

## **Design and Manufacturing of a Stair Climbing Vehicle**

**Md. A. Hossain. Nafis A. Chowdhury, Rubaiat I. Linda and Shamiuzzaman Akhtar**  
**Department of Mechanical Engineering**  
**MIST, Dhaka-1216, Bangladesh**

### **Abstract**

This article deals with the designing and manufacturing of a vehicle, which can climb stair or move along very rough surface. The technical issues in designing of this vehicle are the stability and speed of the vehicle while climbing stairs. However, the steepness of the stairs is also the important concern of this study. The uses of this special vehicle are in the frequent lift of goods such as books for library, medicines for hospital, regular mails for any institutes, or transportation any toxic material for industries and give freedom to the retarded person or paralyzed patients to move anywhere over flat surface as well as stairs. The vehicle has four set of wheels arrangement to support its weight when it moves over the flat terrain. Each wheel frame consists of three sub-wheels attached with the sun wheel through three idler gears. Using of this vehicle, the labour cost can be reduced as well as huge amount of loads can be transferred uniformly with less power consumption. Moreover, considering some drawbacks due to lack of implementation of all techniques during manufacturing phase the test and trial run showed considerably significant and encouraging results that might help the future researchers to incorporate a gear box and steering mechanism to make the vehicle more versatile.

### **Keywords**

Stair climbing vehicle, wheel frame, sun wheel.

### **1. Introduction**

Lifting recurring loads like books, food grains etc. to store upper level, or even patients to move upper level is not easy job, especially where there is no lifting facilities (elevator). More over, in most of the buildings in the world does not elevators or escalators. In this case human labors are considered to be the only solution. Labor is becoming costly in the developed countries, where growth rate is getting negative. This problem can be solved if a vehicle can lift loads while traveling through strains.

The project introduces a new horizon for the transportation of the loads over the stair. Most of the buildings of the country are structurally congested and unavailing of elevator facility so it is difficult and laborious to lift up heavy loads. The stair climbing vehicle can play an important role in those areas to lift loads over a short height, like libraries, hospital, and in construction area. The vehicle, which can move upper level through strain, or run in very rough and rocky surfaces, is called stair climbing vehicle.

In the year of 2000, a group of researchers [1] introduced a rover type of vehicle to run over stepped path. Using a rhombus configuration the rover had one wheel mounted on a fork in the front, one wheel in the rear and two bogies on each side. Researchers around the world are thinking seriously to redesign such vehicle, which will be economical and affordable. Chang Hsueh-Er [2] developed a five wheeler trolley, which was driven by manual power. Anastasios et al. [3] and D. Helmick et al. [4] designed a robotic carrier with belt driven. No wheel was introduced in his robotic carrier. However, none of them think about automatic vehicle that can carry loads through stairs.

In various research projects all over the world the different locomotion concepts for mobile robots have been analyzed and new concepts have been proposed [5, 6]. Good general surveys are provided in [5-12]. In [8] over 300 mobility concepts and more than 400 navigation concepts have been generated and discussed, yielding to three candidate systems, a symmetrical walker with six identical legs, a four-wheeled vehicle and a so called attached scout concept with six wheels.

In this article the design and manufacturing of a stair climbing vehicle has been presented. The vehicle is designed in such a way that it can climb a stepped path (like stairs) with its modified wheel structure. Not only on the stairs, can it also move with load over flat or rocky surface. This is the individuality of this vehicle. Different speed combinations are incorporated depending on the working condition through simple gear arrangement, powered by the local motor drive. Speed reduction at any desired rate, is possible to establish over the existing ratio.

Wheeled rovers are the optimal solutions for well structured environment like roads or habitations. But off-the road, their efficiency is very dependent on the typical size of encountered obstacles that have to be overcome in a standard motion mode. This is the case for [13-15], which can typically overcome obstacles of their wheel size, if friction is high enough. Adding real climbing abilities to a wheeled rover requires the use of a special strategy and often implies dedicated actuators like [16, 17] or complex control procedure like [18, 19].

During the designing process the main focus was given to design its wheel, especially for the stair. Normal circular wheel is substituted here with a sun type wheel (figure 1). The term sun is used here because of planetary small wheels are getting power from the sun wheel (figure 1, and figure 2). The planetary wheels, apart by  $120^\circ$ , are attached with the sun wheel by an especial wheel frame (part-1, figure 4). The modification of the wheel frame was the main task in the project. First straight arm wheel frame (figure 1) was designed, which finally replaced by the wheel frame shown in the figure 2.

## 2. Design and Modification

In this project, the final design was an outcome of a sequential analysis and modification of stages which had been started with a simple roller based design. To attain higher efficiency and greater stability the design was replaced with a gear based curved wheel frame (figure 2).

### 2.1 Modification of roller idler to gear type Idler

In the initial design, each wheel contained frame, a sun wheel and three planetary wheels. The planetary wheel was connected with the sun wheel through an idler. The purpose of using the idler was to rotate the planetary wheels in the same direction of sun wheel. Each planetary wheel was aligned in a straight line with idler and sun wheel. Planetary wheels were  $120^\circ$  apart from each other (figure 1). The tapered idler was also planned to disengage the planetary wheel from the sun wheel, while it was not used to save power. However, the idlers generate frictional force, which requires more powerful motor. Slip might occur if adequate friction is not available. So finally an especial type gear arrangement have been designed which is more stable and consume less power (Figure 2).

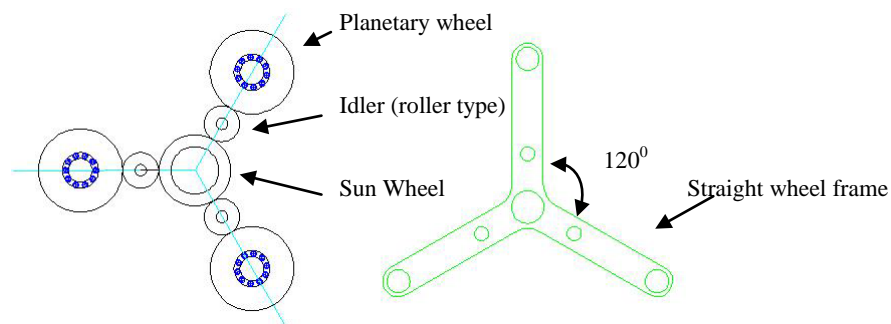


Figure 1: Initial design of Roller based wheel arrangement and wheel frame

### 2.2 Modification of straight to curved wheel frame

The straight wheel frame shown in the figure 1 takes more thrust to tilt the wheel frame to engage next planetary wheel. The length of each arm is high and thus creates vibration and the vehicle would be unstable. In the present design, the wheel frame was made curve so that the front surface of the arm could not collide with the edge of the stair. The optimization of the curvature was done to eliminate above problem. The curve wheel frame (figure 2) also requires less power to tilt compare to straight frame (Figure 1).



(a) Front view wheel arrangement                      (b) Curved wheel frame

Figure 2: Modified wheel arrangement and wheel frame

### 2.3 Modified Final Design

In the first design, the power transmission to the planetary wheel was not adequate for the vehicle to climb on the stair due to the slippage between rollers, idler and planetary wheel. The design of the wheel frame became more complicated and was needed to hold the planetary wheel with the sun wheel to give proper drive, which create more frictional force. For these reason, a gear arrangement was introduced to provide smooth power transmission. Gear arrangement was suitable to transmit exact velocity ratio also. It provided higher efficiency and compact layout with reliable service. Easier maintenance was possible in case of replacing any defective gear. Chain drive was chosen in the project, which is flexible and offer no slip during power transmit from motor to wheels

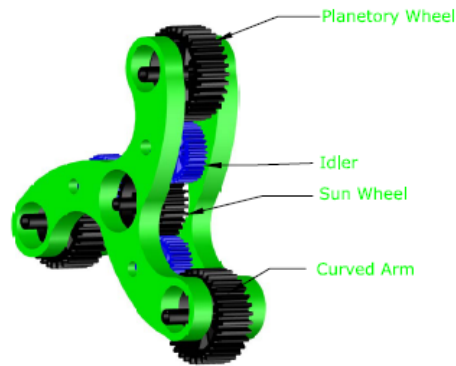


Figure 3: 3D view of wheel arrangement

In Figure 3, the arrangement of sun wheel and wheel frame is shown. The sun wheel is attached to the wheel frame at the centre and the planetary wheels are attached with the wheel frame at the end. Planetary wheels are getting power from the sun wheel via an idler gear. Two wheel frames are attached both side of the wheel arrangement.

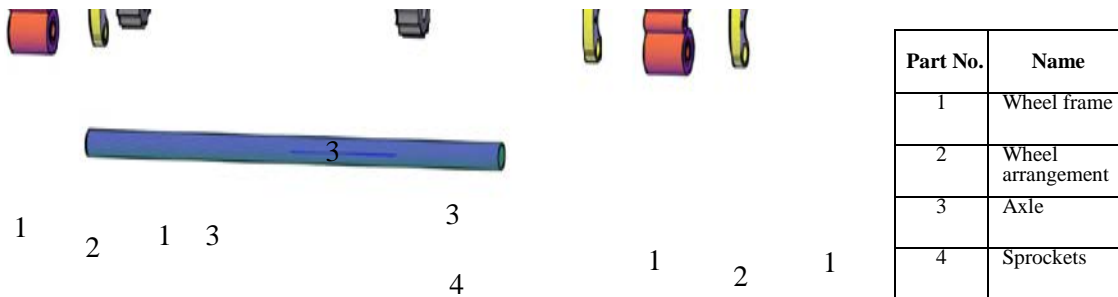


Figure 4: Detail drawing of wheel and shaft arrangement (chain is not shown)

Figure 5: Assemble drawing of the wheel and shaft arrangement

Figure 4 shows all parts required a single shaft. Two similar shafts are need for a four wheeler stair climbing vehicle. The assembly of the parts is shown in Figure 5.

### 3. Results and Analysis

It was found that the vehicle was moving well over the stair. It can move on flat surface uniformly at 20 rpm without any fluctuation. Separate motor worked properly for moving over the steps and there was no variation of speed over steps. It was observed that there was very low noise and vibration over flat surface or stair.

It was observed that the vehicle was disturbed when it faced the stair of different step sizes. This was because of the shape and size of the wheel frame. Therefore for a range of stairs size can be considered for this vehicle. Although, different sizes step are not usually available in building design. It showed good performance when the step size was uniform. Here in this project separate motor was used to move over the stair, which made its circuit design a little bit complicated and increased the weight of the vehicle.

From the test run of the vehicle it was seen that the maximum height the vehicle could climb the stair whose inclined angle was  $44^\circ$  maximum. If the inclination is more than  $44^\circ$  it would fail to climb the stair. In building construction, very few stairs are generally available having inclination more than that i.e.  $44^\circ$ . The smooth ramp angle ( $\theta_s$ ) was not listed for the vehicle. But it can be easily predicted that stair inclined angle ( $\theta$ ) is less than that of ramp ( $\theta_s$ ).

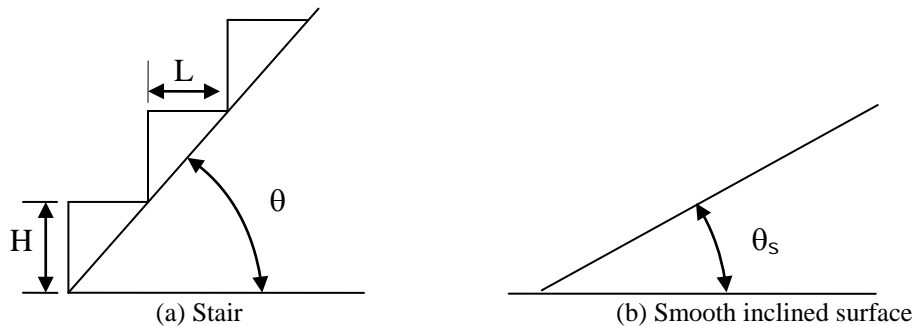


Figure 6: Maximum climbing angle, ( $\theta$ ,  $\theta_s$ )

The velocity of the vehicle during climbing the stair was higher than that on the flat surface as the wheel frame (higher radius) was used to climb stair. The velocity of the vehicle on the stair was 55 in/hr. However; the speed of the vehicle running on a ramp was not measured. This speed should not be higher or equal to the speed on the horizontal surface. From the above discussion, it could be summarized that considering some of the limitations, the vehicle was an effective alternative to transport loads using stairs. Some limitations could not be avoided because of the lacking in technological availability. This pioneer project, with a little further improvement, was hoped to be succeed to meet up the demand of carrying loads over the stair.

#### 4. Recommendation for Future Researchers

A sensor and steering wheel can be implemented to move around the stairs. Sensor would be a replace of a motor, which runs the frame wheel. A suspension system could be incorporated to minimize shock and vibration. Using a timer circuit, the movement would be more precise, accurate and easy to operate. With the help of timer circuits, the vehicle could run over a predetermined step size smoothly without using any switch. Single motor could be used to move over both the flat and tread of the stairs. It might be done by introducing an elongated shaft aligned with the wheel frame by using a spring, the shaft was resisted by an obstacle, and it forced the key to enter inside the notches of the frame. As a result, the whole frame was bound to rotate along the axis of the axle.

#### 5. Conclusions

Though this project had some limitation as a first step of making any Stair Climbing Vehicle, it was a pioneer project. During the test run of this project, it was realized that it would capable of carrying heavy load without suffering any deformation or local fractures if it would go into real world production at an ideal scale. Though the initial cost of the project seemed to be higher but more accurate manufacturing would shorten this.

#### References

1. Siegwart, R., Lauria, M., Mäusli, P., Winnendael, M., 1998, "Design and Implementation of an Innovative Micro-Rover," Proceedings of Robotics 98, the 3rd Conference and Exposition on Robotics in Challenging Environments, April 26-30, Albuquerque, New Mexico.
2. Hsueh-Er, C., "Stair-climbing vehicle, 2008, " Patent No. US2008164665(A1)", Jan 24.
3. Mourikis, A.I., Trawny, N., Roumeliotis, S.I., Helmick, D.M., and Matthies, L., 2007, "Autonomous Stair Climbing for Tracked Vehicles," International Journal of Computer Vision & International Journal of Robotics Research - Joint Special Issue on Vision and Robotics, 26(7), 737-758.
4. Helmick, D., Roumeliotis, S., McHenry, M., Matthies, L., 2002, "Multi-sensor, high speed autonomous stair climbing", IEEE/RSJ Conference on Intelligent Robots and Systems (IROS), September.
5. Schilling, K., Jungius, C., 1996. "Mobile Robots for Planetary Exploration," Control Engineering Practice, Vol. 4, No. 4.
6. Burdick, J.W., Radford, J., and Chirikjian, G.S., 1993, "A 'Sidewinding' Locomotion Gait for Hyper Redundant Robots," Proc. IEEE International Conference on Robotics and Automation.
7. Desai, R.S., Wilcox, B., Bedard, R., 1992, "JPL Robotic Vehicle Overview," in AUVS.
8. McTamane, L.S., Douglas, B.D., Harmon, S.Y., 1989, "Mars Rover concept development," Proc. SPIE Conf. 1007, Mobile Robots III.
9. Spiessbach, A., Clark, B., Larimer, S., Tobey, B., Lindauer, B., Koenig, R., Lisec, T., 1987, "Issues and Options for a Mars Rover", Proc. SPIE Conf. 852, Mobile Robots II.
10. Wilcox, B., Matthies, L., Gennery, D., Cooper, B., Nguyen, T., 1992, "Robotic Vehicles for Planetary Exploration", Proc. of the 1992 IEEE International Conf. on Robotics and Automation.
11. Wright, D.D., Watson R.E., 1987, "Comparison of Mobility System Concepts for a Mars Rover", Proc. SPIE Conf. 852, Mobile Robots II.
12. Lee, G.K., 1993, "System Requirements for Planetary Rovers", Proc. SPIE Conf. 1956, Sensor Fusion and Aerospace Applications.
13. Stone, H. W., 1996, "Mars Pathfinder Microrover: A Low-Cost, Low-Power Spacecraft," Proceedings of the 1996 AIAA Forum on Advanced Developments in Space Robotics, Madison WI.
14. Volpe, R., Balaram, J., Ohm, T., Ivlev, R., 1997, "Rocky 7: A Next Generation Mars Rover Prototype." Journal of Advanced Robotics, 11(4).
15. Kubota, T., Kuroda, Y., Kunii, Y., Natakani, I., 1999, "Micro Planetary Rover 'Micro5'", Proc. of Fifth International Symposium on Artificial Intelligence, Robotics and Automation in Space, Noordwijk, 373-378.
16. Kemurdjian, L., Gromov, V., Mishkinuyk, V., Kucherenko, V., Sologub, P., 1992, "Small Marsokhod Configuration," International Conference on Robotics & Automation, Nice.
17. Leppänen, S. Salmi, Halme, A., 1998, "WorkPartner HUT Automation's new hybrid walking machine", CLAWAR'98 First international symposium, Brussels.
18. Lauria, M., Conti, F., Maesli, P.-A., Van Winnendael, M., Bertrand, R., Siegwart R, 1998, "Design and Control of an Innovative Micro-Rover", Proceedings of 5th ESA Workshop on Advanced Space Technologies for Robotics and Automation, The Netherlands.
19. Tunstel, E., 1999, "Evolution of Autonomous Self-Righting Behaviors for Articulated Nanrovers," Proc. of 5<sup>th</sup> International Symposium on Artificial Intelligence, Robotics and Automation in Space, Noordwijk, 341-346.