# 5 DESIGN AND DEVELOPMENT OF LOW COST ROLLING CYLINDER ROVER (CYBOT)

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Mobile robots are increasingly being used in high risk, rough terrain applications. Researchers are trying to find energy efficient and low cost means to provide multi terrain mobility. This paper discusses such a design and the fabrication of a low cost rolling cylinder robot rover. It consists of two collinear hollow cylinders that can rotate independently and thus steer differentially. The challenge is to be able to negotiate uneven terrain without making the rover oscillate about a point, a problem characteristic of its design. Simulation of candidate designs was done in ADAMS and a feasible design was then prepared in CAD. Deployable Legs and Suspension system have been added to establish versatility of the proposed all terrain rover. Radio Frequency (RF) control was added for remote operation. Successful experimental trial of the fabricated rover over a variety of terrain was done for validation and completion.

*Keywords:* Mobile Robot, Multi Terrain Rover, Deployable Legs.

## 1. INTRODUCTION

Ground autonomous mobile robots have important applications, such as reconnaissance, patrol, planetary exploration, and military operations. In order to accomplish tasks on rough terrain, control and planning methods must consider the physical characteristics of the vehicle and of its environment. To date major research has focused on methods for control and path planning on flat and rigid surface.[1−3] Much of this work is related to finding the most appropriate space in which to represent the robot actions during the navigation task. These methods are not well suited to rough terrain, since they generally do not consider vehicle and terrain physical properties.

There remain major rover design challenges which include increased autonomy of operation (e.g., capability for long ranging, accurate and uninterrupted autonomous traverse), self-guided traverse and mobility in more challenging terrain, reliability and operational fault-tolerance under long, unattended periods of use. Also most of the rovers are complex and expensive to fabricate with a large number of wheels/legs or moving parts.

This paper proposes a simple and robust design for the development of an inexpensive and energy efficient all terrain rover. The obvious advantages are that, the robot has an inherently safe form and it has an amazing capability to recover from collisions with obstacles or other robots. The entire system is enclosed within the shell providing mechanical and environmental protection. The deployable mechanism can be easily stowed and retracted and helps to climbs obstacles as much as three times the size of the rover. This provides unprecedented mobility and versatility for the all terrain planetary rover.

## 2. BACKGROUND AND DESIGN PROCESS

Design of autonomous robots for all terrain navigation has been pursued by researchers for many years. However, it has not been possible to develop a lot of low cost and energy efficient rovers. This is

mainly due to unpredictability of terrain and hence the difficulty in controlling the rover dynamically. This has resulted in studies on obstacle avoidance rather than obstacle negotiation.

Amongst most popular autonomous land robots is RHex.[4] RHex uses the compliance in its legs to negotiate a variety of terrain. However RHex being fully actuated is energy exhaustive. In an attempt to consider terrain properties, a few authors have proposed vehicles with spherical and cylindrical shape for all terrain purposes. Gyrover, developed at Carnegie Mellon University[5] is a single-wheel robot that is stabilized and steered by means of an internal, mechanical gyroscope. Gyrover can stand and turn in place, move deliberately at low speed, climb moderate gradients, and move stably on rough terrain at high speeds. It has a relatively large rolling diameter which facilitates motion over rough terrain; a single track and narrow profile for obstacle avoidance; and is completely enclosed for protection from the environment. Another such work is Cylindrical Mobile robot for all terrain use.[8] The robot has two internal wheels mounted on a vertical link. The wheels move, helping the robot to translate and steer. An external cylindrical shell that encloses a wheeled device (WD) to actuate and control the motion; the internal WD can move inside the cylindrical shell using a motorized and controlled wheel and a free wheel of guidance. A spring system keeps the drive and guidance wheels pressed on the internal track of the shell ensuring pure rolling motion without slipping. Experiments to find the rolling resistance on deformable soil measure were performed. The knowledge of the rolling resistance is used to optimize performance for various terrains. The closest counterpart to Cybot is Scout[6] developed at the University of Minnesota. Scout in its present form has deployable legs, IR camera and Proximity sensors. However, like many such rovers it isn't very energy and cost effective. From an application point of view, Scout is employed in swarms due to its low form factor, whereas Cybot enables standalone operation.

The design of each rover goes through different steps. The general mechanical structure has first to be proposed. It is then required to go through an optimization process to define the length of the elements of the structure, the position of the centre of gravity, the wheels' size and so on. The process ends with the plans depicting the mechanical constraints. Tools such as *Sysquake®, Adams®*[7] can be used in the optimization process. Similarly, if we write the dynamic equations for the rover, we would see that the system oscillates every time we apply torque on it. In order to make the prototype, the first step is to eliminate these oscillations by suitable additions in the design. Subsequently rover's functional capabilities were enhanced through design changes and lastly Radio-Frequency (RF) control was added to the rover in order to facilitate remote operation and handling.

## 2.1. Rover Design and Proposed Modifications

The Cylindrical Rover design consists of two co-linear hollow cylinders and a balancing tail attached to a hollow central cylinder. The central cylinder contains the actuators for the two wheels, thus keeping the components mechanically secured.

Various improvements are suggested to make the rover efficient and adept in handling rough and uneven terrain.

1. Deploy means to prevent oscillating of the cylinders when actuated.
2. In order to climb Stairs, small rocks etc, proposal to use deployable legs. The legs would be retracted in normal position and deployed in order to climb steps etc.
3. The surface of the outer cylinders can be made uneven or have small compliant extrusions like timing belt to help climb small obstacles and steps.
4. Proposal to add compliance to counter transverse vibrations due to terrain.
5. RF control for assisting in remote operation of the rover in hazardous terrain.

## 3. MATHEMATICAL MODELING

The mobility of a wheeled robot can be characterized by the drawbar force ($F_{Drawbar}$) produced. This force is a strong function of the normal force ($F_{Normal}$) between the wheel and the surface, the effective coefficient of friction between the wheel and the surface, and wheel torque ($T_{wheel}$) (Figure 1).
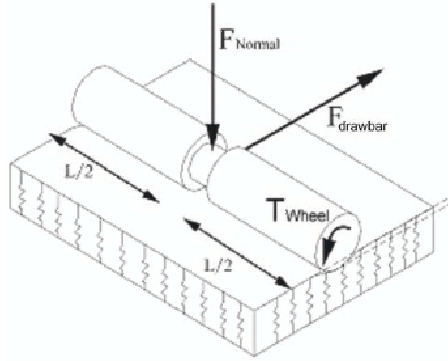
**Figure 1.** Three dimensional model of the rover.

The rotational equation becomes:

$$J\ddot{\theta}_{cm} = T_{wheel} - T_{shear} \tag{1}$$

$J$ is the rotational inertia of the robot and $T_{wheel}$ is the input torque applied by the motor, to the wheel.
Let $F_R$ = Friction Force.

Three cases arise depending upon the direction of the force:

$$T_{wheel} - F_{R1}R = J\ddot{\theta}_{cm} \tag{2}$$

$$T_{wheel} - F_{R1}R = 0 \tag{3}$$

$$T_{wheel} + F_{R1}R = J\ddot{\theta}_{cm} \tag{4}$$

Since the simulation results show that the robot oscillates before coming to a rest, it is evident that $F_R$ must be a function of $\theta$. However since such an empirical relation was unknown, further experimental validation was found necessary.

## 4. CAD MODELING AND SIMULATION

In order to better visualize the candidate design and perform experimental simulations, CAD Model was prepared in AUTOCAD Inventor[9] and MSC ADAMS.[7]

The material selected was PVC and weight of rover was found using standard material properties. The deployable mechanism (discussed later) was simulated and found to be working successfully. The ADAMS model (Figure 2) consists of two hollow cylinders (colored white) of 100 mm length and 25 mm diameter and 6 mm thickness, one solid inner cylinder (black) of length 50 mm and diameter 12.5 mm. The inner cylinder extends up to 20 mm inside the two outer hollow cylinders. A tail (27 mm length rectangular link, red) is added to prevent spinning. Standard value for Coulomb friction has been modeled

Simulation was done in ADAMS with and without a balancing tail. Simulation result showed that a simple rolling cylinder actuated at two revolute joints, tends to oscillate and ultimately comes to a stop. It was found that adding a tail to the rover was useful in stabilizing it and helped to propel the rover forward. This is due to the reaction force provided by the tail, which prevents the direction of friction force to change (Figure 1). Thus, the rover no longer oscillates and is able to move forward, as seen in ADAMS simulation.

## 5. FABRICATION

After successful modeling and simulation of the design for the rover and preventing the cylinder from oscillating, it was important to fabricate and test the design. The utility of the proposed changes such as deployable legs, treads, RF control etc can only be gauged upon successful fabrication and testing
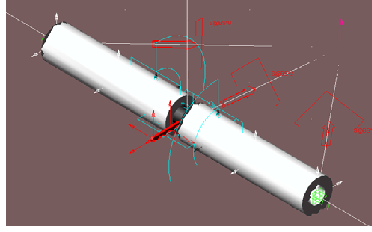
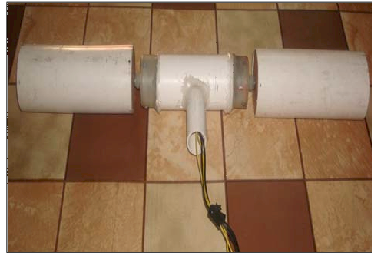**Figure 2.** ADAMS model of rover with balancing tail.



**Figure 3.** First prototype (tethered) with tail.

under various conditions, of the rover. The fabricated prototype consists of two hollow PVC cylinders, mounted on a smaller PVC pipe which contains the DC gear head Motors (100 RPM). A short hollow cylinder is added to the central pipe to act as tail and a conduit for the wires. The prototype (Figure 3) was tested and it moved successfully on flat ground.

## 5.1. Suspension System

After fabricating the minimalist prototype and successfully negotiating the problem of oscillation by adding a tail, the rover was found to lack the required compliance for negotiating uneven and rough terrain. Subsequent improvement over the basic prototype consisted of adding a suspension system.

A suspension system is an integral part of design of an all terrain rover. The profile of the terrain is often such that a suspension system aids in absorbing small transverse vibrations and also negotiating small obstacles with ease. In order to employ a suspension system in a rover there are two main alternatives:

1. Active Suspension system with feedback from the terrain
2. Passive suspension system.

Since, our primary aim is to make the robot energy efficient, the use of passive suspension system was found to be appropriate. It stores potential energy when it is flexed under stress and releases the strain and imparts additional torque. This saves actuator power at the cost of little additional weight of the suspension system. In order to make the design cost effective, flexible PVC pipe (used for sanitary works) was found to have sufficient compliance to provide vibrational stability for the rover, in small uneven terrain. Experimental trials were conducted with suspension added to both the wheels and the rover was able to successfully negotiate obstacles as well as absorb vibrations due to profile of the terrain. The rover is able to climb obstacles of height equal to the diameter of its wheels, with the aid of suspension system (Figure 4).

In addition to use of suspension system, Treads (in form of timing belt of a car) are added to the outer surface of the cylinders. It is found that the treads are helpful in negotiating small obstacles, stones,

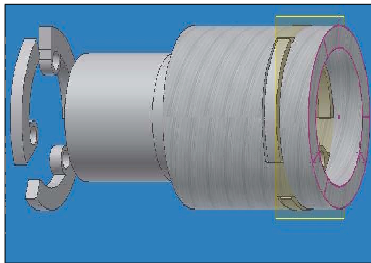**Figure 4.**   Experimental testing of passive suspension system.



**Figure 5.**   AutoCAD Inventor model of three leg deployable mechanism.

pebbles etc, as well as help the rover in forming a better grip over the terrain. At this stage, the rover is still kept tethered for simplicity and ease of testing (Figure 4).

## 5.2.   Design and Development of Deployable Mechanism

In order to assist the rover in climbing over larger obstacles or steps in its path, deployable legs were added to the robot. It is proposed that this unique leg-wheel system would be able to climb over obstacles more than thrice its size with ease. The legs should be such that, when obstacles are equivalent to the diameter of the wheel, the legs would remain stowed inside the cylinder. However, when the rover comes across large obstacles, the legs are deployed and raise the rover above the ground and using the geometry of the legs, it is able to negotiate obstacles as high as two to three times its size.

Designs of two different types of deployable mechanisms for the legs were considered, each having its unique advantages.

### 5.2.1. Cylindrical circumferential deployment mechanism

A circumferential deployment mechanism similar to ones used in stowed solar panels and antennae in satellites was designed (Figure 5). Three legs, each at 120 degrees could be deployed by planetary gear train using a single rotary actuator. The legs can be made from compliant material (polypropylene), to absorb shocks. A prototype leg was fabricated using CNC. This method was however, not eventually employed as it was not cost effective and was more complex than the umbrella mechanism, discussed below.

## 5.3.   Umbrella Mechanism

Prismatic motion is transferred to expanding and contracting of linkages in a simple one D.O.F mechanism (Figure 6). Rotary (actuator) to prismatic motion is converted using a simple nut and bolt arrangement. The advantage of this is that, the threads of the bolt provide a non returning action when it is not being rotated, and hence it can support the weight of the robot on the legs in that position. Also, low-cost umbrella is readily available and is very economical too.
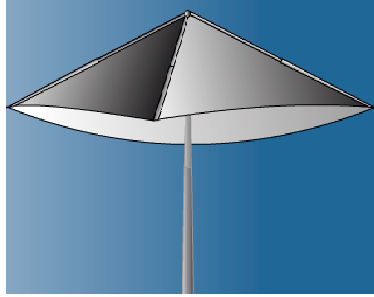
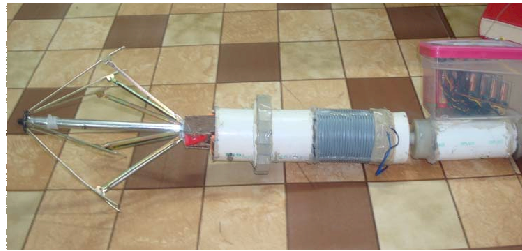**Figure 6.**   Schematic showing the deployment of an umbrella.



**Figure 7.**   Final prototype of the rover with deployed legs, treads and suspension system.

**Development of Deployable mechanism:** Umbrella mechanism was chosen to be added to proto-type of the rover since it was simpler to build and would reduce the manufacturing cost and time. Also relatively cheap umbrellas can be procured and assembled with minimum changes. This is very important as a major objective of the design is to be cost effective. A simple non returning nut and bolt arrangement was used to deploy the umbrella over the land.

## 6.   RADIO FREQUENCY CONTROL

The final prototype of the rover-Cybot is controlled remotely via R.F module mounted on top of the central cylinder. RF circuit of 40 MHz frequency, available in a toy car was used. In order to improve the current rating of the circuit, relays were used. Relay was triggered from the signal received in the RF receiver and thus acting as a switch, controlled the direction of current/voltage to different actuators.

The advantage is that RF control makes the rover remotely controllable. Such remote operation is very useful in sending rover in such terrain where direct human contact is difficult, such as land mines, etc.

Batteries: The rover uses ten, 1.2 V Ni-MH batteries. Each battery has a current rating of 2300 mAh.

## 7.   CONCLUSIONS

The development of all terrain rovers is a challenging area of robotics, which has fascinated students and researchers alike for many years. It explores various facets of engineering from robust design to mechanics and efficient control.

This paper talks about design, analysis and fabrication of a low cost rolling cylinder robot rover. A working prototype solution of the problem has been fabricated from scratch (Figure 7). The prototype is motivated through mathematical analysis of the problem of propulsion of rolling cylinder and subsequent design of a robot. Simulation of the selected design was done before fabrication. The prototype goes beyond that and includes a number of novel means characteristic of its use as a rover

for all terrain purposes. It benefits from a passive suspension system and treads to overcome small obstacles and variations in land profile.

A novel feature of Cybot-the rolling cylinder rover is the unique wheel-leg design. Systems of deployable legs have been employed to help the rover negotiate large obstacles and steps. The legs which remain stowed during normal conditions can be actuated to their deployable condition, increasing the radial size of the robot. Thus, helping it climb over the obstacles. The rover is remotely controlled via RF transmitter, which adds to its versatility and ease of operation.

Thus, we have been able to successfully build a low cost and energy efficient machine. It can negotiate a large variety of terrain successfully using a system of wheel and legs, and can be remotely operated via RF. Such systems are going to be of large use in times to come, in military, space and medical rescue applications.

## 8. FUTURE WORK

There is scope for some more work on the rover, which could further enhance its features and utility in harsh conditions. Such a possibility exists for adding on board camera for exploration of unknown terrain. Cameras are essential features of rovers today, for rescue and military missions. Initial tests with Computer control of tethered rover with USB camera were done. Image processing using Matlab was used for simple object and obstacle identification.

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