Proceedings - 20th Annual International Conference - IEEE/EMBS Oct. 29 - Nov. 1, 1998, Hong Kong

Design of a robotic-hybrid wheelchair for operation in barrier present environments

Murray Lawn*, Takashi Takeda**
*Dept of Computer Science, **Dept of Mechanical Engineering, Nagasaki Institute of Applied Science
536 Aba-Machi, Nagasaki 851-0193, Japan
E-mail: lawnmj@cc.nias.ac.jp

Abstract- The purpose of this paper is to outline a radical approach toward providing wheeled mobility to the elderly or disabled. A robotic-hybrid wheelchair designed for operation in barrier present environments (the real world) is currently under construction at the Nagasaki Institute of Science (Japan). The wheelchair is targeted towards providing increased independence for wheelchair users and/ or provide much needed assistance to care workers in the field of facilitating mobility to those who cannot be independently mobile. The wheelchair incorporates a hybrid of 4 robotic legs resembling human legs in operation interfacing wheels. Each leg provides three degrees of freedom which are actuated hydraulically, two degrees for lift and one degree for dynamically variable track width. Each foot is further equipped with independently operated steering and drive motors. The resultant wheelchair is estimated to be capable of negotiating stairs and a single step of up to 70 cm to allow for direct boarding to a vehicle. The proposed control is via a radio control for operation by the user or assistant in the case of care worker assisted mobility. Key in the design are aspects of safety, aesthetics and not exceeding the size of a standard powered wheelchair.

Key Words- Wheelchair, robotics, care workers, hydraulics, stair climbing

Ⅰ. INTRODUCTION

History recalls many hundreds of wheelchairs and various devices that have been prototyped to deal with the problem of enabling those unable to walk to move about freely in barrier present environments. In terms of wheelchairs, solutions range from the use of wheels, wheel clusters to tracks or combinations thereof. While special purpose track operated wheelchairs are available (assistant required) for climbing or descending stairs major inherent problems include they are unsuitable for ordinary use and unable to negotiate high rises as occurs in the boarding of a vehicle (typically a van) or in the case of Japan the entrance to a traditional Japanese home. Thus the need for a radical new look at the problem, or more precisely the application of advances in robotic, hydraulic, servo-motor and computing technology to this age old problem. The purpose of such being two fold, firstly to provide more autonomy to the walking impaired and secondly to reduce the amount of labour-intensive man-handling of patients required of care workers.

Ⅱ. METHODS

A. Design overview

As the aspect of safety is primary in the design of any rehabilitation aid the wheelchair despite employing a walking mode while negotiating stairs has been designed for static stability at all times [1], safety as it relates to the proposed design has been outlined in detail in "A robotic hybrid wheelchair for operation in the real world" [2] and will thus be omitted. The wheelchair has been designed to not exceed the size of standard powered wheelchairs. Finally the aspect of aesthetics has been considered as far as possible.

B. Barrier free operation

The wheelchair is designed to operate as a standard powered chair in barrier free areas. Figure 1 depicts the wheelchair in barrier free mode, refer to figure 6 for a photograph of the initial model. The ideal of not exceeding the size of a standard powered wheelchair has been achieved.

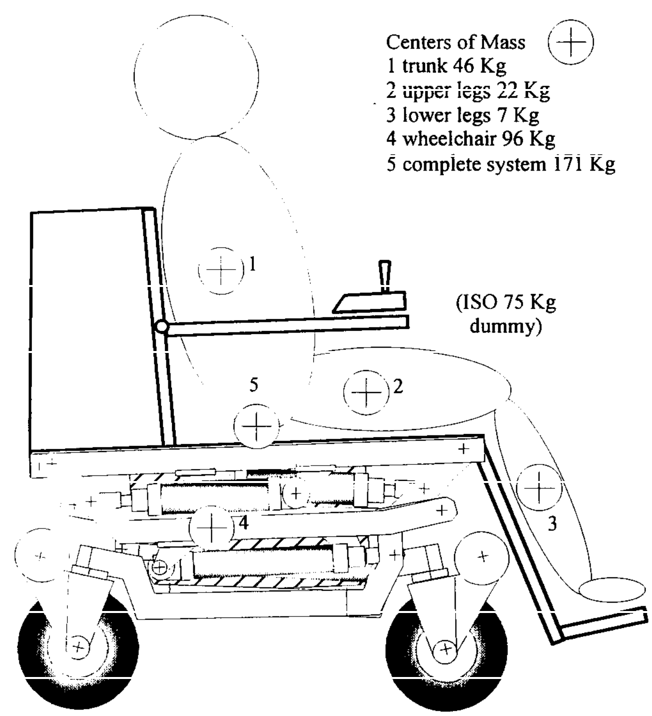


Fig. 1. Proposed wheelchair design side view

However the vehicle's weight (~100 Kg) does exceed that of a standard powered wheelchair (60-80Kg).The issue of weight is significant when man-handling any powered wheelchair in barrier present environments, typically into vehicles or up a few stairs. However the vehicle should be autonomous in such situations, the remaining aspect is that of batteries going flat, a number of steps to ensure controlled power-down are proposed to minimize the likelihood of having to man handle the wheelchair [2].

C. Barrier present operation

Negotiable barriers have been categorized into slopes, steps, obstacles and gaps. Refer to ISO 7171/10 (determination of the obstacle climbing ability of an electric wheelchair), and ISO 7171/18 (stair traversing devices) proposed/ in progress. The proposed means of negotiating each of these is as follows:

Slopes. Standard powered wheelchairs are limited mainly by wheelbase and width in relation to the center of gravity (CG), the vehicles maximum torque that can be applied to a given surface (typically by the back two wheels), and the user's confidence and/ or skill. The proposed chair's advantages in these aspects are a dynamically variable track width and the ability to correct the chair's angle to both increase stability and user comfort thus confidence to some degree and the vehicle's "independent four wheel drive" will increase the vehicles tractive ability on any given surface.

Steps. Standard powered wheelchairs can, with care, negotiate single steps of up to about 10 cm. The proposed wheelchair using hydraulic lifting mechanisms and a statically stable stepping action is estimated to be able to climb stairs in continuous stair climb mode of up to 37°, steeper climbs are possible but any angle above 37° will be directly reflected in the chair's angle. In single step mode the design caters for a step of up to 70 cm, this is sufficient to board most vans directly. This also permits access to homes that have high initial steps, such as traditional homes in Japan.

Stair climbing operation. Continuous stair climbing operation is depicted in figures 2 (a-f) and described briefly as follows: The initial requirement is for the user to confirm whether the automatically detected "barrier" is to be negotiated or not figure 2(a). The chair is raised allowing for stepping operation 2(b). In this case continuous stair climb would be indicated. This also adjusts the center of gravity within a triangle formed (plan view) by the back two wheels and each front wheel providing the necessary stability margins (SM) SMA & SMB as depicted in figure 3(a), wheel positions are calculated as per figure 4. Thus the front wheels can step alternately until the maximum stepping range is reached 2(b-d). The CG is then adjusted within the triangle formed by the front wheels and each back wheel 2(e), as shown in figure 3(b), stability margins being SMC and SMD. The back wheels then alternately step, with the stepping action 2(d-f) repeating until the landing is reached. The stability margin must also account for the shift in the CG as a wheel is lifted. The resultant reduced stability margins are denoted in figure 3 as SMA-D2.

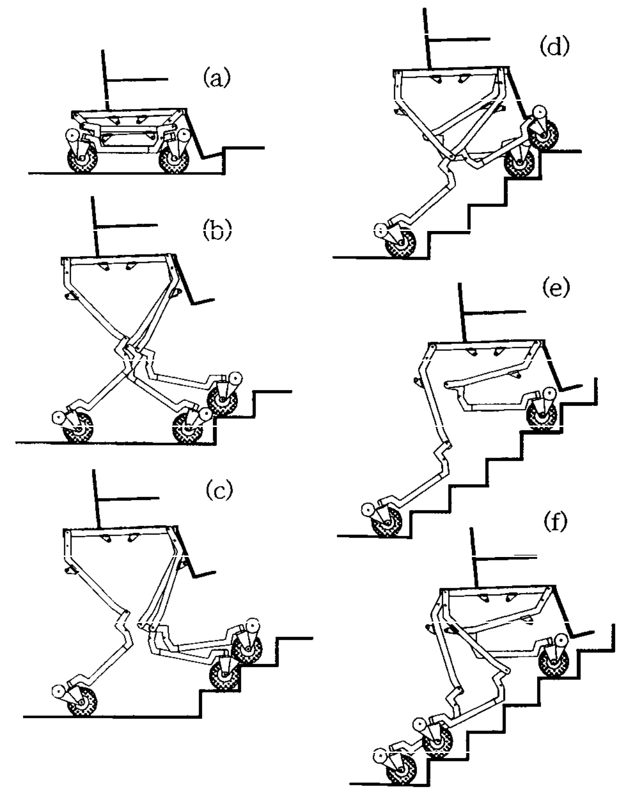


Fig. 2. (a-f) Stair climbing operation

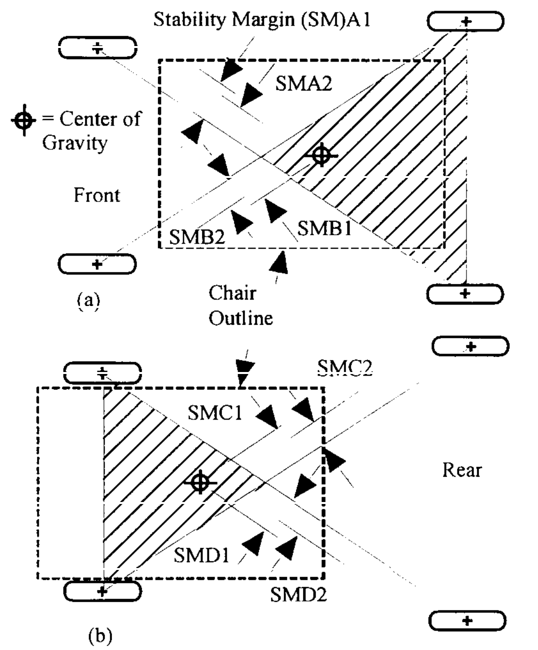
Obstacles. Current wheelchairs ability to negotiate obstacles naturally vary with the nature of the obstacle. The proposed wheelchair's obstacle negotiating ability can be approximated by any obstacle fitting within a 70 cm height and depth at base of 60 cm triangular section. Thus a gap of up to 60 cm is negotiable.

D. Additional functionality

The proposed design also facilitates functionality not usually standard on powered wheelchairs although some special purpose types do provide such functionality. This functionality is detailed in "A robotic hybrid wheelchair for operation in the real world" [2]. In summary this includes;

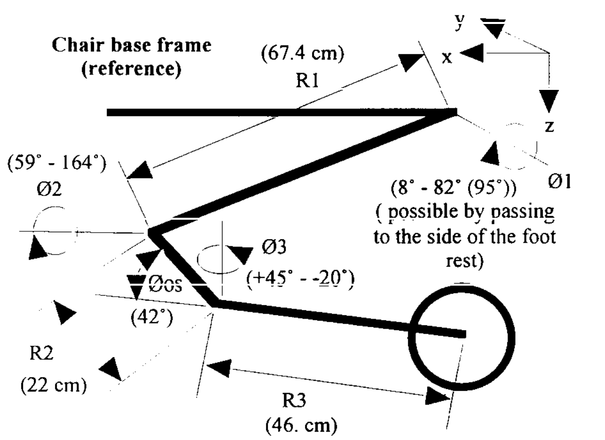
- Assistive standing.
- Reclining (bed).
- Seat raise/ lower 0.45 to 1.2 m.
- Direct transfer (unimpeded side transfer).
- Full remote control operation by the user on or off the chair thus remote parking.
- Full remote control operation by an assistant thus enabling a non-mobile person lacking the control ability to be taken into barrier present environments.
- Independent 4 wheel steering facilitating unimpeded steering capabilities. That is all wheels steer ±90° thus the theoretical turning circle is defined by the

diagonal length of the vehicle. This turning capability is required in tight situations, for example when turning on landings between multiple sets of stairs.



Stability Margins A-D1 = SM with wheel on the ground
Stability Margins A-D2 = SM with wheel lifted off the ground

Fig 3. Stability margins in climb mode



$$x = R_1\cos\Phi_1 - R_2\cos(\Phi_1 + \Phi_2) - R_3\cos(\Phi_1 + \Phi_2 - \Phi_{os})\cos\Phi_3$$

$$y = R_3\sin\Phi_3$$

$$z = R_1\sin\Phi_1 + R_2\sin(\Phi_1 + \Phi_2) + R_3(\Phi_1 + \Phi_2 - \Phi_{os})\cos\Phi_3$$

Fig 4. Wheel co-ordinates wrt chair base

E. Mechanical overview

The design is based on a hybrid of 4 hydraulically operated robotic legs (3 DOF/leg) interfacing wheels each equipped with independent servo motor drives for steering and locomotion. Each leg consists of two hydraulically operated cylinders connected to optimally designed pantographic members for vertical lift as shown in figure 1 and in figures 6 and 7 (initial design). The wheel frames are connected to the pantographic members via a further DOF (not on the original design). The additional DOF shown in figure 5 is also hydraulically activated. The steering is achieved via a servo-motor connected to each wheel frame via a non-slip (toothed) belt drive. Finally the main locomotive force is provided for by a large servo-motor connected to each wheel frame also via a non-slip belt drive.

F. Hydraulic actuators

The hydraulic (oil) cylinders are driven by a single small low pressure (35 kgf/cm^2) hydraulic pump. All cylinders are reversible and servo-controlled using electro-proportional reversible valves. The hydraulic system is detailed in "A robotic hybrid wheelchair for operation in the real world" [2]. In summary the hydraulic system can provide the necessary actuation forces required. Using new technology hydraulic components, clean and virtually maintenance free, smooth operation should be realizable.

G. Electric motors

The steering and main drive motors are stepping servo motors thus permitting the required precision in control. The steering motors are servo-operated based on both angle (fixed reference) as well as rotation data. The main drive motors are servo-operated based on rotation data only.

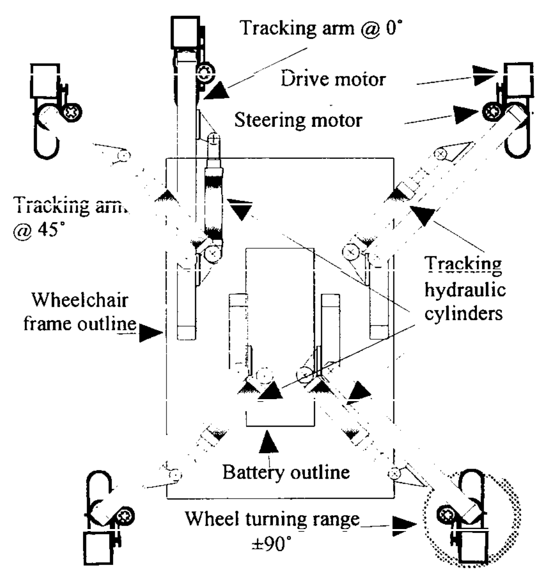


Fig 5. Plan view of wheelchair in maximum tracking mode

H. Control

Operated via radio remote link the controller is proposed to include a standard joystick with the addition of a matrix screen display and variety of switches. In a barrier free environment the vehicle is expected to be equally as user friendly as a standard powered wheelchair. However in barrier present environments more user decisions will be required, thus the remote control for operation by an assistant if needed.

Fig 6 Initial prototype in barrier free mode

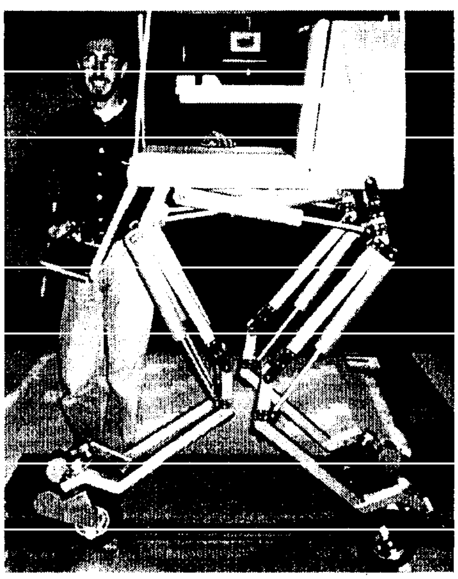


Fig 7 Initial prototype model at full height

The provision and operation of sensors is dealt with in detail in "A robotic hybrid wheelchair for operation in the real world" [2], but in summary is as follows;

- Tilt (lateral and longitudinal)
- Proximity (multiple infrared and ultrasonic sensors per wheel)
- Toe in/out (from differential oil pressure in variable track cylinders)
- Balance (from pressure in top lift cylinders)

Ⅲ .DISCUSSION

Responses from informal discussions with a variety of disabled persons and elderly persons to date have been very positive, from the professional side responses have been understandably conservative with regards to both the weight of the wheelchair and aspects of stability. Clearly these aspects must be resolved through further research well before any form of commercial realization may be considered. With regard to the weight all things being equal (given materials, motive and battery systems) the weight of a wheelchair is roughly proportional to it's functionality, in this regard the proposed design cannot compete in terms of weight however employing dynamically variable track width and effectively base, as well as independent four wheel drive and steering it could potentially exceed the stability of current standard powered wheelchairs in any given barrier present environments.

Ⅳ. CONCLUSION

In conclusion a robotic-hybrid 20 DOF wheelchair has been designed for operation in barrier present environments by employing a hybrid of 4 hydraulically actuated robotic legs (3 DOF/ leg) interfacing wheels each equipped with independent motors for steering and drive. The purpose being to provide a means for the elderly or disabled to gain greater access to and independence beyond "barrier free" environments, or in the case of those lacking control ability to make mobility comfortable for the person themselves and those caring for them by using remote control functionality. The design has been modeled to full scale confirming mechanical feasibility. Much work remains however in the design detail, and production of a working prototype.

ACKNOWLEDGMENT

The Nagasaki Prefecture Society of Innovation and Invention and the Nagasaki Prefectural Chamber of Commerce and Industry for their input awarding the initial design the "1997 Nagasaki Prefectural Chamber of Commerce and Industry Excellence Award" (長崎県商工会議所連合会会長賞 優秀賞受賞).

REFERENCES

[1] P. Wellman, W. Krovi, V. Kuma, W. Harwin, "Design of a Wheelchair with Legs for People with Motor Disabilities", in *IEEE Trans. Rehab. Eng.*, vol. 3, no. 4, pp. 343-353. Dec. 1995.

[2] M. Lawn, "A robotic hybrid wheelchair for operation in the real world" in Computer Science Center Journal Nagasaki Institute of Applied Science No.8, pp. 65-77 1997.