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References

[1] Wheelchair ramp information, Northeast Rehabilitation Health Network, (2002, Oct 16), [Online]. Available: http://www.northeastrehab.com/Articles/ramps.htm

[2] Wheel, Oxford Paperback Encyclopedia, © Oxford University Press 1998

[3] Ancient wheels, (2002, Oct 16), [Online]. Available: http://www.education.eth.net/enrich/inventions/ccorner_invention4.htm

[4] K. Yoneda, Y Ota, and S Hirose; *"Development of a Hi-Grip Stair Climbing Crawler with Hysteresis Compliant Blocks"*, Proc. of 4th International Conference on Climbing and Walking Robots (CLAWAR 2001), pp.569-576, 2001

[5] I. Yoneda, "Particular about wheels – dynamics of a wheelchair's wheel," in Proc. 6th Japanese Rehabilitation Engineering Society's Wheelchair SIG conference, Sasebo, Japan, pp. 25-47 (in Japanese), 1997.

[6] Honda P3 robot negotiating stairs, Kids Web Japan, (2002, Oct 19), [Online]. Available: http://jin.jcic.or.jp/kidsweb/news/00-08/p3.html

[7] M. Nishikawa, N. Ozawa, "System for detecting and controlling the position of a mobile robot," US patent 5,737,217, Apr. 7, 1998.

[8] Y. Suzuki, "Control apparatus for legged mobile robot," US patent 6,377,013 B2, Apr. 23, 2002.

[9] M. Kurihara, S. Ota, *Nagasaki Emergency vehicles and rehabilitation – from emergence medical services toward local care*, Shodosha (in Japanese), 1999.

[10] Lecture and practical session on wheelchair handling and assistance for staff, Nagasaki Junshin Catholic University, March 20 2001.

[11] Eliminating stairway barriers, Max-Ability Inc., (2002, Sept 24), [Online]. Available: http://www.sonic.net/jtfig/maxability/stair-lift2.html

[12] Access partner, Meiden Kohsan Co. Ltd, (2002, Nov 22), [Online]. http://www.meidenkohsan.co.jp/pages/index.html

[13] Stair lift platforms, Garventa Accessability, (2002, Nov 22), [Online]. http://www.garaventa.ca/sl/index.html

[14] Wheelchair ramps and lifts, American Wheelchairs, (2002, Nov 22), [Online]. http://www.americanwheelchairs.com/default.htm

[15] Stair-Chair SC-1 (earlier version CDM-2), portable wheelchair lifter, track based wheelchair transporter, Sunwa Ltd., 571 Negishi, Sayama-shi, Saitama-ken, Japan 350-1325.

[16] Retrofit wheelchair lifter, Tennessee Mobility, (2002, Nov 22), [Online]. http://www.tennesseemobility.com/tennesseemobility/web/2jozb7os.html

[17] Curb skipper, Shoprider Co. Ltd, (2002, Dec 4), [Online]. Available: http://www.arabmedicare.com/curbskipper.htm

[18] S. P. Levine, D. A. Bell, L. A. Jaros, R. C. Simpson, Y. Koren, J. Borenstein, "The NavChair Assistive Wheelchair Navigation System," in Trans. On Rehab. Eng., vol. 7, No. 4, pp. 443-451, 1999

[19] H. B. Wang, T. Ishimatsu, J. Mian, et al., Vision-guided navigation for a wheelchair, Proc. IASTED Int. Conf. Robotics and Manufacturing, Honolulu, Hawai-USA, pp. 145-148, 1996.

[20] H. B. Wang, C. U. Kang, T. Ishimatsu, et al., Auto-navigation of a wheelchair, Int. J. Artificial Life and Robotics, pp. 141-146, 1997.

[21] STEERING CLEAR OF BUMPS: New Navigation System to Help Wheelchair Users, (2002, Sept 24), [Online]. Available: http://www.jinjapan.org/trends00/honbun/tj010210.html
[22] Pride Jazzy XL 1170, A1 Mobility Co. Ltd, (2002, Dec 4), [Online]. Available: http://www.a1mobility.com/wheeltoc.shtml
[23] World's first 4WD scooter, Serio Co. 2-2-23 Hagunishi, Hanamatsu, Shizuoka Prefecture, 〒 433-8111, (2002, Sept 24), [Online]. Available: http://www.fukushi.com/yougu/data/files/serio/1.html
[24] S. Hirose, T. Sensu, S. Aoki; *the TAQT Carrier: A Practical Terrain-Adaptive Quadru-Track Carrier Robot*, Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, Tokyo, pp.2068-2073, 1992
[25] Stair assist wheelchairs and carrier, Hospimedia group, (2002, Sept 24), [Online]. Available: http://www.hospimedicaintl.com/chair.htm
[26] Scalamobile, Ulrich Alber GmbH + Co. KG, Sigmaringer Str. 100, D-72458, Albstadt, Germany.
[27] KSC-A-11, KSC-A-12 & KSC-C-10, Kyowa Elect. Industry Corp., 10-2 Kawaguchi-cho, Nagasaki, Japan 852-8108.
[28] Nagasaki Hillside Association, (2002, Sept 18), [Online]. Available: (in Japanese) http://www1.odn.ne.jp/nha/
[29] RH-2001A, (2002, May 20). [Online]. Available (in Chinese): http://www.runsoft.com.cn/fwzx/fwzx4(wtjd).htm
[30] K. Cox, "Battery powered stair-climbing wheelchair," US Patent 6,484,829 B1, Nov. 26, 2002.
[31] D. Kamen, R. Ambrogi, R. Heinzmann, "Transportation vehicles and methods," US Patent 5,975,225, Nov. 2, 1999.
[32] INDEPENDENCE™ iBOT™ 3000, John Williamson's Now this is an electric powerchair that I will buy with my own money!, (2002, Sept 24), [Online]. Available:http://www.dynopower.freeserve.co.uk/homepages/newchair.htm
[33] Tomo Co. Ltd, Tamagawa University. (2002, May 20). Freedom. [Online]. Available (in Japanese only): http://www.tomo-co.co.jp/free.htm
[34] Overhead stair lifter, Outa Co.Ltd, (2002, Nov 22), [Online]. http://www.ohta-shokai.co.jp/index2.html
[35] Welcab, Toyota Co. Ltd, (2002, Nov 22), [Online]. http://www.toyota.co.jp/welcab/index.html
[36] Government Weighs Sales Of Wheelchair That Can Climb Stairs, Primedia newsroom, (2002, Nov 21), [Online]. http://www.worknews.pwpl.com/healthcare.htm
[37] C. Doman, P. Rowe, L. Tipping, A. Turner, E. White, "Tools for living," (2002, Sept 27), [Online e-book]. Available: http://www.elsevier-international.com/e-books/pdf/31.pdf
[38] Hiwin Corp, (2002, May 20). LAH Series linear actuators [Online]. Available: http://www.hiwin.com
[39] 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, pp. 343-353, 1995.
[40] R. Misawa, "Stair-climbing vehicle for wheelchair," Japan Patent 8-286753, Oct. 29, 1996.
[41] R. Misawa, "Stair-climbing vehicle for wheelchair," US Patent 6,158,536, Dec. 12, 2000.

[42] Tracked stair-climber Tajimi Station, Media Park Himawari volunteer group (2002, Sept 19), [Online]. Available: (in Japanese) http://www.mediapark.ne.jp/himawari/98takayama2.html

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

[44] M. Lawn, T. Sakai, M. Kuroiwa, T. Ishimatsu, "Development and practical application of a stairclimbing wheelchair in Nagasaki," Journal of HWRS-ERC, Int. Journal of Human-friendly Welfare Robotic Systems, pp. 33-39, 2001.

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

[46] M. Lawn, T. Takeda, "Development of a 20 DOF wheelchair for operation in a barrier present environment," Proc. 8th ISMCR Int.l Symp. Measurement and Control in Robotics, Prague, Czech Republic, pp. 411-416, 1998.

[47] Alias Wavefront.

[48] M. Lawn, T. Ishimatsu, T. Takeda, "Towards a "Barrier Free" wheelchair," Proc. 16th IMEKO World Congress, Vienna, Austria, vol. 7, pp. 63-67, 2000.

[49] M. Lawn, T. Takeda, "Design of a robotic-hybrid wheelchair for operation in barrier present environments," Proc. 20th IEEE/EMBS Int.l Conf., Hong Kong, ROC, vol. 20, pp. 2678-2681, 1998.

[50] Macromedia Flash 5J

[51] T. Jozaki, M. Tanaka, M. J. Lawn, T. Ishimatsu, "Motored wheelchair applicable to a variety of disabled," Proc. Int.l Conf. on Control, Automation and Systems, Jeonbuk, Korea, pp. , Oct. 2002.

Curriculum Vitae

Murray J. Lawn received a B.E (hons) at Canterbury University, Christchurch, New Zealand in 1989. After 12 years as a technician and later engineer for New Zealand Railways worked for New Zealand Telecom as a Communications Consultant. In 1994 he came to Japan and currently is an assistant professor teaching Computer Science at the Nagasaki Junshin Catholic University and a visiting Lecturer at the Nagasaki Institute of Applied Science. Studies and interests include the development of Stair-climbing devices, multimedia in education and the use of Virtual Reality in rehabilitation training

Appendices

Appendix A Background to the high step and stair-climbing mechanism design concept

A side view of the initial high step and stair-climbing mechanism proposed in 1997 is shown in Fig. 71. Fig. 72 shows photos of a life size model of the mechanism in barrier free mode and stair-climbing modes respectively [45].

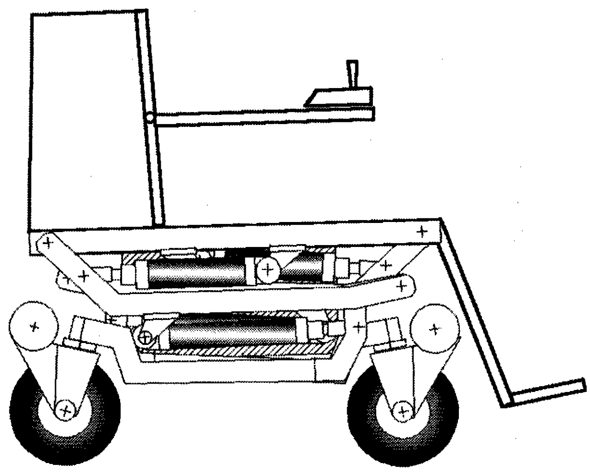
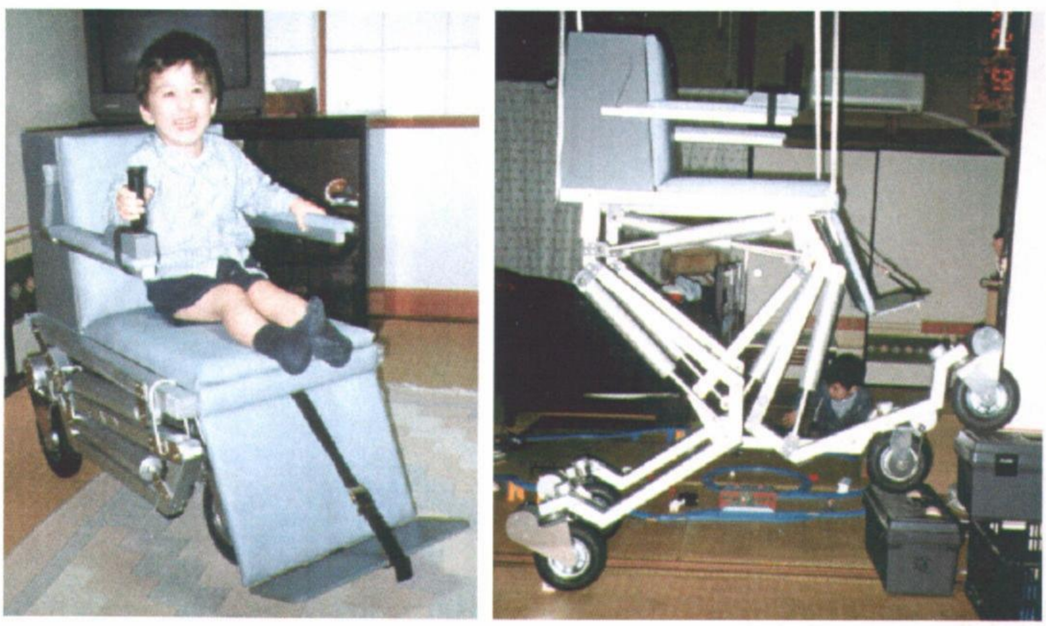


Fig. 71 First high step stair-climbing proposal (side view)

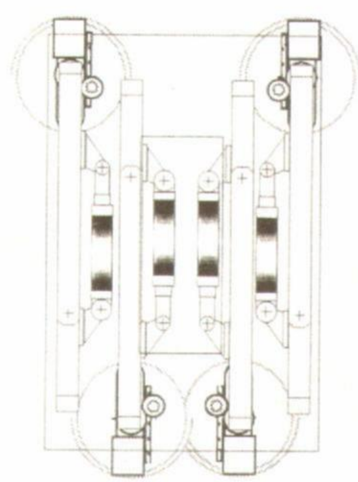
The proposed system of actuators was based on the use of oil hydraulics, at that time (1996-7) this represented the only relatively lightweight and cost effective means to provide the linear output torque required for leg actuation.

Most of the initial design effort was in designing legs that would be sufficiently compact to maintain a standard wheelchair base height (approx. 45 cm), but at the same time be able to articulate the legs to raise the wheelchair and occupant 1.2 meters. The initial modeling process was mainly carried out by working with actual size 2D articulated card models over a 35 degree stairway taped to an office floor. The modeled components were based on low cost components available at that time. The process consisted of several hundred iterations, ranging from intuitive to calculated. The actuators were based on low pressure (30kgf/cm^2) 40 mm cylinders providing a maximum output of ~450kgf. Although a hydraulic pump and associated equipment represented significant weight it was a fraction of the weight and cost of the main alternative which was to use electric cylinders. At that time each hydraulic cylinder represented about 1kg in weight and per cylinder valves (electric) for switched hydraulic control also about 1kg, the pump and associated common equipment weighed about 20kg. This compared to electric power cylinders that were over 10kg each, and lacked the high output pressure and speed required. Furthermore the cost of such cylinders at that time was very high (built to order).

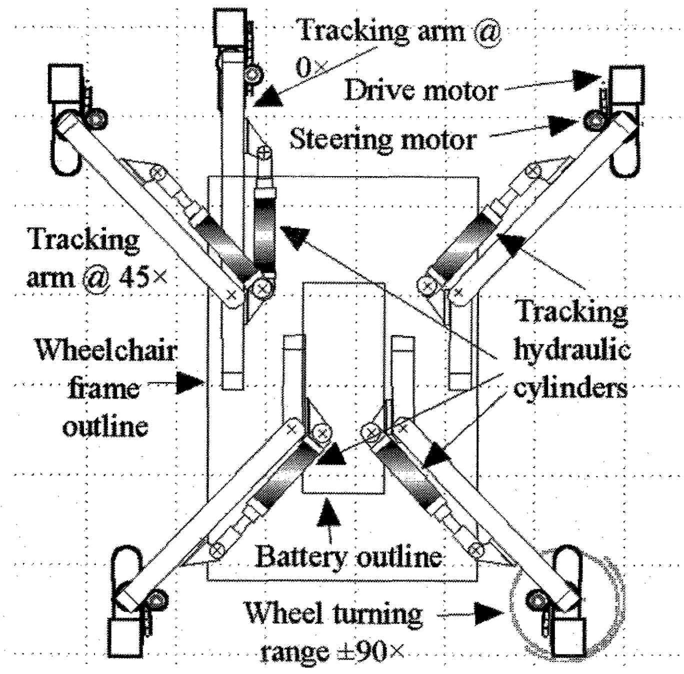


(a) barrier free mode (b) stair-climbing mode

Fig. 72 Initial high step and stair-climbing mechanism – proposed



(a) barrier free configuration



(b) variable track width mechanism, max. stability

Fig. 73 Second proposed high step mechanism plan views

Negative attributes of the initial design (Fig. 71 and Fig. 72) were quickly apparent. The narrow tread or footprint provided unacceptable lateral stability margins. The initial work-around for this was to add an extra degree of freedom at the base of each leg, thus permitting adjustable tracking width. This is illustrated in Fig. 73(b). While variable tracking did provide lateral stability it also introduced significant control complexity, the proposed control schematic is shown in Fig. 74 [46].

Overall kinematical feasibility during the stair climb was modeled in 3D CAD animation software [47] on a Sun workstation. A further problem was noted, that was the fact that while the mechanism could in fact board a van it required about 30 cm head clearance to do so. Verification of how much head clearance was actually available when considering the average van and occupant seated in the wheelchair found the actual available clearance to be close to zero. This led to a long period of reconsideration of the leg articulation structure. Until that time the legs both front and rear were symmetrical, this ensured equal operating ability in stair ascent or descent in either direction, however in order to enter a van with "near zero head clearance" the rear legs could not fold under the wheelchair base.

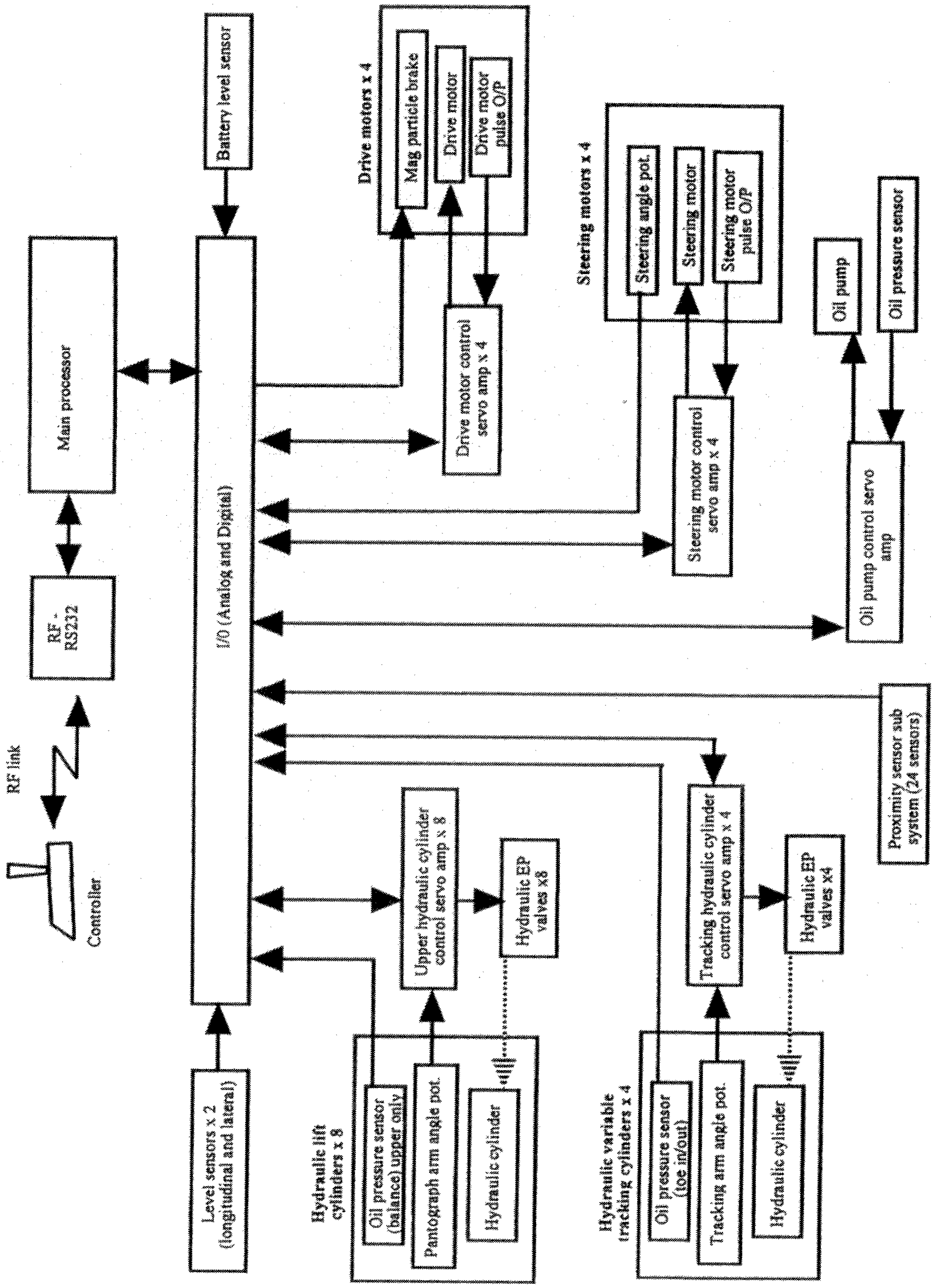


Fig. 74 Control schematic for second proposed hydraulic based high step stair-climber

This led to the concept of folding the legs behind the chair shown in Fig. 75. This rear leg redesign led to two significant outcomes, firstly vehicle boarding became possible with "near zero head clearance" shown in Fig. 76 and secondly it became possible to bring the front wheels out to the edge of the chair increasing the front tread width sufficiently to no longer require the variable track mechanism [48].

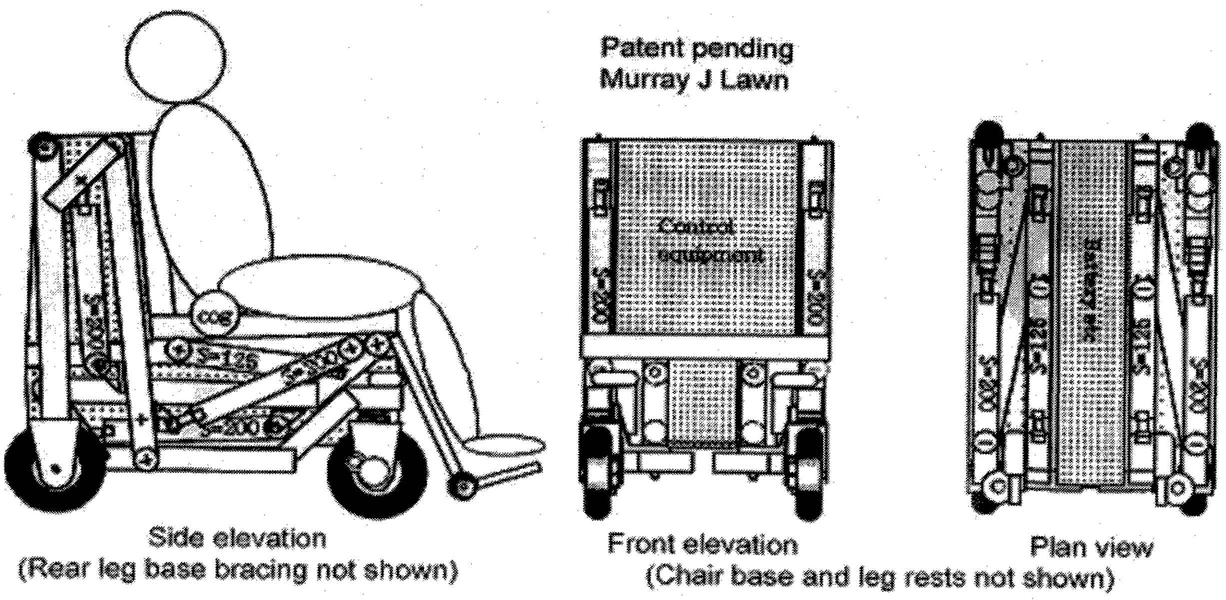


Fig. 75 Third proposed high step and stair-climbing mechanism

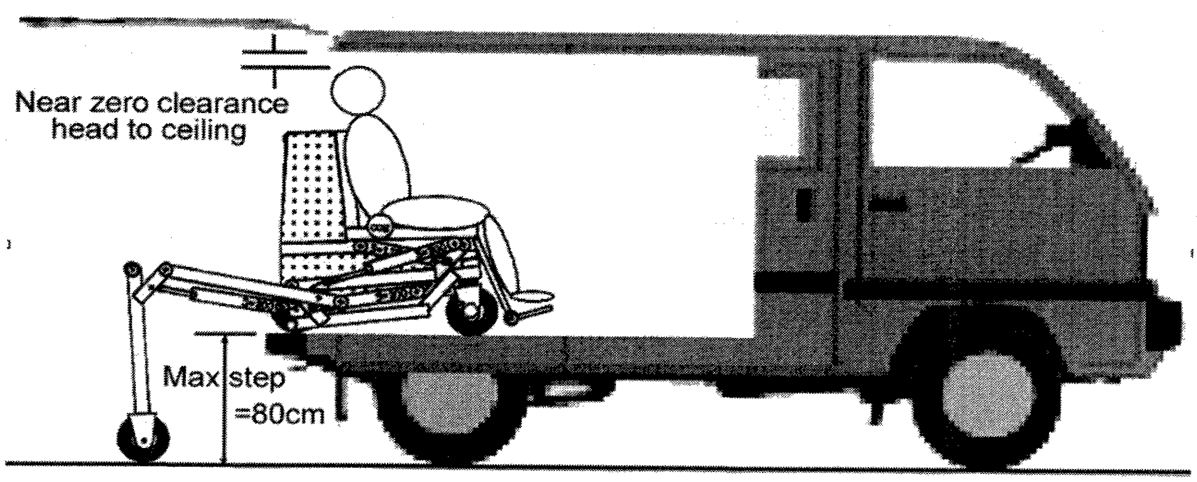


Fig. 76 Third proposed high step and stair-climbing mechanism – near zero head clearance upon van entry

Shortly after the third proposed mechanism was presented in 2000, it was noted that electrically adjustable beds were starting to come out using lightweight high power low duty cycle 24V DC linear actuators. Initial enquires to the cylinder manufacturers were that the cylinders were not available outside the bed manufacturing industry. However in early 2001 the actuators become commercially available [38].

(a) front right (b) rear right

Fig. 77 Third proposed mechanism modeled with electric actuators – barrier free mode

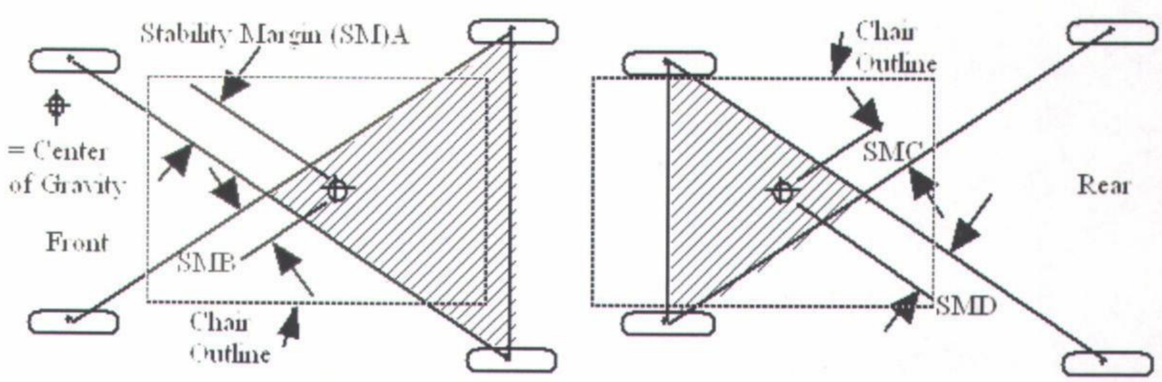
As soon as a lightweight high-power electrical linear actuator was noted as being manufactured the third proposed mechanism was redesigned to cater for the different actuator configurations and modeled in life size. This is shown in Fig. 77 barrier free operation and Fig. 78 stair-climbing operation.

The proposed means of maintaining balance during stepping is explained with regard to Fig. 79 to Fig. 81. Upon encountering such as a step, wheels would step one at a time as shown in Fig. 80 ascending and Fig. 81 descending.

For the front wheels to step the combined vehicle's and uses' center of gravity (COG) would be altered to within the shaded area in Fig. 79(a), and for a rear wheel to step the COG would be altered to within the shaded area in Fig. 79(b). In order to achieve the high step shown in Fig. 80(h) small protrusions from the foot rests were proposed, to take the chair and user weight while the front wheels were folded in (ascending). Illustrations Fig. 79 to Fig. 81 are video frames from a video created using an articulated flat paper model used to simulate the stair-climbing action. A video camera was set to take still photos and replay them in 1/8 second sequence. The result was a simple animation of the stair-climbing action.

(a) (b)

Fig. 78 Third proposed mechanism modeled with electric actuators – stair-climbing mode



(a) front wheel step (b) rear wheel step

Fig. 79 Climb mode stability margins - plan view

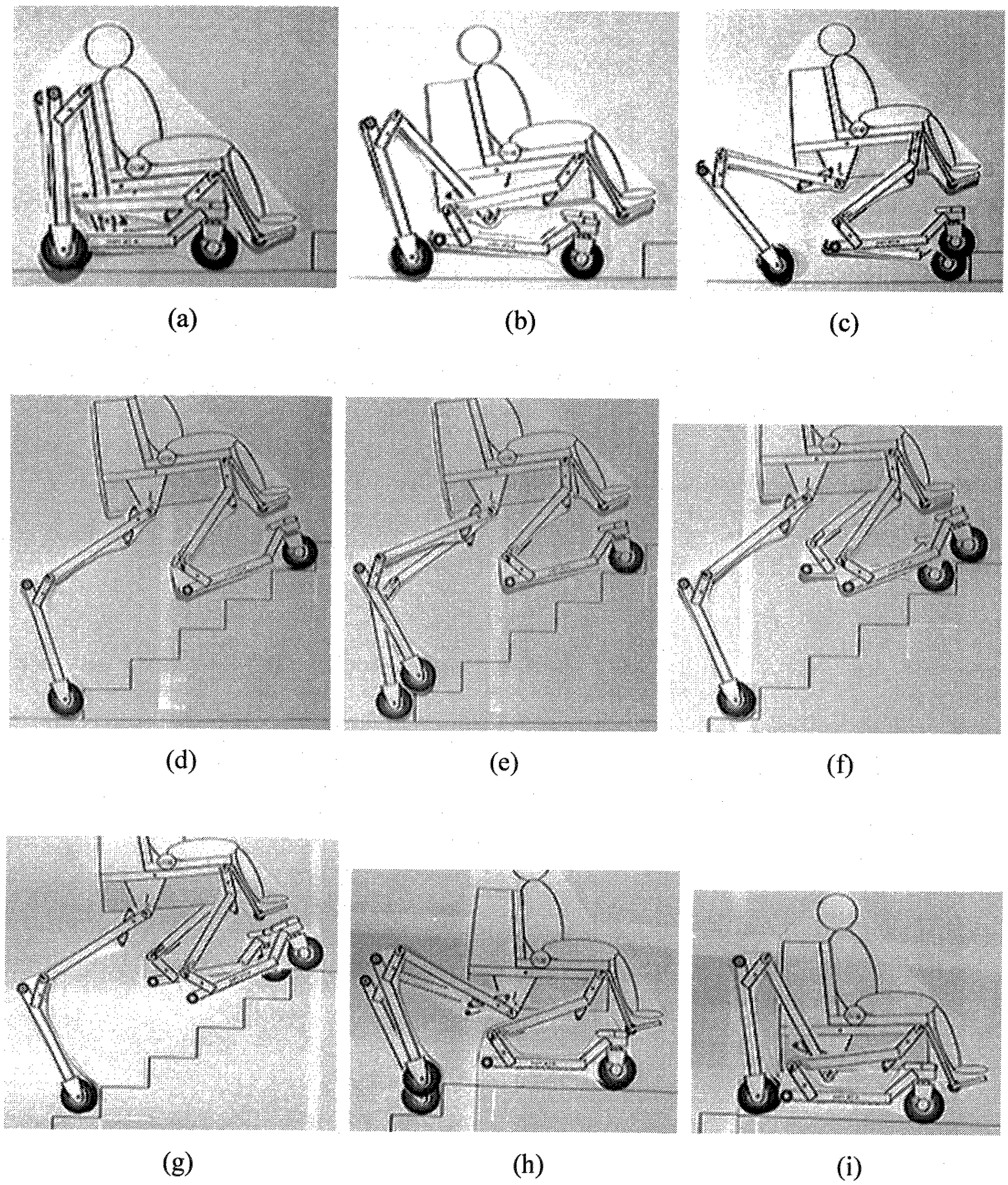


Fig. 80 Stair ascent – Third proposed stair-climbing mechanism

However regarding achieving the fine balance necessary was considered very complex and the stability margins too low for practical consideration. After re-visiting the target stairs such as those shown in Fig. 63 the need for 4 points of contact with the ground at all times was reconsidered.

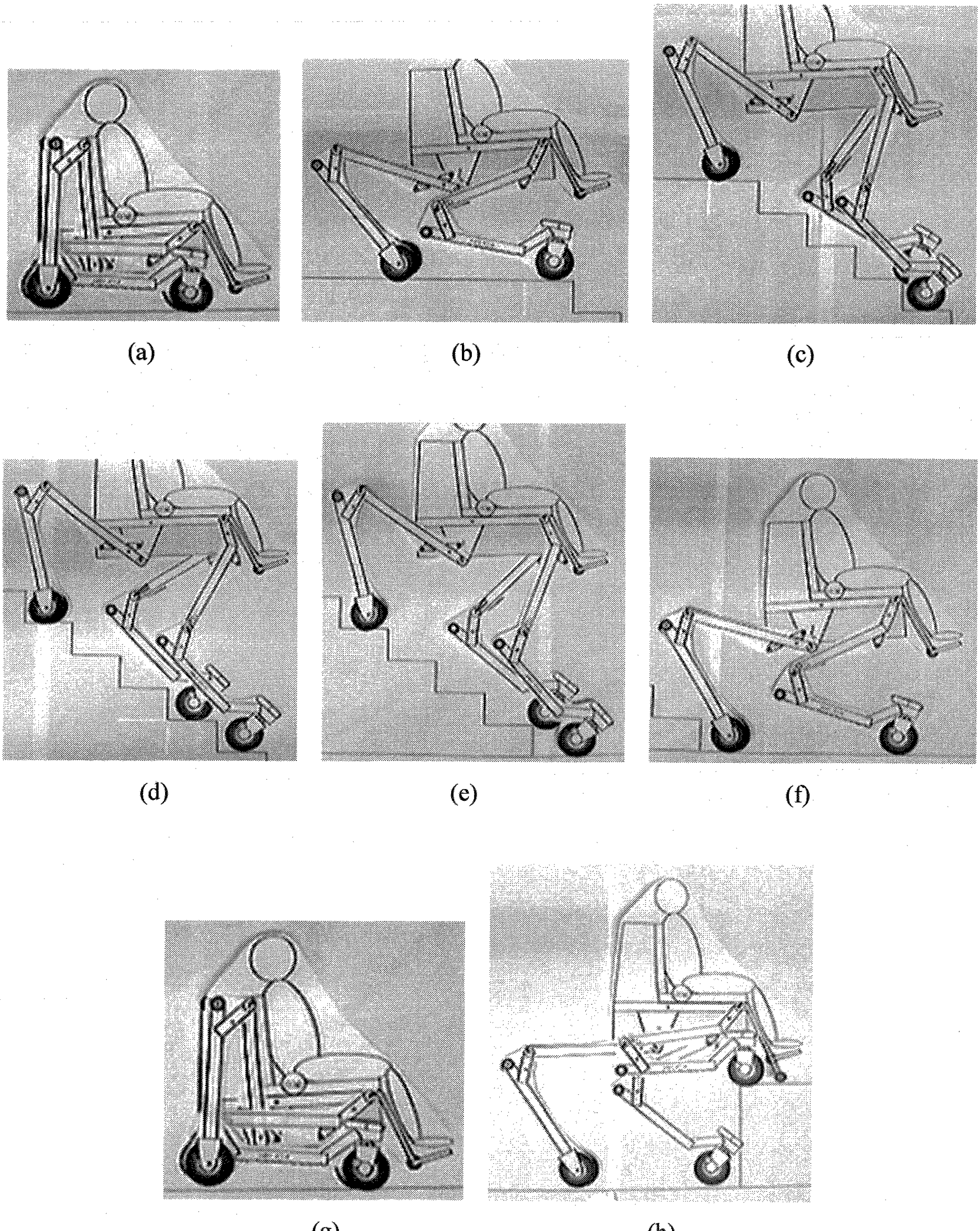


Fig. 81 Stair descent and high step - third proposed stair-climbing mechanism

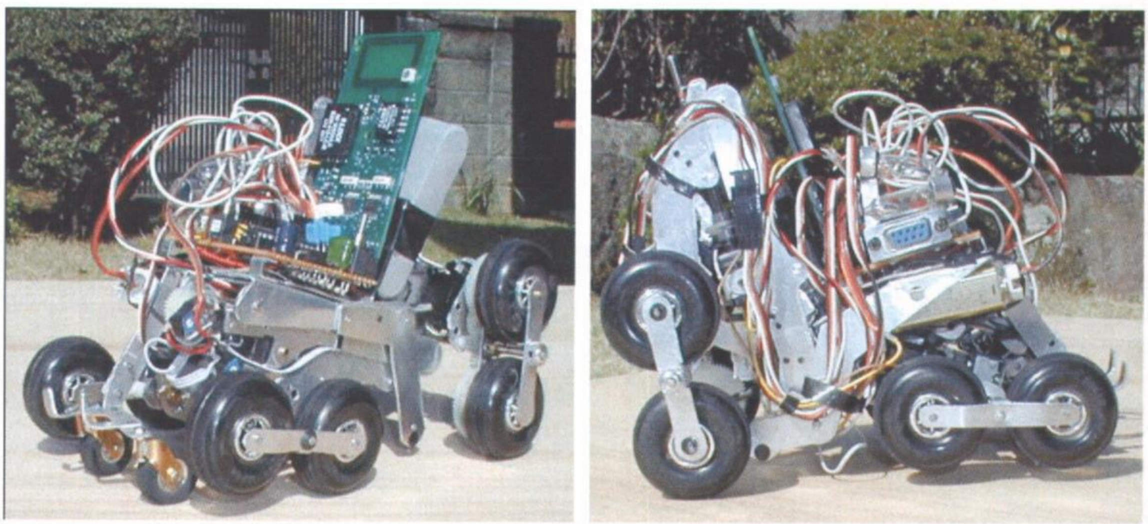
The resultant redesign was to replace the alternately stepping leg mechanism with wheel clusters, thus providing at least four continuous points of contact with the ground at all times. While inclusion of wheel clusters increased the lower section complexity the number of articulated legs reduced from four to two thus significantly reducing control complexity in the upper section.

The resultant mechanism outlined in Section 3 was targeted at providing autonomous operation on stairs, as well as providing autonomy in the negotiation of a single high step such as that encountered when entrance to a van is required.

Appendix B High step and stair-climbing mechanism - computer controlled scale model

A computer controlled 1:6.25 scale model of the high step and stair-climbing mechanism was built. Two single chip CPUs were used to provide a minimal control system. The purpose of the scale model was to verify the overall practicality of the design as well as provide an experimental base for a minimal control system. Experiments were successful in the ascent and descent or model stairs and in the boarding and disembarking from a model van.

This Section provides details regarding the modeling and building process of the computer controlled model high and step stair-climbing mechanism.



(a) front casters and front leg mechanism visible (b) rear leg mechanism visible

Fig. 82 High step and stair-climbing scale model in barrier free mode

Fig. 82 pictures the scale model in barrier free mode. That is the mode of operation used on flat level surfaces. The control system and associated peripherals are located where the chair (model chair) should be. The vertically orientated circuit board visible in Fig. 82(a) is the radio control link, behind that is the battery for the servo motors. The horizontally orientated circuit board is the main circuit including the CPU I/O etc. Visible in Fig. 82(b) is a second battery under the chair for the electronics and an RS232 port for computer interface, above that are two mercury angle sensors.

The scale model was modeled precisely as per the numerical model but slightly exceeded the numerical model in width. This was due to the use of mechanical components that were not available in an appropriate scale.

The high step mechanism modeled used eight Futaba S3103 RC servos. All eight servo motors were modified for continuous rotary operation. The position potentiometers were replaced by external potentiometers for centering adjustment. The linear actuators such as that seen in Fig. 85 were made by connecting a threaded shaft (M5) to the servo output. Appropriate swivel mounts were provided on the servo bodies and the shafts operating into appropriately threaded pins as shown. The maximum operating speed of the S3103 is about 1.5 rps (revolutions per second - S3103 servo spec. 0.11 sec/ 60° @ 4.8 v) providing a linear actuation speed of about 1.2 mm per second. The servos output 1.2 kgf/cm was well in excess of that required by all actuators except the wheel cluster rotation motors. Particularly the rear cluster motor, due to 3 of the 8 servos and associated gear trains being mounted on the rear wheel cluster, compared with only one motor being mounted on the front wheel cluster.

The linear actuators were modeled based on recent availability (at the time of writing) of low cost, lightweight linear power actuators (Max. 6000N, 5mm/sec no load, 3mm/sec max. load, 24v, weight 2.5 kg, duty cycle 10%). Initial papers [45][46][48] and [49] were written based on the use of hydraulic cylinders powered by a single hydraulic pump. Such lightweight, high power linear electric actuators were initially developed for hospital bed articulation.

Scale model

The model pictured in Fig. 82(a) and (b) is based on the 1 to 6.25 scale. This choice was influenced by the ready availability of 4 cm pneumatic tires (used on RC model aircraft) and miniature (S3103 servo 21.8 x 11 x 19.8 mm) RC servos. The leg design is based on that shown in Fig. 75 [48], with the addition of the wheel clusters to overcome the need for precise balancing. Initially a calibrated 2D (two dimensional) articulated paper model was created and checked for basic kinematics. This was then modeled in 2D animation software [50], to provide step by step visual feasibility analysis, 190 frames provided sufficient resolution to cover the 8 basic phases of operation, which are as follows:

1. Entry to a stair-climb
2. Stair-climbing
3. Stair-climb to a landing
4. Entry to stair-descent
5. Descending stairs
6. Stair-descent to a landing
7. Boarding a vehicle (high step)
8. Disembarking from a vehicle (high step)

One of the 190 animated frames is shown in Fig. 83 in the environment in which it was created.

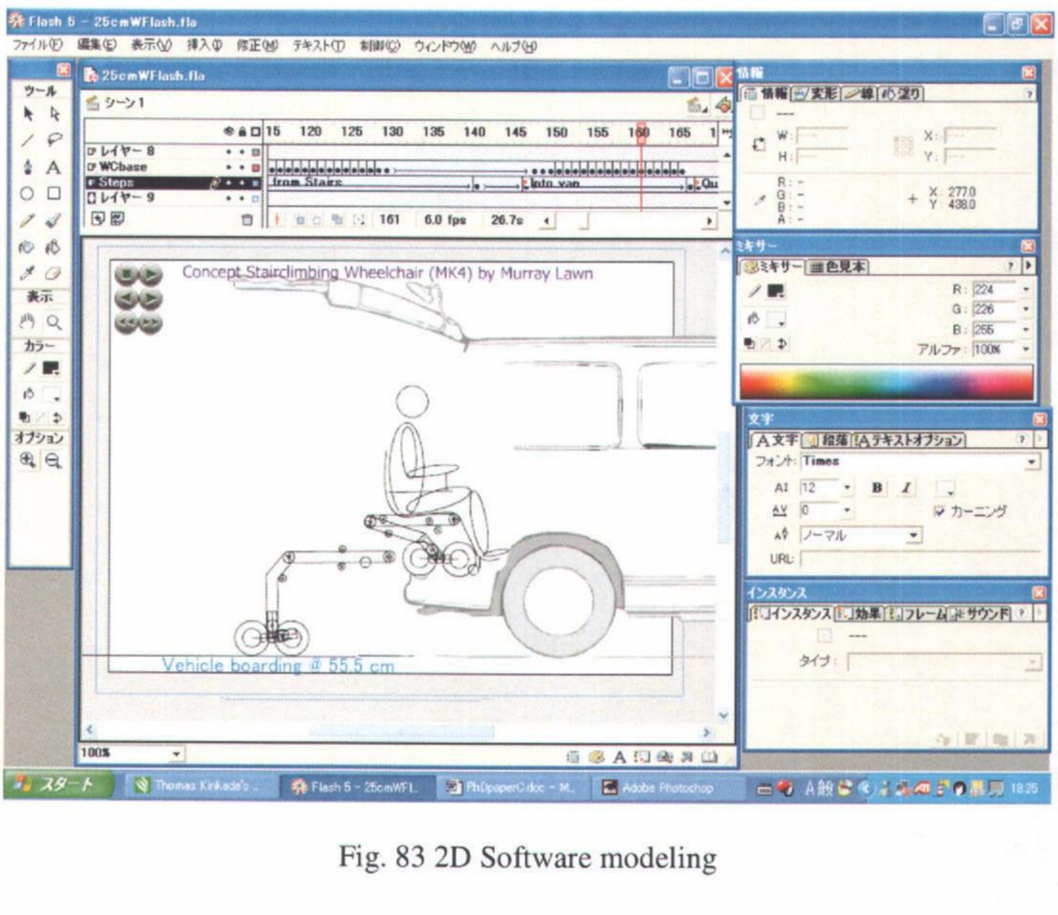


Fig. 83 2D Software modeling

Following the 2D modeling initially a simple form of 3D modeling was employed to provide basic 3D feasibility analysis, this model is pictured in Fig. 84.

With regard to creation of the controlled scale model mechanism, parts were collected on a best effort basis to provide scaled parts that closely matched the characteristics of the parts they were representative of. In this regard however notable parts that could not be scaled were the wheel cluster rotation mechanisms. The very high torque required - peak rear cluster drive torque ~ 160kgf/cm based on R=5cm sprocket @ 220 kg loading – peak, for a full size mechanism would most typically be chain driven, however an appropriately scaled high torque - 2.2 kgf/cm to a 5 mm radius sprocket, chain was not available for the scale size mechanism.

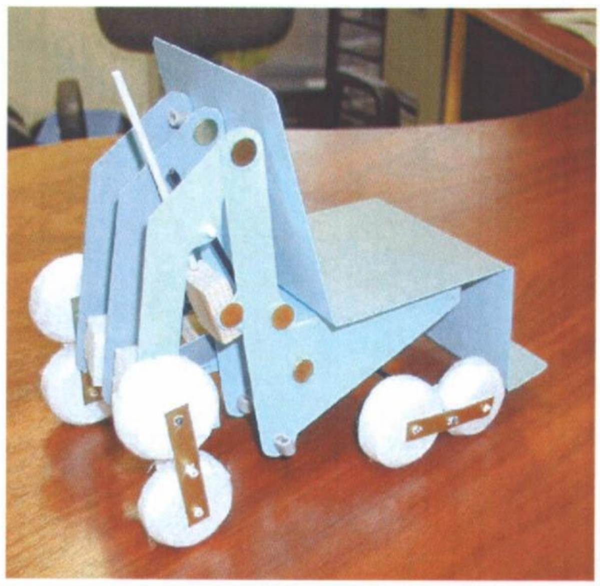


Fig. 84 Simple 3D feasibility model

Thus as can be seen in Fig. 85 a modified worm drive gear boxes (Tamiya) were employed. However the high frictions encountered made operation close to the maximum output of the rear servo motor (1.2 kgf/cm). The friction appeared to be due to the miniature worm-drive gearbox used lacking any anti-frictive thrust mechanism and resulted in overheating of the rear cluster RC servo when used for continuous stair climbs. RC servo motors are designed for position control, that is they will rotate to and maintain any requested angle. However the requirements for all RC servo motors for the high step mechanism was to provide continuous rotary operation. Therefore all RC servomotors were modified for continuous operation, the control signal provided precise speed control rather than position control. It must be noted that modifying an RC servo to continuous rotary operation nullifies any manufacturer warranties, a duty cycle specification is not provided but in the case of the Futaba S3103 experience would indicate sub 50%. Further not all RC servo motors can be modified for continuous operation. Most RC servo motors output

±45° or ±90°, therefore the final output cog on some servos is provided with only 180° of teeth. In the case of the Futaba S3103 360° of teeth are provided but the unused 180° of teeth are about 1/3 the width of the used 180° side. This has resulted in a high failure rate of the output cogs.

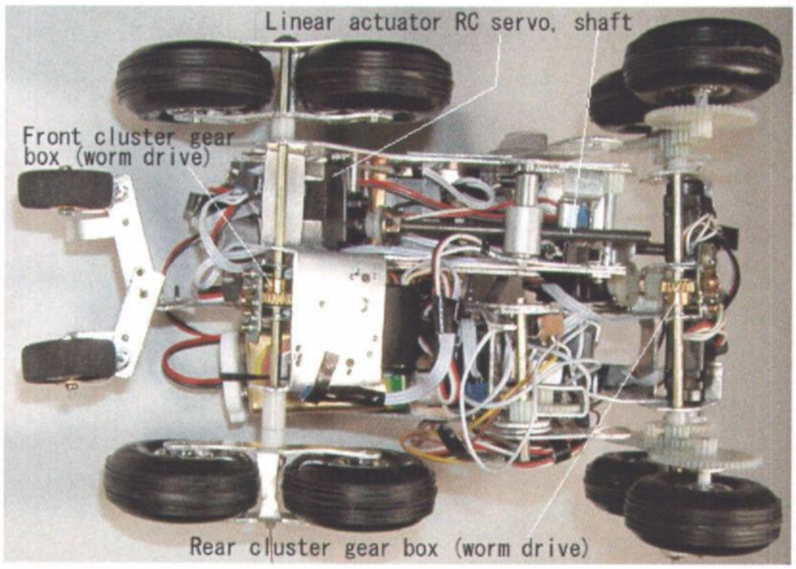
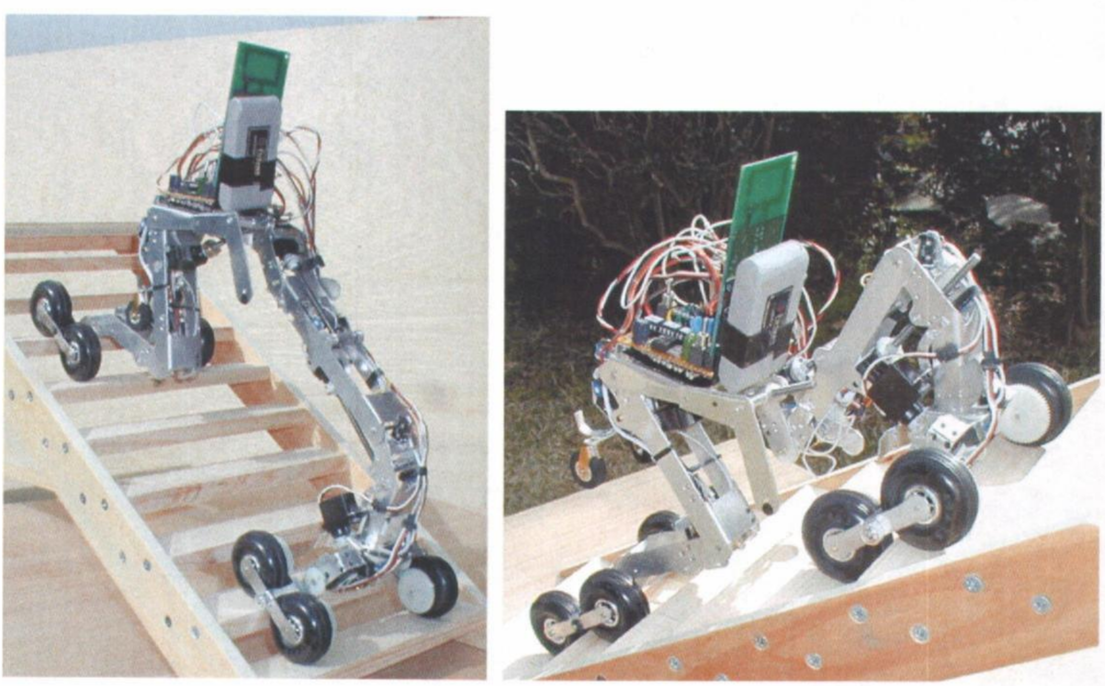


Fig. 85 Scale model high step and stair-climbing mechanism viewed from below

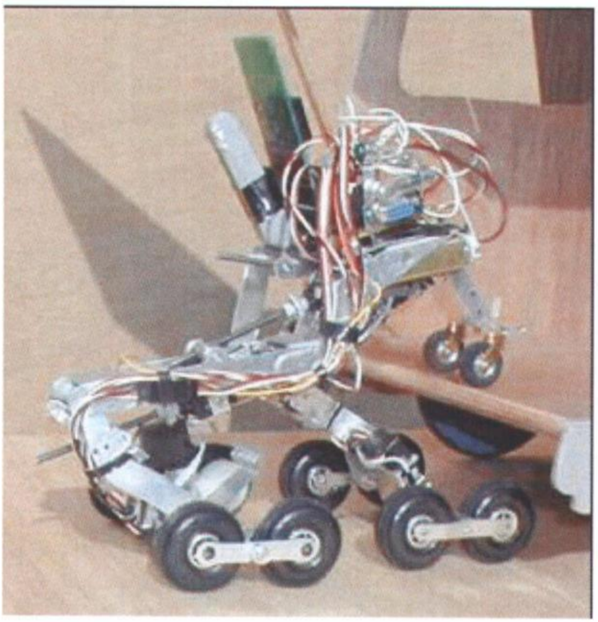


(a) stair ascent

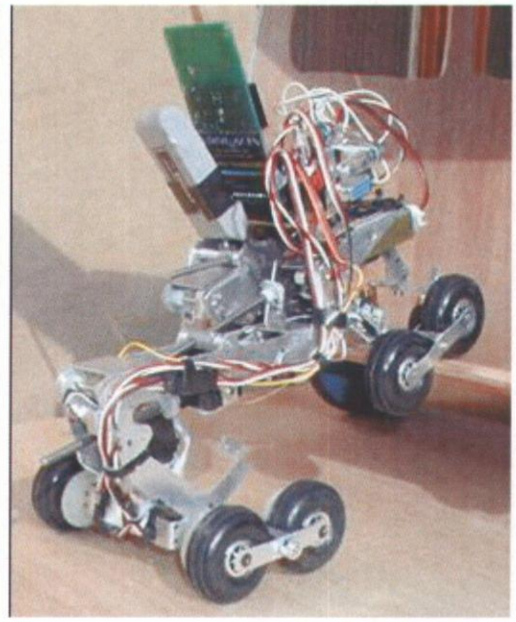
(b) stair descent

Fig. 86 High step stair-climbing scale model in stair negotiate climb mode

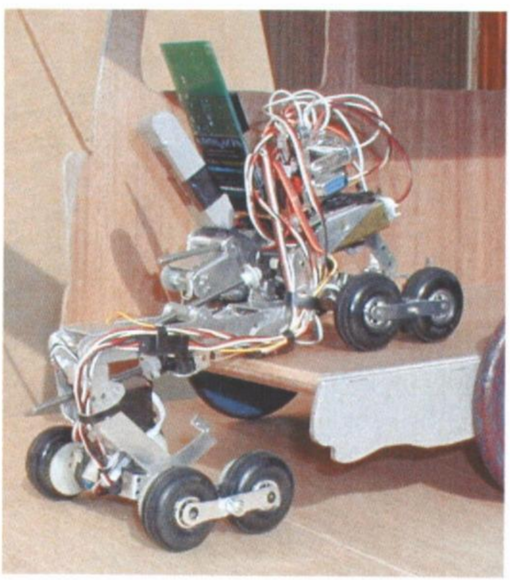
Stair ascent is pictured in Fig. 86(a) and descent in (b). Details regarding stair ascent and descent are provided in Sections 3.4 and 3.5 respectively.



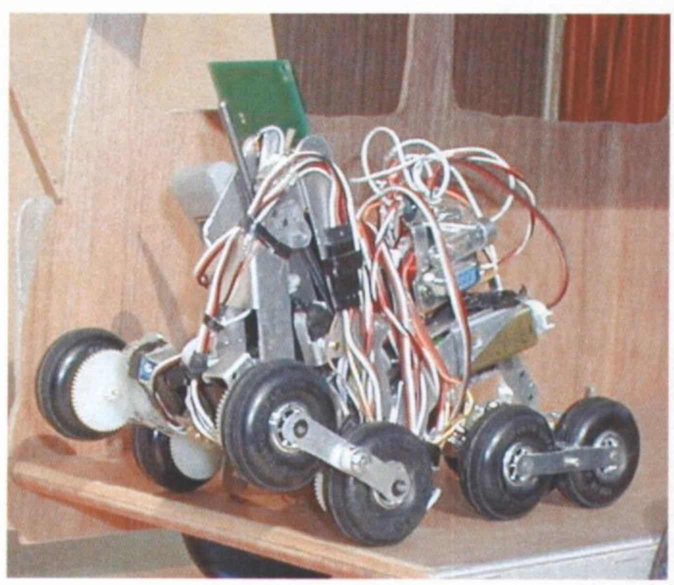
(a) front caster positioning



(b) front cluster boarding



(c) weight on temp. rest point



(d) rear cluster boarding

Fig. 87 High step and stair-climbing scale model boarding a van

The stages of boarding a van are pictured in Fig. 87(a) to (d). Details regarding this operation are provided in Section 3.6.

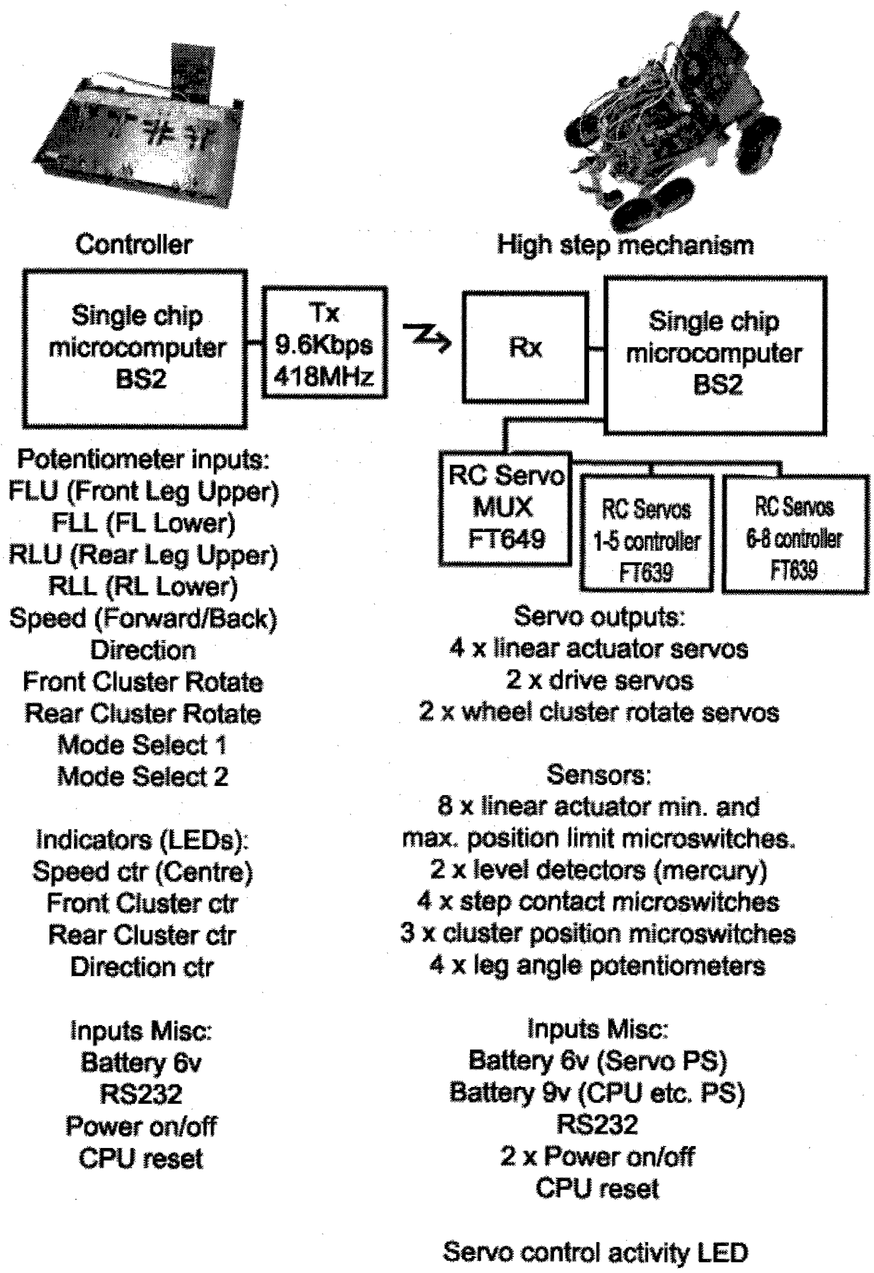


Fig. 88 Model - controller and high step mechanism schematic and I/O

The model high step and stair climbing mechanism control system schematic is shown in Fig. 88. The control system required to compensate for wheel cluster rotation is detailed in

Section 3.7.4. A simplified version of this control system was implemented on the RC model. The rotation correction required is theoretically linear, however in the system actually built shown in Fig. 88, the combined characteristics of both the RC controller chip and the RC servo-motors was measured and are shown in Fig. 89. The characteristics are far from linear and asymmetrical with regard to motor direction. The compensation required with regard to speed and direction was calculated, converted to closest match values, and implemented on the BS2 chip using a lookup table. The result was no visual error (drift) in wheel position during cluster rotation in either direction.

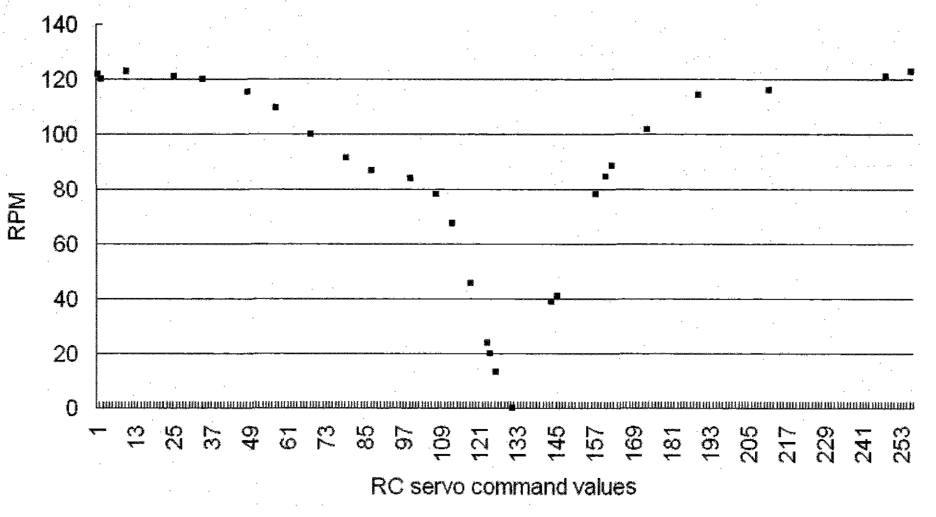
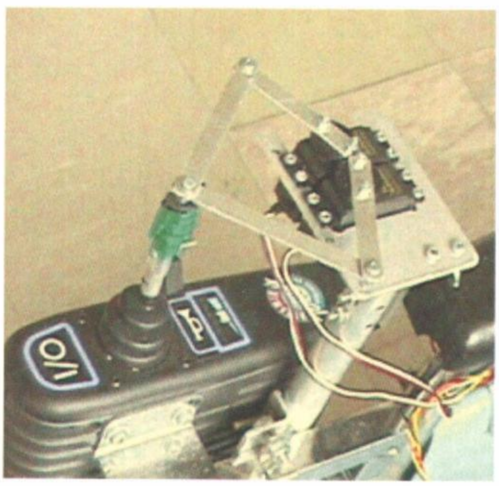


Fig. 89 RC servo command values vs. measured speed in RPM

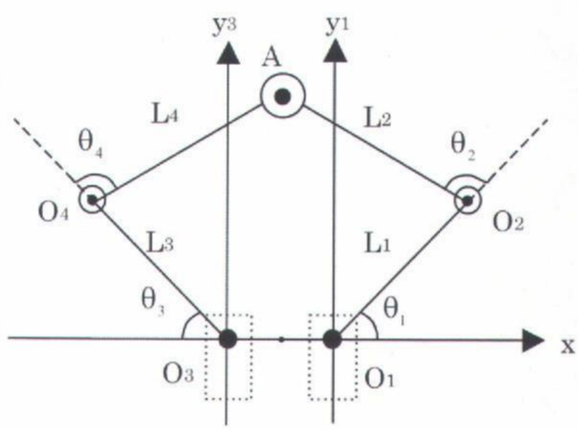
In summary the scale model provided significant insight regarding the kinematics as well as controllability. The scale model high step stair-climbing mechanism successfully ascended and descended scaled model stairs. The model also successfully boarded and disembarked from a scaled model van.

Appendix C Image processing based guidance system - further application

The ability to control any wheelchair is a relatively complex task. The task is relatively simple for persons with full upper body functionality. However many wheelchair users have great difficulty in operating such as the joystick which is used to control most powered wheelchairs. The directional guidance system outlined in Section 4.4.4 has been used to provide guidance data for a standard powered wheelchair. The task of providing a directional assistive device for a commercial wheelchair presented a major problem in that the manufacturer of most wheelchair controller systems will not permit any modification to the controller device. Any modification to the controller system immediately voids any warrantee. Furthermore altering the controller electronics to facilitate such as a computer assisted interface is a very time consuming task, and understandably not recommended by manufactures in light of the very high standards that must be adhered to in the manufacture of such safety critical systems.



(a) Link module



(b) Model of link mechanism

Fig. 90 General purpose joystick interface prototype

A very simple and low cost means of providing a general purpose joystick system interface was proposed and prototyped. The interface is pictured in Fig. 90(a) and the kinematical model illustrated in Fig. 90(b). The interface consisted of a pair of two section linkages each connecting to an RC servo motor. The electro-mechanical interface provided full operation of the joystick without any interference to the controller electronics. The link module was installed onto the joystick of a conventional powered wheelchair as shown in Fig. 90(a).

Kinematical control of the mechanism referred to as the link module is described below. This module is composed of a closed link mechanism actuated using two servomotors. The module moves the tip of the joystick with two-dimensional freedom.

In Fig. 90(b) a simplified model of the proposed link mechanism is shown. Links L_1 and L_3 are rotated by the servomotors θ_1 and θ_3 respectively. L_2 and L_4 connect the controlled links L_1 and L_3 to the tip of the joystick the resulting angles are θ_2 and θ_4. Point A denotes the tip of the joystick. In order to realize the desired two-dimensional movement of the tip of the joystick, it is necessary to calculate the desired rotating angles θ_1 and θ_3.

Firstly, calculating $x - y_1$

$$x_1 = L_a \cos\theta_1 + L_b \cos(\theta_1 + \theta_2) \tag{18}$$

$$y_1 = L_a \sin\theta_1 + L_b \sin(\theta_1 + \theta_2) \tag{19}$$

where we consider $L_a = L_1 = L_3$, $L_b = L_2 = L_4$ we obtain coordinates x_1 and y_1 , $L_b = \{L_b \sin(\theta_1 + \theta_2)\}^2 + \{L_b \cos(\theta_1 + \theta_2)\}^2$. Substituting the above relationships into Eqs.(18) and (19), we obtain

$$y_1 \sin\theta_1 + x_1 \cos\theta_1 = \frac{\left(x_1^2 + y_1^2 + L_a^2 - L_b^2\right)}{2L_a} \tag{20}$$

When we define $a\sin\theta_1 + b\cos\theta_1 = c$, the above relationships give

$$\phi = \tan^{-1}(a/b), \quad \cos(\phi - \theta_1) = \frac{c}{\sqrt{a^2 + b^2}} \quad \text{and} \quad \sin(\phi - \theta_1) = \sqrt{\frac{a^2 + b^2 + c^2}{a^2 + b^2}}$$

Where θ_1 is

$$\theta_1 = \tan^{-1}\frac{a}{b} - \tan^{-1}\frac{\pm\sqrt{a^2+b^2-c^2}}{c} \tag{21}$$

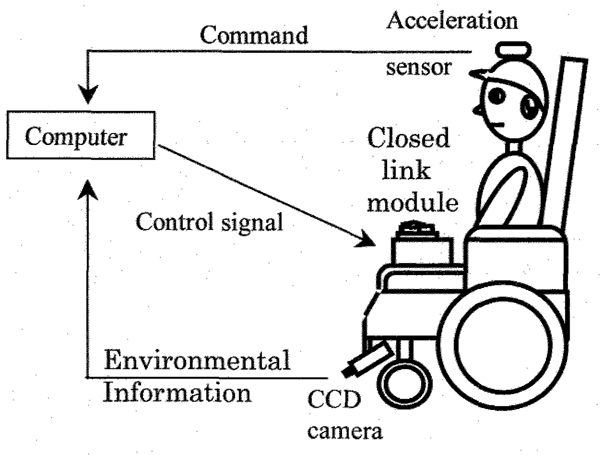


Fig. 91 Closed link module system diagram

The closed link mechanism consists of two identical mechanisms. Therefore $x-y_3$ may be solved similarly. Therefore, we obtain

$$\theta_1 = \tan^{-1}\frac{y_1}{x_1} - \tan^{-1}\frac{+\sqrt{y_1^2+x_1^2-c_1^2}}{c_1} \tag{22}$$

$$\theta_3 = \tan^{-1}\frac{y_2}{x_2} - \tan^{-1}\frac{+\sqrt{y_2^2+x_2^2-c_3^2}}{c_3} \tag{23}$$

where $c_i = \frac{(x_i^2+y_i^2+L_a^2-L_b^2)}{2L_a} \quad (i = 1 or 3)$

The co-ordinates of point A are calculated using Eqs.(22) and (23) reference points being

O_1 and O_3 respectively. The experimental module links were designed around L_a = 50 [mm] and L_b = 80 [mm].

The overall directional guidance system is illustrated in Fig. 91 and experimental system shown in operation in Fig. 92. The user interface consisted of an accelerometer located on the user's head as shown. The control signals were: tilt forward for forward operation, tilt to the left for turning left and tilt right to go right and tilt back for stop. A red line provided route information and an additional short yellow line prepared the system for an intersection. When the intersection was encountered the direction defined by the users' head bearing was chosen.

Fig. 92 Auto-navigation using image processing

Variations of the above closed link navigation system were experimented with, they included remote monitoring of the CCD camera via a TCP/IP based link, operating the wheelchair purely from the head mounted inclinometer data and using a teaching and playback system to record and repeat operation of the powered wheelchair.

A low cost mechanism capable of providing a navigation interface for most powered wheelchairs was realized [51].

Appendix D Improved accessibility and mobility administration in Nagasaki

Background – Nagasaki

Nagasaki is built on the slopes surrounding the beautiful Nagasaki Harbor, while the views from the hillsides are magnificent difficulty in negotiating the slopes has gradually left many elderly and or disabled persons housebound or faced with leaving their world of familiarity. This was the finding of a team of medical personal who conducted longitudinal studies on the Nagasaki hillside residents - particularly stroke victims - Cerebral apoplexy.. often resulting in partial paralysis [9]. 20% of Nagasaki Hillside residents are over 65 as at 1999, cf National average of 17% of Japanese persons over 65 [9]. While the stair-climbing would seem most suited to the young, it is the younger people who have been first to leave the hillside areas, to relocate to places of greater convenience, that is areas with more immediate vehicular access.

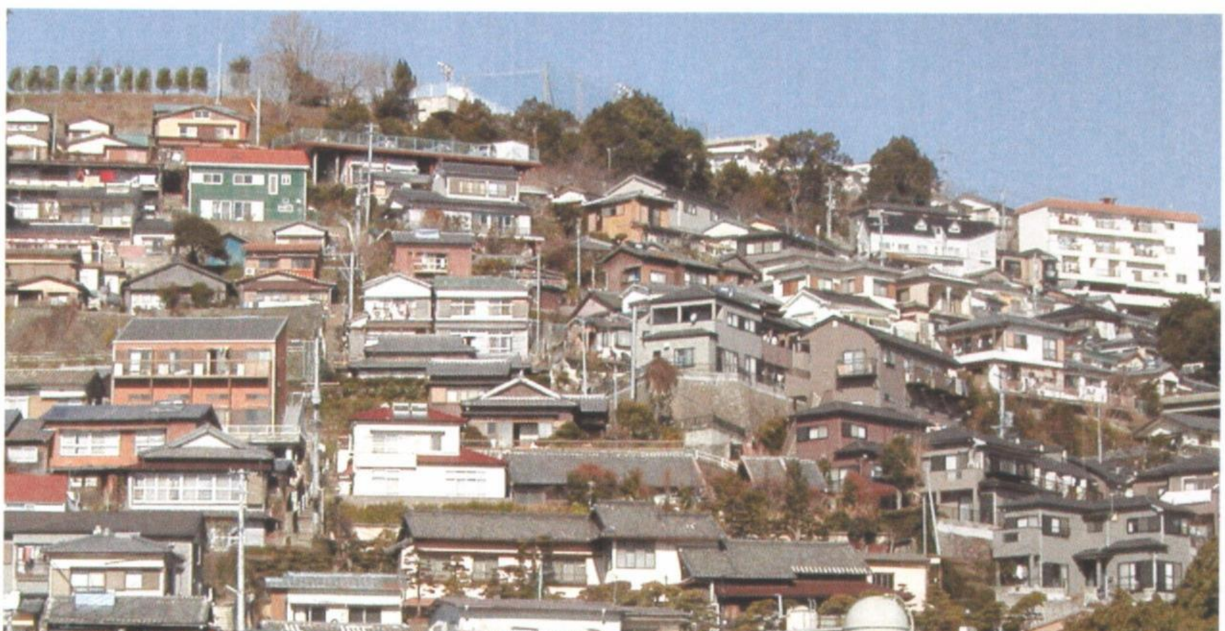


Fig. 93 Typical Nagasaki hillside - Suwa suburb

The recommendations of emergency medical groups servicing the hillside areas was to seek long term assistance addressing both transportation technology issues as well as administrative issues, that is the support provided by various care groups, care workers and volunteers as well as requesting support from the prefectural government. Specific steps taken in Nagasaki in relation to local terrain induced welfare needs was to initially create a number of volunteer support groups.

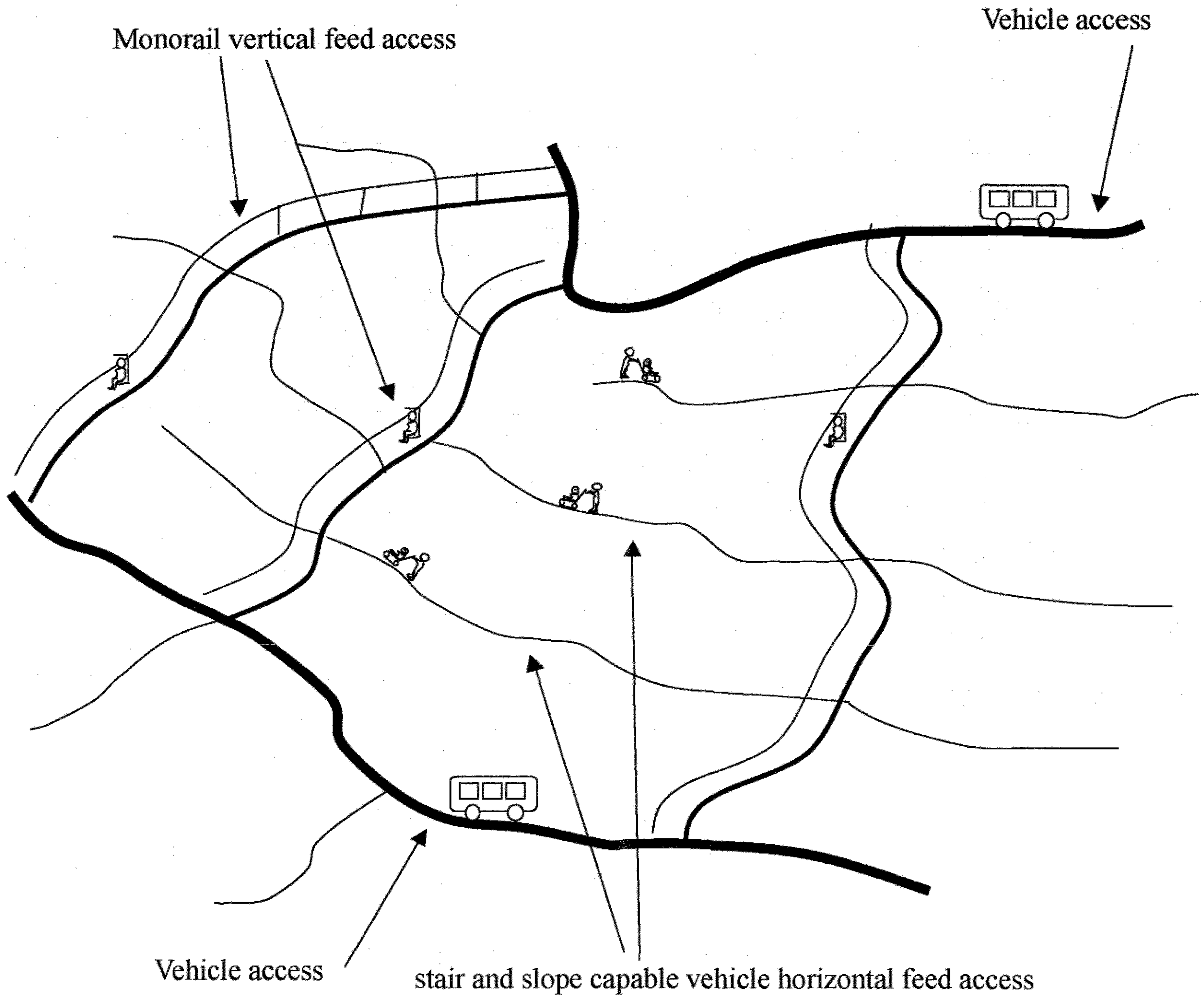


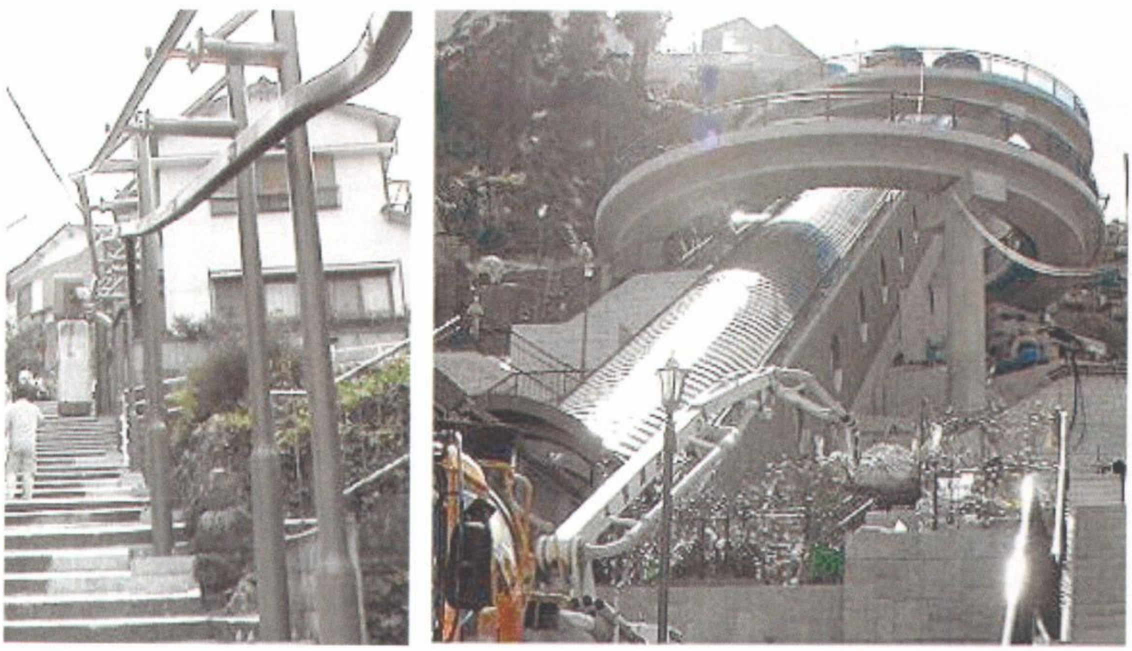
Fig. 94 Image of a hillside residential area employing monorail and stair-climbing vehicles

The Nagasaki Hillside Association [28] is one such support group. Other support groups include the Nagasaki Aging Society Research Group (consisting largely of retired engineers), this group seeks practical support for the elderly themselves as well as running workshops and symposiums for the public regarding raising the Quality of Life (QOL) for the aging etc. The organizations work together to arrange a constant calendar of events for the Nagasaki communities, with the support of local Schools, Universities and medical institutions.

Central in the agenda of the Nagasaki Hillside Association and other groups has been the realization of the need for a cost effective means to transport mobility impaired persons to and from homes in the Nagasaki areas where access is difficult.

Monorail or Slope elevator access

Access to some hillside residential areas in Nagasaki has been considered impractical even using the stair-climbing vehicles discussed in the Section 4. In areas involving for example over one hundred stairs, to the nearest road, access is considered difficult for anyone. As such the issue of access in such areas has been broken up into two parts, firstly a "vertical feed system" and then "horizontal feed sub-systems." This concept is illustrated in Fig. 94, an overhead monorail or slope elevator system has been proposed to provide main vertical feeds. A sub-system of horizontal feeds is then proposed. The vertical feed would provide a high level of accessibility to the general population in the respective residential areas, the horizontal feeds would then be made available to mobility disabled persons to "fill in the gaps".



(a) Monorail – Tenjin Machi (b) Slope elevator – Kita-Oura Chiku

Fig. 95 Vertical access feed mechanisms - Nagasaki, Japan

The overhead monorail and slope elevators targeted at providing vertical feed access support are shown in Fig. 95(a) and (b) respectively.

Mobility administration

This thesis has focused on the technical side of providing mobility. However an issue which must be considered at least as equal is the administrative aspects of making mobility readily available to persons when and where required. Until recently this responsibility had been shared by a number of volunteer groups in the case of Nagasaki. However more recently the aspect of mobility was taken up at a Prefectural Government level and assistance is now provided for persons certified eligible for the "Mobility Assistance Service" - IsouShienSa-bisu in Japanese. The person requiring mobility assistance makes a single phone call and one or two persons come to assist, a small fee is payable about 70 cents US (80 Yen as at May 2002) for one assistant for under 30 minutes or $1.40 US for two persons under 30 minutes. The actual cost of service provision is covered mainly by the compulsory National Health Insurance fund. In the case for example of calling a taxi, two taxis will come, one with a wheelchair, both drivers then take the person in the wheelchair up or down stairs as necessary to then board one of the taxis (a minimum of 20 stairs has been decided upon to make use of this service), again a small extra surcharge is added to the taxi fee for this service but is mainly covered by the Health Insurance.
A copy of the brochure that was circulated explaining this service is provided in Fig. 96 - Fig. **99** (in Japanese).

Fig. 96 Mobility assistance service brochure, front page

Fig. 97 Mobility assistance service brochure, center left

Fig. 98 Mobility assistance service brochure, center right

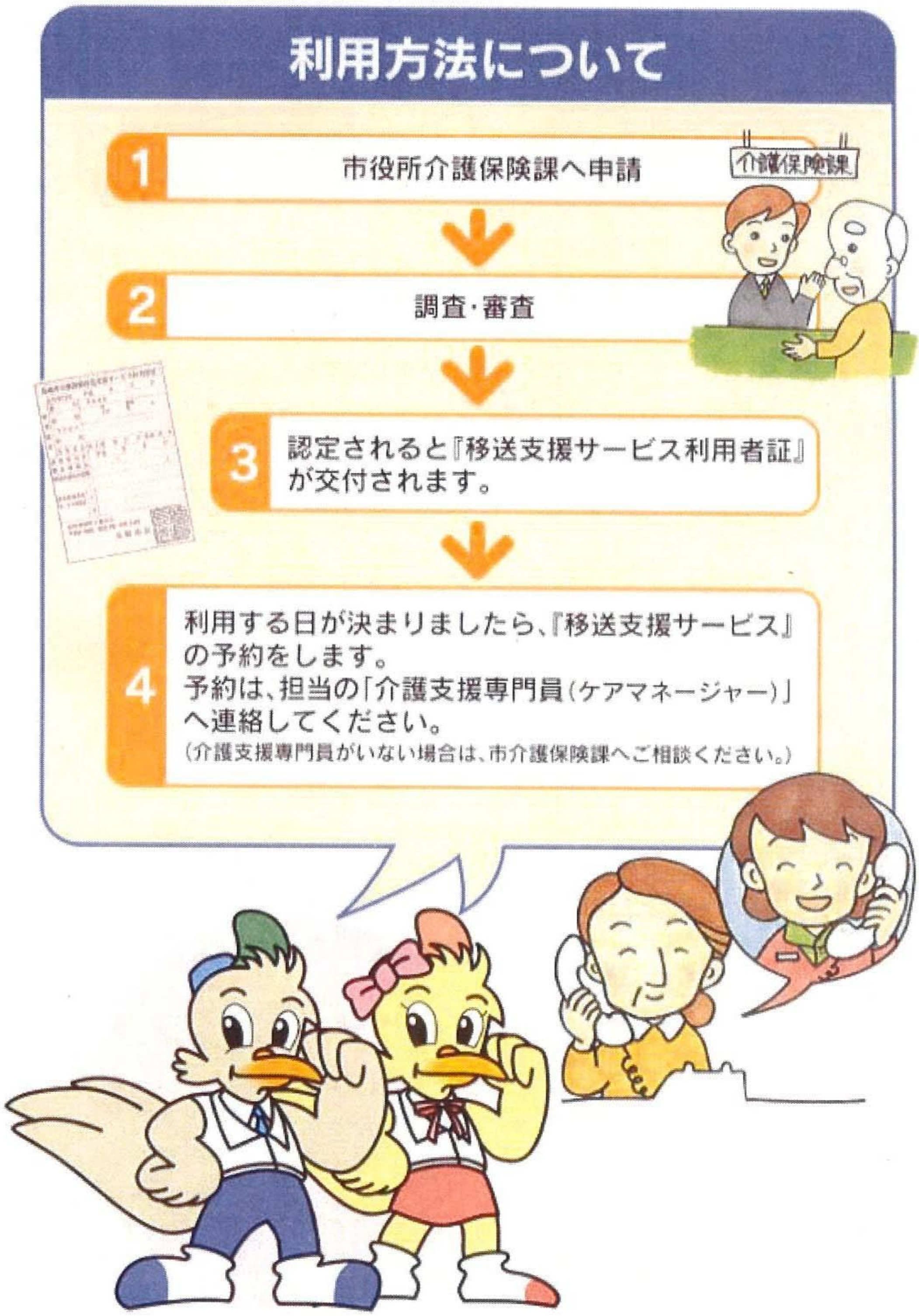


Fig. 99 Mobility assistance service brochure, back page