TOWARDS A "BARRIER FREE" WHEELCHAIR

M.J.Lawn[*1], T.Ishimatsu*[*2] and T.Takeda*[*3]*
*[1]Computer Science Center, Nagasaki Junshin Catholic University, Japan 852-8558
*[2]Dept of Mech. Systems Eng., Nagasaki University, Japan 852-8521
*[3]Dept of Mech. Eng., Nagasaki Institute of Applied Science, Japan 851-0193

Abstract: In the field of providing mobility to the elderly or disabled one aspect that remains largely unresolved is that of providing mobility into "barrier present" environments. Perhaps the most formidable and yet common barrier to a wheelchair is the boarding of a secondary form of transportation, often a van of some form, representing a single step of height ranging 60 to 80cm. At present vehicles intended for transporting powered wheelchairs are equipped with specialized and often expensive lifting apparatus. Building on the design concepts detailed by the authors in previous papers, "towards a "barrier free" wheelchair" focuses on major redesign extending the author's stairclimbing wheelchairs ability to make direct vehicle boarding possible. The simulated wheelchair is based on four legs operated by oil hydraulics for lift (2DOF/leg) and the base of each leg being equipped with a motor driven and motor steered wheel. Central in the design are safety and not exceeding the size of a standard powered wheelchair. Future work includes the prototyping of the new design planned to begin mid 2000.
Keywords: Stair climbing, Powered wheelchair, Computer control, Hydraulics

1 INTRODUCTION

Providing the elderly and disabled with freedom in terms of mobility is of significant importance. The basic reasons being increasing quality of life and reducing the load on care workers [1], the two being closely linked by reasoning of a persons conscious sense of being a "burden". While work in the area of providing mobility beyond "barrier free" environments continues [2], to date only 1 (Johnson and Johnson US) powered wheelchair is known to becoming close to providing a general purpose stairclimbing capable means of wheeled mobility. However beyond the immediate focus of "stairclimbing" which is often considered synonymously with barriers, the most formidable barrier often encountered comes in the form of entry to a secondary form of transportation. A common form of secondary transportation is the van.

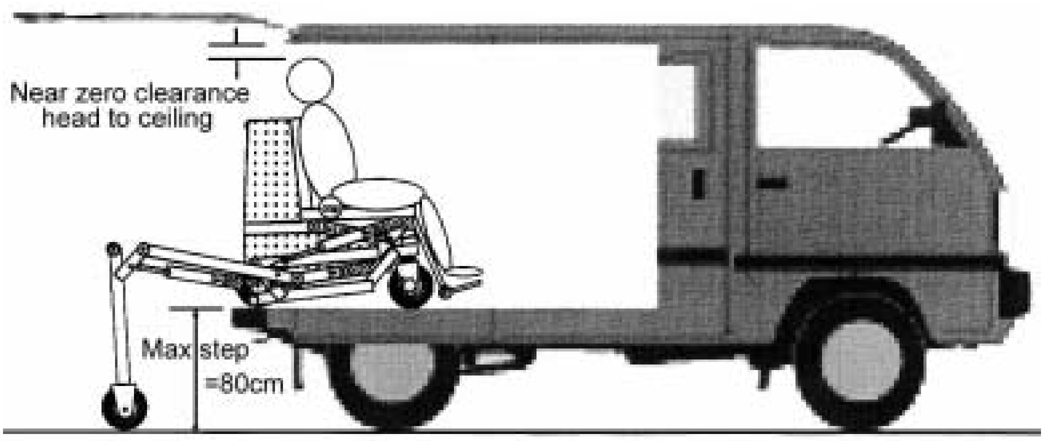

Figure 1. Boarding a van with minimal head clearance

To date entry to a van is made possible typically by some form of special lifting apparatus which is fitted to the van, the cost of providing such often represents a major cost and reduces the vehicles efficiency in other respects (space, weight etc). Entry to such as a van can be most simply represented by a single step of 60 to 80cm, refer figure 1. The design of a stairclimbing wheelchair capable of a high single step is outlined in detail in previous papers [3][4][5], however the design required significant space above the occupant's head in order to negotiate the high step. This is acceptable under some conditions, for example access to a traditional Japanese home where the first step varies between 45 to 60cm, however this is not acceptable for entry to the average van as is illustrated in figure 1.

2 DESIGN

2.1 Concept outline

The wheelchair detailed in this paper is based on the use of each of the wheelchairs four wheels rather than being directly fixed to the wheelchair being connected to the wheelchair base via 2 mechanical linkages independently actuated by oil hydraulic cylinders as shown in figure 2 (the front wheel linkage can be seen better in figure 4). Each wheel is then equipped with a motor for drive and a motor for steering.

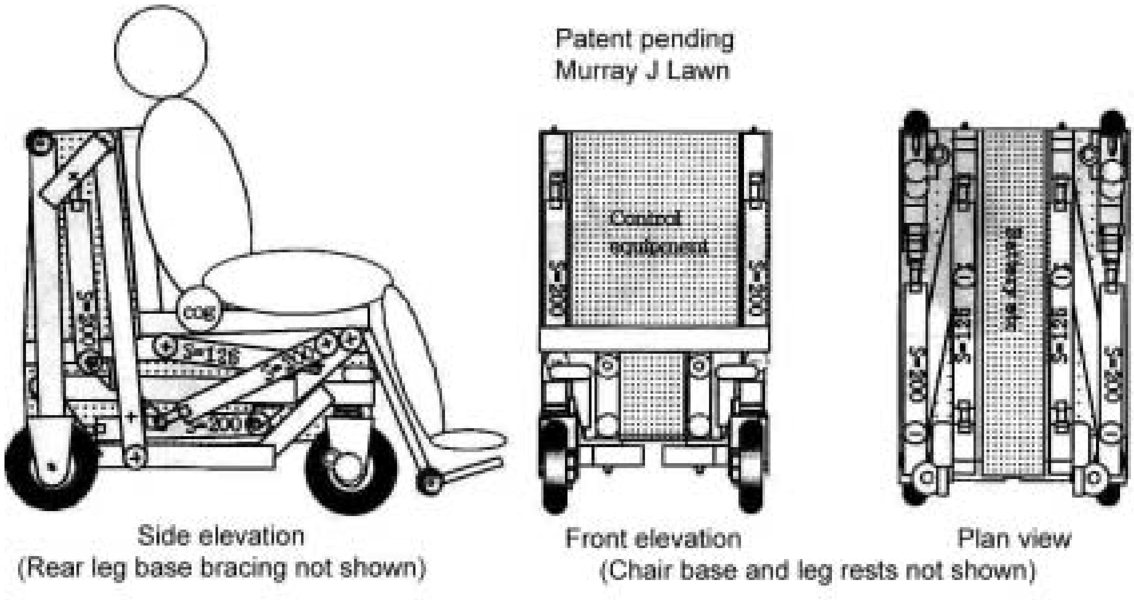

Figure 2. The concept barrier free wheelchair

The author's previous papers have detailed the wheelchair shown in figure 3. Three notable points of variation exist between the Mk2 stairclimbing wheelchair (figure 3.) and the wheelchair being presented in this paper (figure 2.), the following summarizes main points regarding the general design but focuses primarily on the advantages of the redesign.

The first and perhaps most notable point of variation is the design of the rear wheel linkage arm, this variation is the most central factor in making a high single step under near zero overhead constraint possible (figure 1.). Secondly inherent stability is increased by being able to bring the front wheels out to the side of the wheelchair, this was not possible in the Mk2 due to the obstruction of the rear linkages. Finally the complexity has been reduced by reducing the lift mechanism to 2DOF (degrees of freedom), on the Mk2 the lift mechanism was 3DOF, the additional DOF was used to spread the wheels widthwise to counter the narrow track width particularly at the front due to the second point detailed above. In terms of control complexity the reduced DOF is very significant. For detail of design refer to previous papers [3][4][5].

2.2 Design considerations

Central in the design are providing a wheelchair that does not exceed size specifications of a standard powered wheelchair and consideration for safety. The wheelchair presented in this paper does not exceed the physical dimensions of a standard powered wheelchair [3] (W=50cm, L=110 incl. footrests). The weight however does exceed that of a standard wheelchair and is of central concern in the wheelchairs design, the prototype due to begin mid 2000 pending funding is estimated at around 100Kg compared with standard powered wheelchairs which are usually under 60Kg unless equipped with special equipment [6]. The wheelchair must be as easy to use as a standard joystick operated wheelchair, such operation can be equaled in a barrier free environment, however on account of the wheelchair’s increased obstacle negotiating ability increased operational complexity is inherent.

On the side of disadvantages, the previous design was symmetrical in terms of the wheelchairs ability traveling forwards or backwards with regard to the single high step. Thus the asymmetrical nature of the new design limits the high step to being negotiated up – forward (eg board vehicle) and step down backwards (eg disembark). In the case of boarding such as a van this is not considered a major limitation. Regular stairs (up to 36 degrees) can be negotiated in any order however, (forward up, forward down, backward up or backward down), stairs above 36 degrees are theoretically possible but the increased angle above 36 degrees is added to the chair base angle. While this may be acceptable for going up stairs, is liable to be of concern going down stairs.

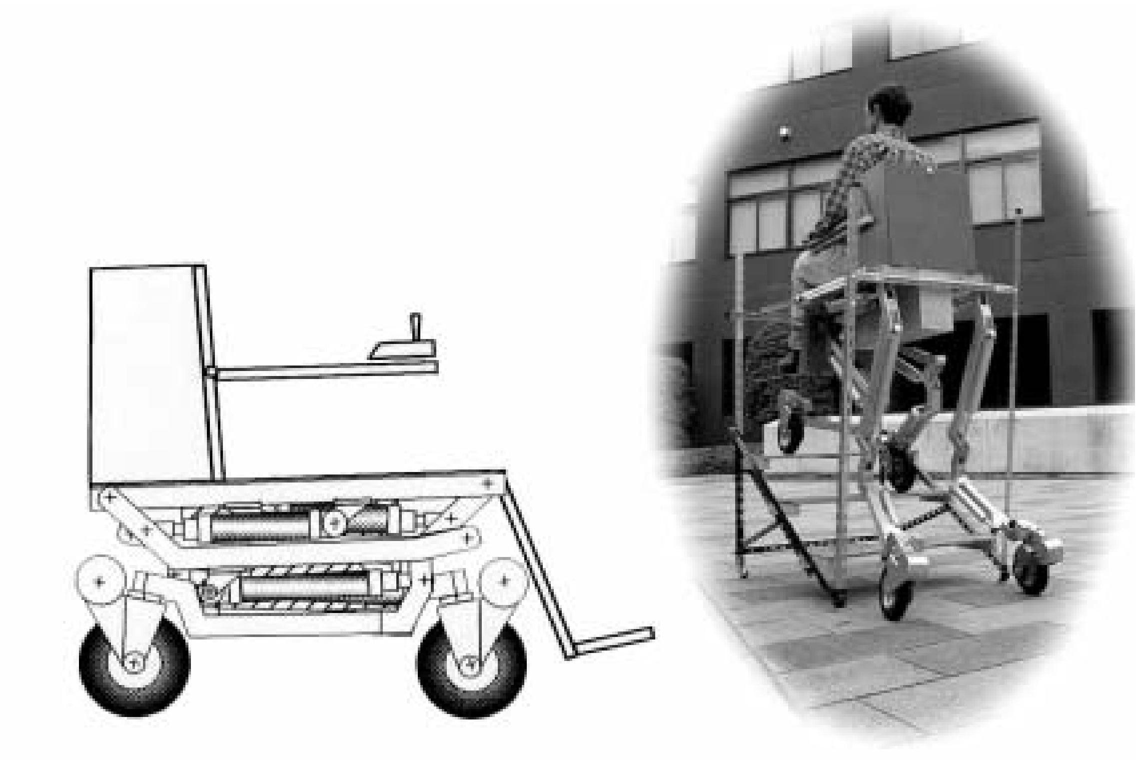

Figure 3. Mk2 stairclimbing wheelchair

3 Operation

3.1 Barrier free operation

Barrier free operation (that is operation as a standard powered wheelchair [3]) based on the design outlined will be via a joystick. The independent 4 wheel steering making turning easier, the theoretical turning radius being defined by the wheelchair measured diagonally. All direction operation is also theoretically possible (that is the near instant ability of the wheelchair to move in any direction irrespective of the direction in which the wheelchair is facing). The need for the independent steering is mainly for maneuvering on the landings between sets of stairs however would certainly enhance the general agility of the vehicle.

3.2 Barrier Present environments

Barriers or obstacles can be classified in various ways, negotiation of a wide range of obstacles by the Mk2 stairclimbing wheelchair is detailed in previous papers [3] [4] [5]. Thus the following is a summary of the wheelchairs negotiation of barriers, except with regard to new features of the redesign.

Firstly the most commonly considered barriers – stairs. By necessity some form of stair (negotiate obstacle) confirmation will be required, that is for the user to indicate “Yes” this is a set of stairs to be negotiated (not just a wall or such) when the sensor system detects the presence of an obstacle. Further operation would follow the command of the joystick. The wheelchair raises the chair height in accordance to the height of the step and proceeds to set the systems (wheelchair and user) center of gravity (COG) to the rear. Thus the front wheels step one at a time to the first step, stepping continues until the rear wheels by necessity need to step (refer fig.4). In order to step the rear wheels the COG is shifted to the front. The stepping action is then repeated between the front wheels stepping and the rear wheels stepping to the top of the stairs. Finally once the top of the stairs is reached only the rear wheels step and then the chair height is lowered to its normal position.

Finally negotiating a high single step under near zero overhead clearance as occurs when boarding a domestic van (figure 1.). This is achieved by raising the height of the chair to a level appropriate for entry to the vehicle. Then upon ensuring the COG is towards the rear one wheel at a time is put on the edge of the vehicle. Once both front wheels are on the vehicle the wheelchair moves forward and rests the rear weight of the wheelchair on the auxiliary wheels provided on the front wheel linkages (refer fig 1.). Operation is then completed by folding in the rear wheels back into position.

The wheelchairs raise functionality also provides for a variety of other key roles such as matching the height of the user's bed, reaching the top shelves etc.

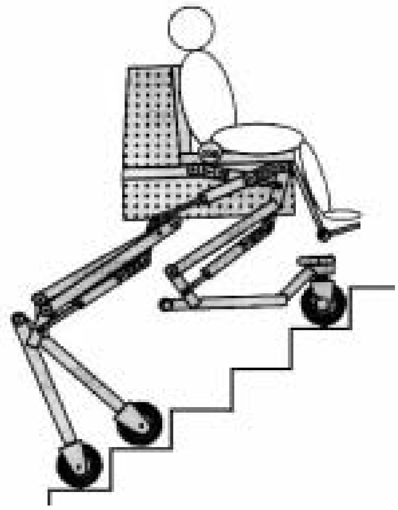

Figure 4. Stairclimbing

4 CONTROL

Control at a user level is proposed via a wireless controller [3]. The reasoning for wireless operation being in summary to allow operation by an assistant, particularly on stairs and to permit remote relocation of the wheelchair by the user. Operation of the computer system required is based on a central computer dealing with various inputs and outputs detailed in [3], and a secondary sub system dedicated to obstacle/ barrier proximity detection from a dual infra-red and ultrasonic system [7] (six sensor sets per wheel). Other sensors include chair pitch and role detection, position sensors on each of the wheel/ leg linkages and pressure senses on each wheel essential for the COG calculation [4].

At a mechanical level the lift mechanism has been optimized to make the standard wheelchair specification possible and requires an oil hydraulic actuator output of ~450kgf max (initial lift pressure in the front lower cylinder), and the theoretical hold pressure maximum being close to double this occurring when balancing for stepping. The current design is based on a 35kgf pressure system but a higher pressure (thus smaller actuators etc) system is being considered.

The aspect of balance while stepping is of extreme importance, while static stability is inherent the stability margins are low. In this regard possibility of inclusion of computer controlled gyroscopic assistance is under investigation (as is currently successfully used in the Johnson and Johnson US stairclimbing wheelchair).

5 CONCLUSION

In conclusion a concept "barrier free" wheelchair has been described. The purpose of the wheelchair being to reduce the load on care workers and to increase autonomy in terms of mobility to the elderly or disabled as and when required. The proposed wheelchair has been simulated in the roles of both stairclimbing and direct boarding of such as a van under conditions of near zero overhead clearance. Central in the design are aspects of safety and not exceeding the size of a standard wheelchair.

Future work includes more rigorous mathematical modeling of and prototyping of the wheelchair. This work is proposed for mid 2000 pending approval for financial assistance.

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, Dec. 1995, p. 343-353.

[2] T. Ishimatsu, K. Sugiyama, M. Kurihara, Development of a stairclimbing machine in Nagasaki, *Proc. 3rd International. workshop of Advanced Mechatronics*, Kanwon, Korea, 1999, p.214-217.

[3] M. Lawn, A robotic hybrid wheelchair for operation in the real world, *in Shoho Journal No.8*, Computer Science Center, Nagasaki Institute of Applied Science, Dec. 1997, p. 65 – 97.

[4] M. Lawn, T. Takeda, Design of a robotic-hybrid wheelchair for operation in barrier present environments, *Proc. 20th International Conference of the IEEE Engineering in Medicine and Biology Society*, Hong Kong, Oct. 29 – Nov. 1, 1998, p. 2678-2681.

[5] M. Lawn, T. Takeda, Development of a 20DOF wheelchair for operation in a barrier present environment, *Proc. 8th International Symposium on Measurement and Control in Robotics*, Prague, Czech Republic, 1998, p. 411-416.

[6] K. Matsuo, Wheelchair user's disabilities in relation to their wheelchairs, *Proc. 6th Japanese Rehabilitation Engineering Society's Wheelchair SIG Conference*, Nagasaki, Japan, Aug. 25-26, 1997, p.112 – 126 (in Japanese).

[7] R. Fuji, Powered wheelchairs using a VLSI based computer system, *Proc. 12th Japanese conference on Advancement of Rehabilitation Technology/ Rehabilitation Engineering Society's of Japan*, Nagasaki, Japan, Aug. 27-29, 1997, p.61 – 64 (in Japanese).

AUTHORS: Ass. Prof. Murray J. Lawn, Computer Science Center, Nagasaki Junshin Catholic University. 235 Mitsuyama-machi, Nagasaki, Japan 852-8558, Phone: Int ++81-95-846-0084 Ext 229, Fax: Int ++81-95-846-0737, E-Mail: lawnmj@n-junshin.ac.jp

Prof. Dr. Takakazu Ishimatsu, Dept. of Mechanical Systems Engineering, Nagasaki University, 1-14 Bunkyo-Machi, Nagasaki, Japan 852-8521, Phone: Int ++81-95-847-1111, Fax: Int ++81-95-847-3842, E-Mail: ishi@net.nagasaki-u.ac.jp

Prof. Dr. Takashi Takeda, Dept. of Mechanical Engineering, Nagasaki Institute of Applied Science, 536 Aba-Machi, Nagasaki, Japan 851-0193, Phone: Int ++81-95-838-5183, Fax: Int ++81-95-830-2091, E-Mail: takeda@csce.nias.ac.jp