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Review Article: Evolution of a Stair-Climbing Power Wheelchair

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ABSTRACT : *The goal of this article is to review the state of the art in the technology for Stair-Climbing Power Wheelchair for people with disabilities, with a particular focus on the technology that is loosely referred to as assistive devices. In the process, we review research that has been done by different groups on Stair-Climbing Power Wheelchair for manipulation and locomotion. We will be less interested in examples of devices that simply perform the mechanical function of a person's limb further therapeutic applications are beyond the scope of this article. Main goal is to provide the reader with an understanding of how the technology and science can be used to develop assistive devices for people with manipulative and locomotive disabilities. Also the analytical work carried out so far in this context is reviewed and discussed.*

***Keywords*:** *Staircase Climbing Wheelchair, Impaired Mobility, Low Cost Design.*

I. INTRODUCTION

There are many examples of assistive devices for people with manipulative and locomotive disabilities. These devices enable disabled people perform many activities of daily living thus improving their quality of life. Disabled people are increasingly able to lead an independent life and play a more productive role in society.

II. CRITICAL REVIEW

There are a number of rehabilitation devices currently available or in development. The most well-known device is the MANUS (1), which is a wheelchair-mounted seven axis (plus gripper) robot. The MANUS, a Dutch project, was designed with the disabled person in mind. It was a unique collaboration between the engineering and rehabilitation worlds, which rendered a well-engineered, quiet, and aesthetic device. The MANUS folds up into an unobtrusive position at the side of the wheelchair and folds out when commanded. Its present inputs include a 16 button keypad, trackball and joystick. The MANUS allows task space control. In other words, the user may directly control the motion of the end effector in Cartesian coordinates (translations along and rotations about Cartesian axes). This is in addition to the less sophisticated joint space control mode in which each joint is controlled independently. There are currently approximately fifty users of the MANUS, mainly in the Netherlands. Despite rapid scientific and technological progress in allied disciplines, there has been very little innovation in wheelchair design over the last 200-300 years. The folding wheelchair came in 1933, and powered wheelchairs were developed in the early 1970s (2). New materials such as plastics, fiber-reinforced composites and beryllium-aluminum alloys have found their way into the design and manufacture of lighter, stronger and more reliable wheelchairs (3). The wheelchair industry has also benefitted from the development of lighter, efficient, durable and reliable motors, better amplifiers and controllers and most important of all superior batteries. There is considerable research and development activity focused on wheelchairs. Since the user is in intimate physical contact with the chair for extended periods of time, the contact surfaces especially the seat requires a certain degree of customization to ensure comfort (4). Commercially available stand-up wheelchairs afford better seating and reaching, relief from pressure sores, and better health (5, 6, 7). They also allow users to operate equipment designed to be operated by standing people and improve the quality of social interaction with non disabled standing people (5). Conventional wheelchairs are difficult to maneuver in constrained spaces because they only have two degrees of freedom (forward/backward movement and steering). However, the Alexis Omni-directional Wheelchair (8), TRANSROVR (9) and the European TIDE Initiative OMNI Wheelchair (10) can move omnidirectionally by adapting non-conventional wheels developed for use by robotic vehicles (11, 12) for this application. A number of computer controlled wheelchairs have been developed in recent years, including the CALL Smart Chair (13), NavChair (14), TinMan (15) and WALKY (16). Wheelchair systems with customized user interfaces, sensors, and controllers, suitably integrated (19), can potentially make the operation of a wheelchair much simpler and make it more accessible to people with disabilities. Such chairs may use a wide variety of sensors ranging from ultrasonic range sensors (18), cameras, encoders, accelerometers, and gyroscopes and any desired input device (communication aids, conventional joysticks, sip and puff switches, pressure pads, laser pointers, speech recognition systems and force reflecting joysticks (17)). Suitable control algorithms assist the user in avoiding obstacles, following features such as walls, planning collision-free paths and travelling safely in cluttered environments with minimal user input (20 - 23). While motorized wheelchairs with sophisticated controls are well-suited locomote on prepared surfaces, most are unable to surmount common obstacles like steps and curbs. Special purpose aids (24, 25), including stairway lifts (26), stair climbers (27, 28) and customized outdoor buggies have been developed for specific environments, but they are not versatile enough for multipurpose use. For example, a wheelchair that can go up and down any flight of stairs has remained an open research and development issue over the past couple of decades. One innovative proposed by Professor Shigeo Hirose (29) is shown in Fig. 1.

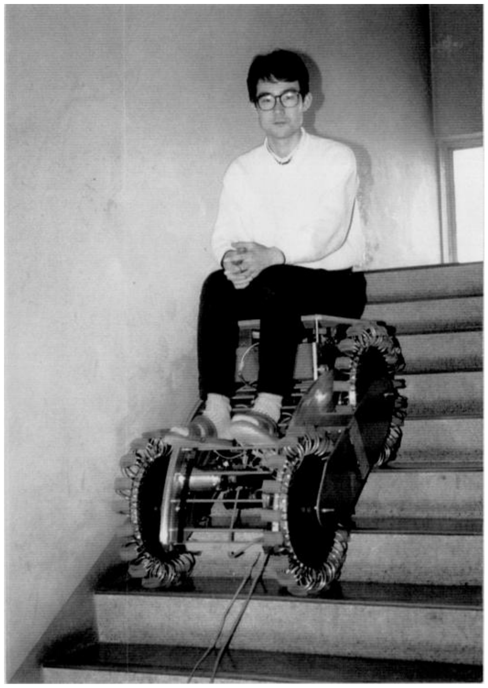

Fig.1. Photograph of the stair-climbing wheelchair rolling down stairs
(Courtesy, Professor Shigeo Hirose, Tokyo Institute of Technology)

A novel *remote center mechanism* (30) moves the seat on an elliptical arc as the attitude of the chair changes and maintains the posture of the user independent of the wheelchair posture. A minimal degree of active control is required which is accomplished by a simple attitude sensor and a relatively small actuator. Users cannot drive their chair on beaches nor can they easily cross muddy patches and potholes. One approach to improving the mobility of a wheelchair by an order of magnitude involves the use of legs instead of wheels as locomotion elements. Advances in robotics have made it possible to build and control legged machines (31 - 34). It is not difficult to imagine wheelchairs with legs climbing slopes, stepping over obstacles and walking on uneven terrain. A four legged chair developed by the University of Illinois at Chicago and the Veterans Administration Hines Rehabilitation Research and Development Center based on research in quadruped walking (36, 37) was developed in 1987. The walking chair was designed to enable the user to walk up and down stairs, steep slopes, cross rough terrain, with curb weight less than 113.6 kg. (250 lbs.) and capable of carrying a payload of 113.6 kg. (250 lbs.). A full scale prototype (35) design incorporating computer-controlled pantographic legs walked in the laboratory in October 1988, with a simple linear gait. However, it did not carry a passenger, and it was connected by a tether to a stationary controller. There are several inherent disadvantages in the concept of a legged chair. The legs are responsible for keeping the rider in a stable posture. There is a natural concern of safety that arises here. In wheeled systems, the wheels passively support the chair and do not require any sophisticated actuators or control electronics. In a legged system, stability must be maintained actively. Because of the complexity of the system, reliability is a natural concern. Further, for stability, at least three support legs must be on the ground and a vertical line through the centre of gravity must pass within the polygon formed by the support points. This implies that at least four legs are required to make a legged system walk with one leg is moved forward while three others support the chair. In the worst case, one leg must support half the weight of the chair and the user. This implies that each leg must have strength (payload) to weight ratio several times greater than one, with a payload of the order of hundred pounds. The leg designs and actuators scale very poorly to such high payloads. Since the actuators must run off wheelchair batteries, and since there are severe restrictions on how large the chair can be (for example, the maximum width must be less than 0.762 m (30 inches)), there are serious constraints that make it difficult to design a practical legged chair. An alternative design for a wheelchair (38, 39) for locomotion on uneven terrain tries to combines the advantages of legged locomotion (versatility, adaptability) with wheeled locomotion (reliability, superior stability). This *hybrid* (39) wheelchair has two powered rear wheels, two front castors, and two legs as shown in Fig. 2.

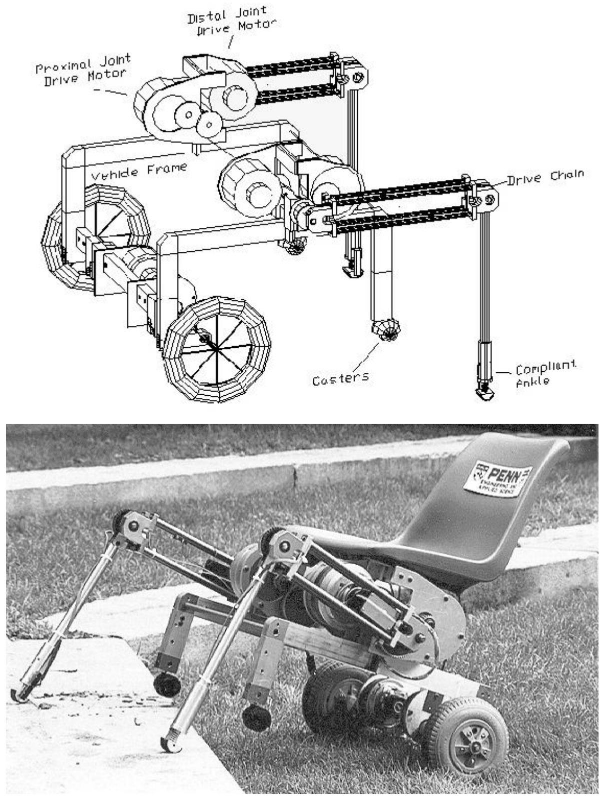

Fig.2. (a) CAD model and (b) Photograph of The hybrid all-terrain wheelchair
developed at the University of Pennsylvania.

The experimental prototype is equipped with six dc motors, position and force sensors and an on-board computer. It weighs 28.2 kg. (62.0 lb.) without the batteries and controller, and can climb a 1 foot curb with a payload of 68.2 kg. (150 lb.). The powered wheels are used to navigate on a flat surface as in a conventional wheelchair, while the legs and wheels are used to traverse uneven terrain. In addition to enhancing the chair's mobility, the legs provide additional traction on unprepared and slippery surfaces. The controller uses foot force information to coordinate the actuators of the legs and wheels so that the tendency to slip is minimized. The hybrid system is more attractive than a walking chair because it relies on wheeled locomotion that is established to be reliable and safe. The legs are used as crutches and only when they are needed. Further, because the legs are not used to support the entire weight of the chair, the motors, controllers and the legs can be made as compact as needed. When the legs are not required for support, they can be used as manipulators to push open doors, reach for objects and move obstacles out of the way. When they are not needed, they are tucked away below the arm rest to make them inconspicuous. However, unlike a legged system, the hybrid chair cannot locomote without wheels. The reduced complexity, lower cost and improved reliability and safety is at the expense of some loss in mobility. An important design consideration is the aesthetics of the design and consumer acceptance. The disadvantage of employing a fundamentally different method for locomotion is that the user may feel conspicuous using such a chair. While this "distractibility factor" depends to a large extent on the environment and society, it is necessary to make any design more “unrobot- like”.
The designs proposed by Murray Lawn (40-42) are better acceptable but yet to be converted in actual products. The schematic configuration of the said chair is as shown in Fig.3.

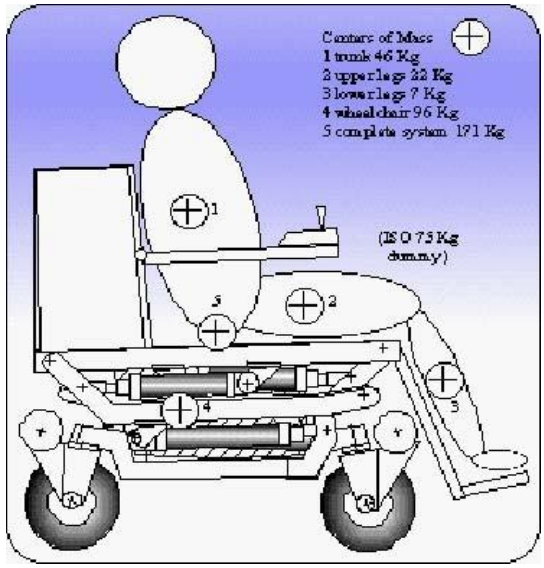

Fig.. 3

R.Moreles et al. (43) are proposing new prototype of the design along with the validation, but in that analysis, the key parameters are hardly discussed. In an article (44) published by MSNBC on 25th May 2009, it is mentioned that "By using the stair climbing chair we feel comfortable but while buying the chair we feel miserable". According to this article, the first ever practicable staircase climbing wheelchair is launched in 2009 in USA. A stair climbing wheelchair 'VARDAAN' (45), recently developed by four students of IIT, Kanpur, is a low cast solution to the problem, but operation of that wheel chair is purely manual. So, substantial driving force is needed to operate the chair. Considering the health and weakness of the elderly people, it may not be useful all the time. Totally new Design consisting with the Simple construction and thereby with less cost is proposed in our paper (46) whereas the idea of conjugate profile for the wheels is put forth in our second paper (47).

III. CONCLUSION

Many papers right from 1996 up-to 2012 are critically studied in detail. Most of the designs are incorporating 'Epicyclic Gear Train' as the driving unit for the chair. While maintaining the diameter of the circumscribing circle of the epicyclic wheels at about 300mm, the **Diameters of Sun and Planet** gears can be varied from 50mm to 125mm. Accordingly the **Speed of Travel** and also **Length of Epicyclic Arm** goes on changing. The design by earlier researchers like B. Most (27) is using 'Three lobe' epicyclic arm while the latest design by Murray Lawn (40-42) uses 'Two arms'. This means the **'Arm Angle'** is one more variable ranging from 180^o to 90^o if we limit the arms upto 4. Two more parameters like **'Step Height'** and **'Step Width'** is not considered, may be due to the fact that these two are uncontrollable parameters. Since variables are many and so are the designs, optimum design is not clearly identified. From this, we can conclude that **Design of Experiments** approach is the best suited for finding the optimum solution from the available designs.

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