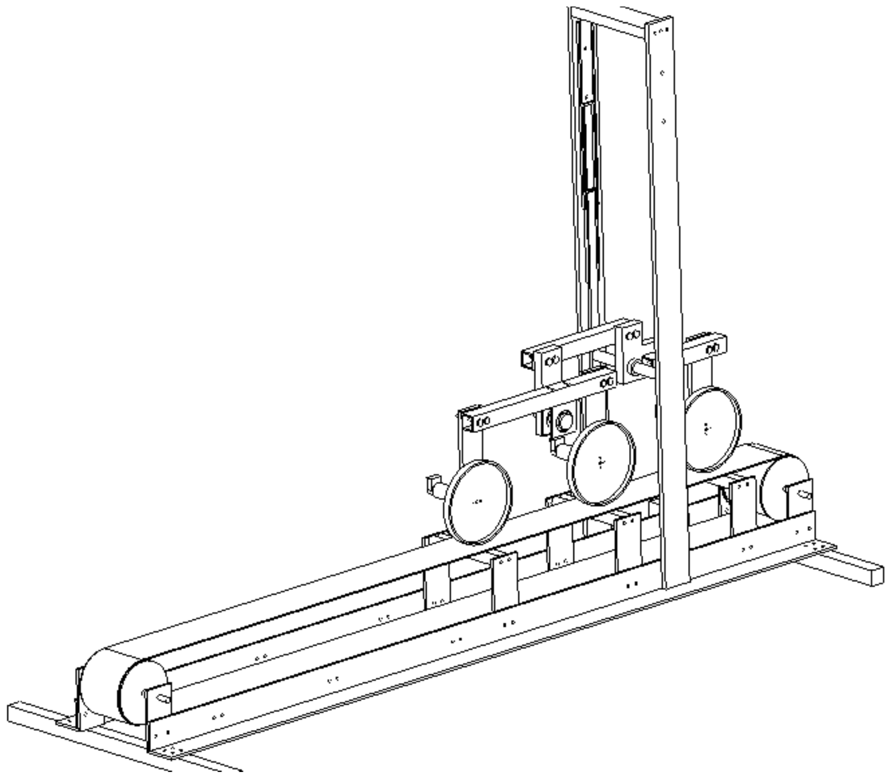
to the differential and so is suspended at an angle that is the average of the two sides. The ride is further smoothed by the rocker which only passes on a portion of a wheel's displacement to the main bogie. Each wheel is independently driven, and cab independently steered. The maximum speed of the robots operated in this way is limited to eliminate as many dynamic effects as possible, and so that the motors can be geared down so that the wheels can individually lift a large portion of the entire vehicle's mass.

Figure 1: Side View of Rocker-Bogie Configuration



In order to go over an obstacle, the front wheels are forced against the obstacle by the rear wheels. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle. The middle wheel is the pressed against the obstacle by the rear wheel 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.

Figure 2: The Rocker Bogie Test Track



The Need for Speed:

The latest version of NASA's family of rocker-bogies is JPL's FIDO rover[3,4]. NASA Ames has a copy of the rover which they have outfitted with an arm. The Ames copy has been dubbed K-9. The robots have a top speed of 6cm/second or .21km/hr.

One of the future applications for rovers will be to assist astronauts during surface operations. A small number of tests of this concept have been carried out. ASRO (Astronaut-Rover Surface Operations) tests were done during NASA's 1999 field test near Baker, CA [5]. One of the conclusions of these tests were that for the rover to be a useful assistant, it needed to be able to move much faster – it needed to approximate or exceed human walking speed which is 10-15X the current speed of FIDO. Other missions which have been proposed such as the Sun-Synchronous Lunar rover require even greater speeds (4-10 km/hr).

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
2. The frame is not strong enough to withstand the forces encountered at these speeds

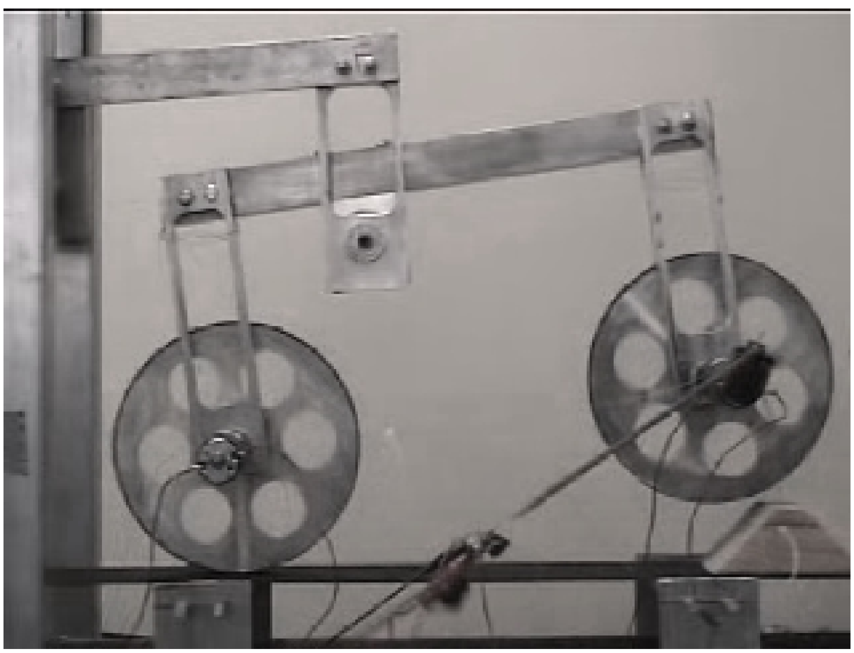
3. The way rocker-bogies climb obstacles would cause the robot to be damaged or flipped if it ran into an obstacle at these speeds.

The remainder of this paper will suggest a strategy to overcome these problems.

Test Track:

As was mentioned previously, existing rovers pretty much come to a dead stop when they first run into an obstacle with their front wheels. At high speeds, this shock would probably damage the frame and/or flip the vehicle. These problems could be overcome if the vehicle never impacted against the obstacle, but instead its wheels were lifted over the obstacles with no or limited contact. This can be accomplished by changing what was often considered a problem with rocker-bogies into a feature.

Figure 3: Front Wheelie



Most users of rocker-bogies have at one time or another had some wheels slip on the surface while other maintained traction. The result of this differential traction was for one or more of the robot's wheels to be lifted off the surface. If unchecked, this could cause a bogie to flip over, disabling the vehicle. Since experiments with the earliest rocker-bogie models, most of these robots have had mechanical stops added to the bogies to limit the amount of rotation allowed on any particular pivot. This has eliminated the danger of flipping a bogie, though the possibility of lifting wheels off the surface has remained.

To investigate this effect further, we have constructed the rocker-bogie test track (Figure 2). This consists of an un-powered conveyor belt and the left side of a rocker-bogie vehicle. At the differential point where the body would normally be mounted, the frame is mounted to a vertical bearing that is affixed to the conveyor belt frame. As the wheels turn, they move against the belt which also turns. The beams holding each wheel have been instrumented with strain gauges.

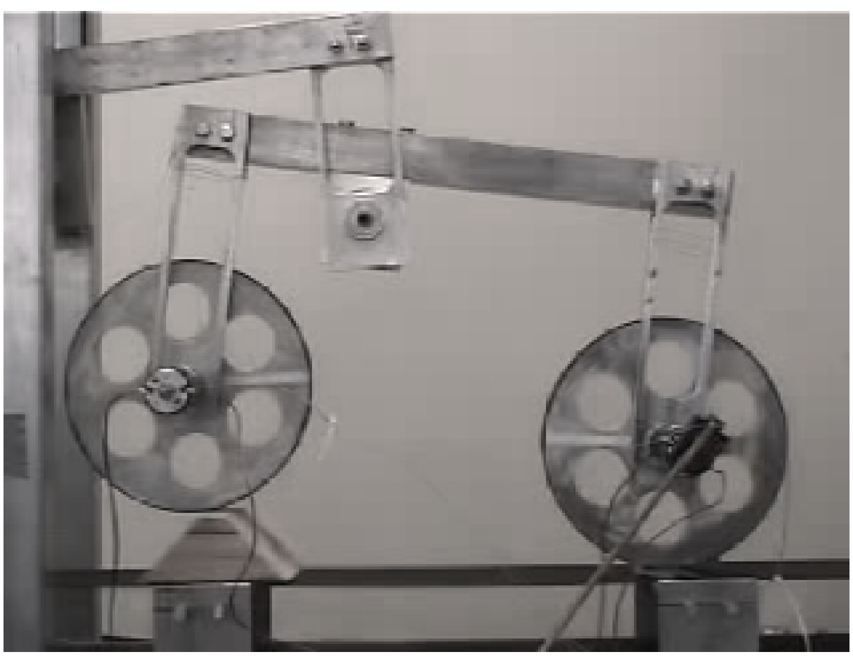
Wheelies:

The test track has been used to measure the forces acting on the rover frame as it encounters various sized obstacles at different speeds. The details of those results will be published elsewhere. Many of the shocks and stresses encountered by the frame may be reduced or eliminated by performing wheelie maneuvers. A wheelie consists of varying the speeds among the three wheels so that they articulate the frame in such a way as to allow the wheels to move closer or further apart. As this happens, one of the wheels is forced into the air.

To lift the front wheel off the ground (see Figure 3), the following actions are taken:

1. Run all wheels at same speed
2. When obstacle approaches front wheel,
    - speed up the middle wheel
    - slow the rear wheel
3. When obstacle is under front wheel
    - Return all wheels to normal speed

Figure 4: Middle Wheel Wheelie



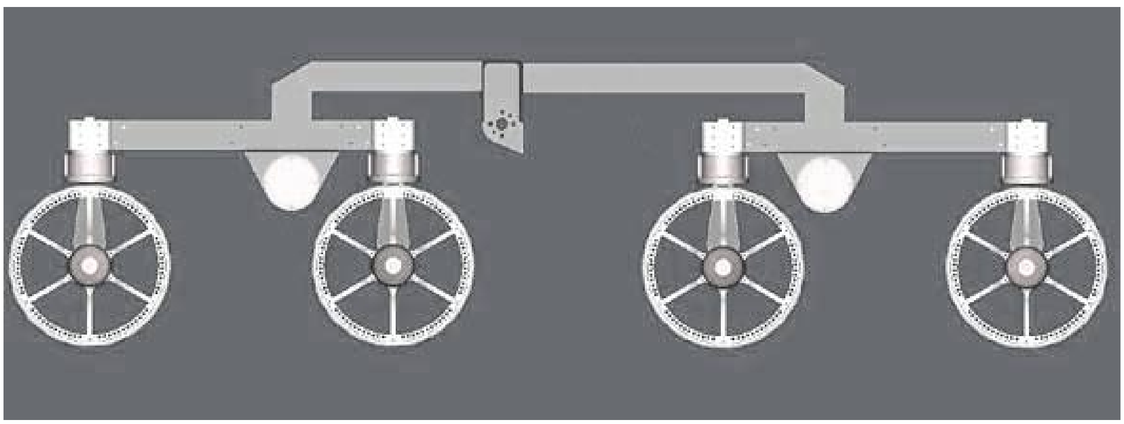
The middle wheel can also be raised to avoid impacting an obstacle by doing the following (see Figure 4):

1. Run all wheels at same speed

2. When obstacle approaches middle wheel
    - slow front wheel
    - speed rear wheel
3. When obstacle is under middle wheel
    - Return all wheels to normal

Unfortunately, there is no way to lift the rear wheel prior to it impacting the obstacle. This is because there is no equivalent to the front rocker on the rear side on which to lever the wheel off the ground.

Figure 5: Proposed Wheelie Friendly Design



Experimental Results and Mechanical Modifications:

The test track uses motors and gearboxes that are capable at driving the vehicle at speeds in excess of 1m/sec. The wheelie maneuver has been used at these speeds successfully (on the test track). The initial front wheelie is initiated when an obstacle gets within one wheel diameter of the front wheel. At this point the rear wheel is slowed and the middle wheel has the PWM signal given to it increased by 30%. When the obstacle is directly under the front wheel, the wheel speeds are turned back to normal, causing the front wheel to ride down the forward side of the obstacle. Based on the speed of the wheels, the middle wheel wheelie is initiated at the appropriate time, and the wheel speeds are returned to normal at a time when the object should be under the middle wheel. The initial sensing is currently done with IR proximity sensors.

We are in the final stages of constructing a full scale model of FIDO that differs from the original mechanically only in its wheel assembly. The assembly has been redesigned to accommodate the larger motors used in these high speed runs. We are also planning to modify the mechanical arrangement to that shown in Figure 5. This will allow us to perform the wheelie maneuver on all the wheels on the vehicle, and potentially traverse obstacles without any wheel impacts at all.

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