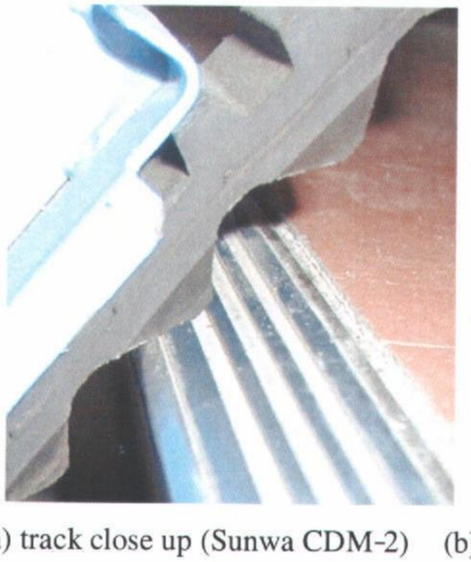
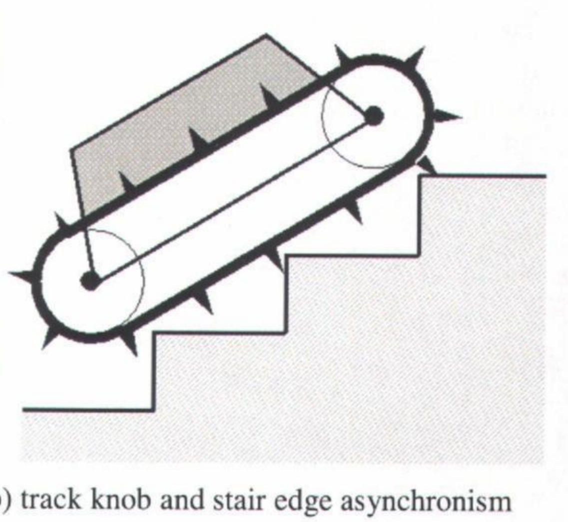
Chapter 4 Proposed track based stair-climbing mechanism

4.1 Introduction - tracked operation

The previous section outlined a wheel-cluster based high step stair-climbing mechanism. The realization of such a mechanism will most likely take significant time. This section outlines a track based solution using proven technology on stairs. Track based stair-climbing wheelchairs are commercially available, the track based mechanism outlined in this section proposes to provide additional functionality to such mechanisms.

Commercially available track based stair-climbing wheelchairs were introduced in Section 2.3. The major advantage of tracked operation is simple control and robustness in regard to operation on irregular stairs. However track based stair climbing mechanisms do present a number of problems. A disadvantage of track based operation is the high pressure exerted on stair edges. When the mechanism changes angle at the top of a set of stairs some form of device is required to ensure the tilt is controlled. Track based operation also requires a means of preventing slip while negotiating stairs, this is typically the provision of tread or knobs on the track. The tread or knobs do not necessarily coincide with the stair edges as illustrated in Fig. 58(b).





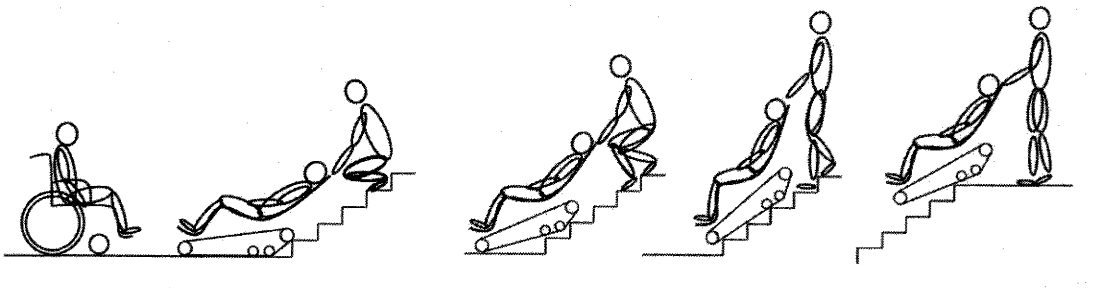
(a) track close up (Sunwa CDM-2) (b) track knob and stair edge asynchronism

Fig. 58 Close up of stair edge Sunwa CDM-2 track

Illustration (b) courtesy of Shigeo Hirose

The proposed mechanism is based on the use of a dual section track. This reduces the pressure exerted on stair edges at the top and bottom of stairs and largely overcomes the problem of uncontrolled tilt at the top of stairs. Fig. 58(a) shows a close-up of a tracked stair-climber in contact with a stair edge. In the case of the final tread illustrated in Fig. 59(d) and Fig. 61, most or all of the weight is borne by a single stair edge, in the case shown in Fig. 58(a) this calculates to a total static weight of approximately 160 Kg (wheelchair plus passenger - StairChair CDM-2) resting on 50 mm (track width) x 2 (No. of tracks) by ~5 mm (depth of stair-edge contact), a resulting ~32 Kg/cm^2. Dynamic considerations may exceed this value by magnitudes depending on operator skill. This pressure thus limits tracked stair-climbers to stairs with robust and preferably chamfered edges (typically concrete, steel or solid timber). In this regard the track forms are optimally designed to maximize contact area away from the stair edge, however the limiting aspect is the inherent randomness of track (knobs) to stair edge contact that occurs. For example when the tip of a tread (knob) engages the edge of a stair the vehicle will slip to the next knob, this re-synchronizing gives rise to exaggerated and non-linear pressures on stair edges. This stair edge and track asynchronism is illustrated in Fig. 58(b).

4.2 Single Section track stair-climber



(a) (b) (c) (d)

Fig. 59 Wheelchair to single track stair-climber transfer and stair-climbing operation

Operation of a single track stair-climbing wheelchair is illustrated in Fig. 59 and Fig. 60 and photo shown in Fig. 62 (large tire is a local modification for non-stair-climbing high speed operation). This type of stair-climbing wheelchair became commercially available in Japan around 1995 [15]. Advantages of the single stage tracked stair-climber include operational independence to the type of stairs, curbs or slopes encountered for example those shown in Fig. 63(a).

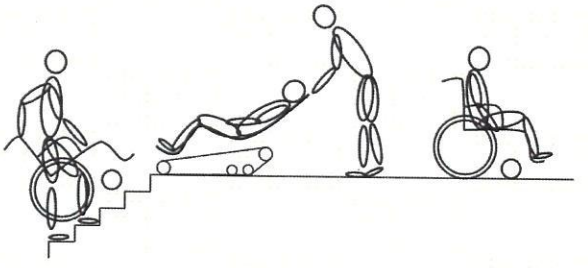


Fig. 60 Stair-climber to wheelchair transfer

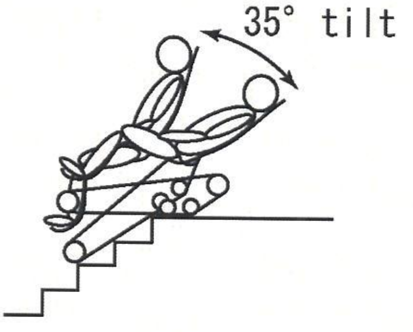


Fig. 61 Top of stair tilt detail

Fig. 62 High speed operation modification (pictured wheelchair Sunwa, CDM-2)

One such single track stair-climbing wheelchair was purchased by Nagasaki University in conjunction with a number of volunteer groups and put to work on the Nagasaki Hillside areas to provide mobility for elderly and disabled persons. While the basic mechanism performed well a number of aspects led to the development of a local stair-climber outlined in this section. The low operating speed necessary when negotiating stairs was frustrating in areas where stairs were interleaved sections of sloped pathways such as shown in Fig. 63(b).

(a) highly irregular stairs (b) mixed slopes and stairs (c) regular stairs

Fig. 63 Nagasaki's various stairs, (a) Takahira suburb, (b) and (c) Tenjin suburb

Fig. 64 Stair-climbing at a station in Japan (pictured stair-climber Sunwa Stair-ship TRE-52)

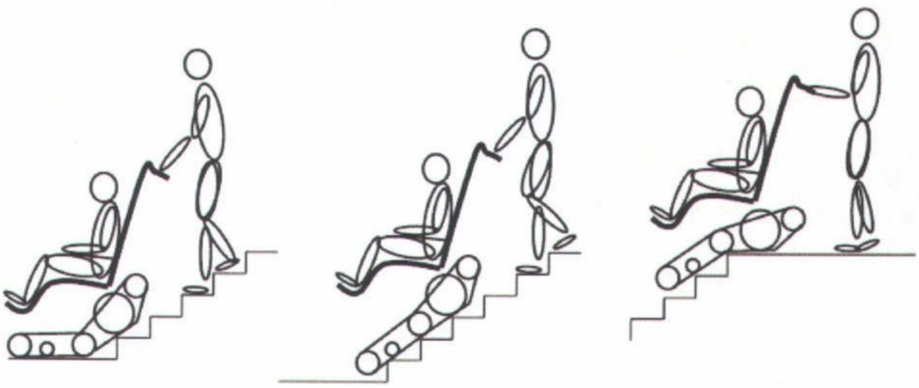
Photo courtesy of Media Park Himawari volunteer group

The track based stair-climber was provided with non-powered auxiliary wheels positioned to provide the vehicle with free-wheeling capability on level surfaces, the small set of double wheels on to the back of the wheelchair in Fig. 62. This function is essential to move the stair-climber about efficiently in barrier free environments, but such functionality namely the reduction of braking and powered motive ability was noted as being inappropriate for use on slopes. This specific problem was been dealt with on the commercial stair-climber shown in Fig. 62 at Nagasaki University by equipping the chair with 30 cm pneumatic wheels which are connected to the track drive train. The modification provided inherent high speed operation when operating on a flat surface and yet maintained full control of the vehicle.

Single stage tracked vehicles are commercially available in non-powered forms typically provided for emergency escape purposes. Single section track stair-climbers are also available that simply provide a platform on which a manual or powered wheelchair can be wheeled onto, refer to patents [40][41]. This approach is used at some railway stations around Japan where elevators are not available such as at Tajimi Station Japan Fig. 64. Comments made by the disabled volunteer support group regarding the stair-climber was "it sure takes time" (original comment in Japanese) [42].

4.3 Dual section track stair-climber

A common complaint from persons being transported by the stair-climber shown in Fig. 62 on the Nagasaki slopes was "it's scary," (the actual Japanese word being "kowai" meaning "I'm afraid" or "It's scary"). When asked specifically what was scary people (those being transported) explained when the stair-climber was tilted over the first step to begin the descent they felt very insecure, this condition is illustrated in Fig. 61. While the stair-climber represents no real danger, and has been designed to maximize passenger safety by providing a well reclined seat to anticipate this situation, the sense is of being tipped over (tilt angle equals stair angle typically 35 degrees) is perhaps exaggerated by the passenger not being able to see well where they are going on account of the well reclined seat angle. This along with a variety of other concerns prompted research at Nagasaki University in conjunction with local industry [27] and a number of special research groups to look into the wider aspect of transportation of the elderly and disabled on the Nagasaki slopes [43][44]. Part of the result of the research was the development of a stair-climbing wheelchair code-named "Sakadankun" shown in operation in Fig. 66(a) and more recent models Fig. 66(b) and (c). In Japanese "saka" means slope, "dan" stairs and "kun" is equivalent to master as in honorific reference to a young boy, thus a direct translation could be "Master of slopes and stairs".



(a) bottom of stairs (b) stair operation (c) top of stairs

Fig. 65 Dual section Track Stair-climbing operation

(a) KSC-A-11 (b) KSC-A-12 (c) KSC-C-10

Fig. 66 The Nagasaki stair-climbing wheelchairs "Sakadankun"

The concept of the two stage stair-climber is shown in Fig. 65 (a) to (c). A single track is replaced by two shorter track sections pivoted centrally. Motive power transmission is provided at the central pivot point thus providing in effect 4TD that is 4 track drive. The advantages of this approach were to allow the vehicle to begin and complete the stair climb is such a way as to ensure contact with a larger number of stair edges or surfaces and reduce the instability inherent in the single stage design at the top of a set of stairs that is illustrated in Fig. 61. Smooth change of angle is further enhanced by using the wheelchair's rear wheels. The rear wheels are usually used for barrier free operation. The stair-climbing wheelchair was also equipped with a chair-base that could be controlled so as to provide a constant chair angle, irrespective of the angle of the slope or stair being negotiated. The wheelchair was also provided with electrically switched operation between track operation and slope or barrier free operation.

Table 4 KSC-A-12 and KSC-C-10 Stair-climber main specifications

	KSC-A-12	**KSC-C-10**
Maximum stair-climb angle	35 degrees	35 degrees
Stair-climb speed (max.)	6m/min	6m/min
Stair descent speed (max.)	10m/min	10m/min
Speed on the flat (max)	25m/min	10m/min
Operating range (time)	40 minutes cont. operation	40 minutes cont. operation
Size length, width, height	1,350x550x1,180mm	1,420x460x1,230mm
Power source (battery)	12V 12Ah x2	12Vx2
Drive motors	24VDC 208W x2	24VDC 208W x2
Vehicle weight	145Kg	100Kg
Max. passenger weight	80Kg	90Kg (+9Kg wheelchair)

This switching was provided using an electric linear actuator. The electrical switching between stair and slope or barrier free operation provided efficient transportation in areas involving combinations of stairs and slopes.

After exhaustive tests in and around the slopes of Nagasaki the "Sakadankun" stair-climbing wheelchair was made commercially available in 1999. Research on the stair-climber has since continued particularly regarding the aspects of providing a more automated user interface, this and other related facets are outlined in the following sub-sections.

Table 4 outlines the main specifications of the more recent Nagasaki Stair-climbers.

4.4 Further proposal - Controlled pivoting, automatic seat leveling and guidance system

A number of the Nagasaki Stair-climbers described in the previous Section having been put into operation around the Nagasaki area has provided significant feedback regarding their performance or more specifically aspects open to potential improvement.

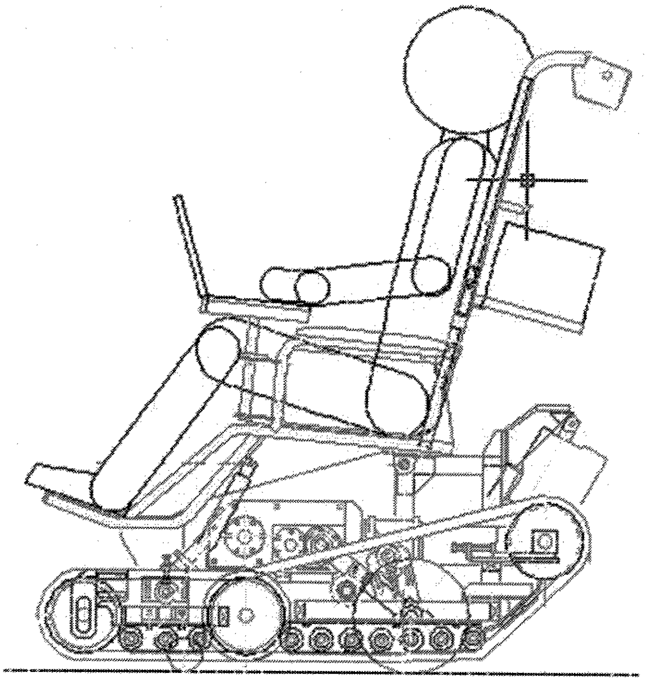


Fig. 67 Semi-automated stair-climber, side elevation

Overall the KSC-A-11 dual section tracked wheelchair pictured in Fig. 66(a) performed well, aspects requiring improvement included providing better control of the pivoting mechanism and making the control of the wheelchair more user friendly. Fig. 67 shows a side elevation of the semi-automated stair-climber.

4.4.1 Pivoting and auto-seat leveling

The pivoting mechanism between the two track sections was initially passive (gravity operated), this resulted in rather sudden pivoting at times, particularly at the top of sets of stairs. This was improved by providing hydraulic damping, however the mechanism continued to pivot when not required, or more specifically to follow contours best not followed. This was resolved by actively controlling the pivot angle using an electric linear actuator.

The seat angle was controlled manually, that is the operator was required to visually monitor this parameter and provide adjustment as required. In order to simplify operation the manual control of seat angle was replaced with automated control of chair angle based on data from an inclinometer mounted on the chair.

4.4.2 Control simplification

The overall operation of the wheelchair was fully manual and therefore required some operator skill. While the skill level required was not considered significant one of the goals in the design was to make the stair-climber operable by any person, for example a mobile spouse, or an acquaintance. Operation by the user was theoretically possible due to the vehicle's inherent stability, however this mode of operation was not planned or advised on the slopes of Nagasaki. The typical users lacked basic vehicle control skills or the necessary confidence to be involved in the control of such a vehicle.

The parameters requiring operator control were judgment of and appropriate adjustment of the chair angle, vehicle speed, direction and the switching between tracked or wheeled operation. The addition of controlling the pivot angle between the front and rear track sections further added to the control complexity, and resulted in the need for some level of automation.

4.4.3 Semi-autonomous control system

In order to simplify the Nagasaki Stair-climber's operation a control system was proposed and implemented. An overall schematic of the control system is shown in Fig. 68.

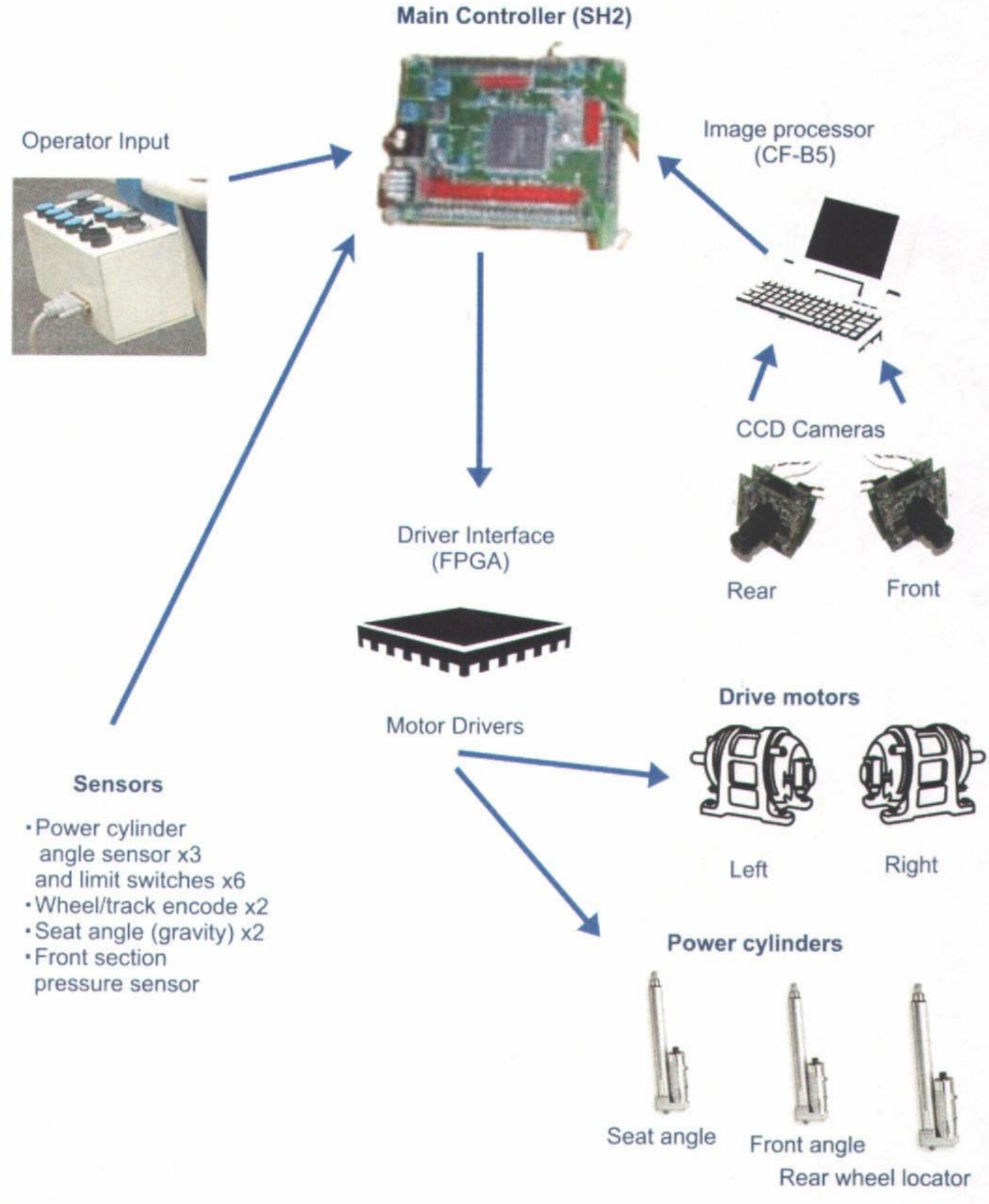


Fig. 68 Dual section tracked wheelchair control system diagram

The goal of the automation was to provide a series of buttons defining possible destinations, somewhat likened to predefined bus or train stops. The role of the operator being to simply choose the destination for example A, B, C or D and to press start or stop buttons as appropriate. In order to preprogramme the vehicle it was planned to be operated once by a skilled operator in record mode, the vehicle following a line for basic directional information supplimented with additional information as required. Additional information including such as "prepare to descend" a set of stairs after a given distance, change the vehicle to barrier free operation that is wheeled operation. Start and stop being provided to deal mainly with unexpected problems, children enroute etc. Central in the automated control was the aspect of directional guidence. This was achieved via a CCD video camera at both front and rear of the wheelchair. The video camera in use is based on direction of travel. The camera data is processed in real time. A yellow line was provided on the path to provide basic guidence and special marks to provide additional information. Fig. 69(a) shows the stair-climber in barrier free mode aligned with the target line.

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

Fig. 69 Semi-Automatic Nagasaki Stair-climber

4.4.4 Image processing based guidence system

In order to minimize operation complexity the provision of an automated or semi-automated directional guidance system was considered desirable. Considerations for the type of system included cost efficiency, reliability and suitability to the environment, in this case the target environment was the Nagasaki slopes including those pictured in Fig. 63.

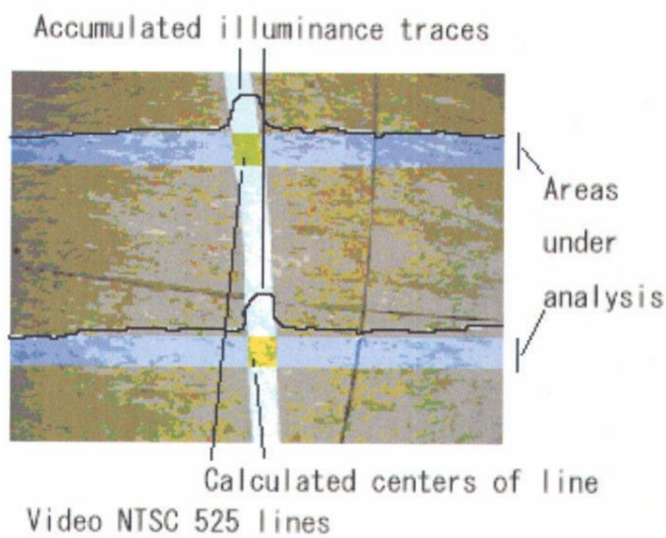


Fig. 70 Calculation of marker center from video data

Initially the detection of such as metal inserts in the concrete was considered. The somewhat random presence of steel drain-lids and steel reinforcing in the concrete ruled such a system as impractical. Rather a simple line following CCD camera based approach was employed. Major concerns regarding a CCD camera based system included dealing the wide variety of weather conditions that must be considered such as low light, reflections that occur in wet conditions, the maintenance of a clear line on very rough concrete surfaces and keeping the CCD camera lens clean.

Basic operation of the guidance system is shown in Fig. 70. This shows actual image data from a CCD video camera as seen on the screen of a notebook computer along with resulting image analysis data (actual trace data has been redrawn in solid black for clarity), the central white strip is the line to be followed. The two darkened horizontal zones are the areas used on which line recognition is carried out. Specifically the illuminance of each pixel is added vertically at each point of the "area under analysis" (50 pixels) the result produces an accumulated illuminance at that point in the horizontal direction. To reduce the effect of sporadic noise in the image a moving average is calculated (30 pixels wide) the result of this image illuminance accumulation and averaging then results in the "accumulated illuminence traces" shown in Fig. 70. The center of the peak shown is obtained and considered the center of the yellow line. The input signal was 29.97 frames per second (fps) but after calculation time resulted in an 8 fps output. This frame rate was considered adequate based on the vehicles' speed and could be increased by providing dedicated hardware to perform such calculations.

The output is shown as "calculated centers of line" in Fig. 70, in this case the calculated center at the top is to the left of that at the bottom, thus the vehicle would be directed a little towards the left. Robustness was provided in the control program to cater for false readings, this included the ignoring of secondary peaks that occurred outside of given boundaries, an "ignore and wait" approach to multiple peaks and automatic stopping of the vehicle in the case of persisting multiple peaks. For experimental purposes a notebook computer was used to provide image processing. However this functionality would be provided by dedicated image processing hardware and sub-system CPU or FPGA.

4.5 Summary – track based operation

Reliability and comfort

The track based mechanism outlined in this chapter has provided a reliable and relatively comfortable means of transporting elderly and disabled people on the slopes of Nagasaki. The main advantage of track based operation being the simplicity of operation irrespective of stair irregularity. The employment of a dual section track based mechanism in conjunction with provision of a constant chair angle has proved to be a very "practical" mobility solution on the slopes of Nagasaki.

Track based problems

Disadvantages associated with track operation, such as the high pressure exerted on step edges has been a relatively minor problem on the slopes of Nagasaki. Some of the steps in Nagasaki are hewn from soft rock, particularly slopes leading to historical sites, shrines, temples etc. The tracks have been occasionally noted to damage such stair edges. Other track based mechanism problems such as leaving black marks when turning are resolved by using auxiliary wheeled operation when stair negotiation is not required. Track tread or knob and stair edge asynchronism is also a problem, efforts towards resolving this issue by using a deformable track is discussed in Section 1.4.1.

The problem of changing angle particularly at the top of stairs has been largely resolved by using a dual section track in conjunction with partial extension of the rear wheels. This ensures a smooth and controlled change from and to stair negotiate angles.

User friendly

The prototyping of a semi-autonomous control and guidance system will potentially increase the wheelchair's level of user friendliness. The ultimate aim in the case of Nagasaki is to be able to operate the mechanism somewhat as a local train service. That is being pre-programmed with fixed points of call, simply requiring an assistant to press a button to go to a given household or area from the road side or nearest monorail access point. Refer to Appendix D for detail.

Image processing based further application

Image processing was used to further simplify operation of the dual section track based stair climber. A CCD camera based guidance system made it possible to follow a line painted on the pathway. Further applications of the CCD camera based guidance system have included assisting the navigation of a standard powered wheelchair is detailed in Appendix C. A simple two servo motor based closed link modular interface was prototyped to control a standard wheelchair without interfering with the wheelchair's electronics.

Two layered accessibility approach

In light of the large number of stairs present in many residential areas on the slopes of Nagasaki a two layered access approach has been considered and is outlined in Appendix D. Firstly an overhead monorail system has been proposed to provide a vertical feed to central points on the slopes, this would also provide easier access for the general public. Secondly by using such vehicular technology as the dual section track based mechanism a horizontal or local feed could be provided specifically for the elderly or disabled.

Mobility administration

The aspect of "Mobility administration" in Nagasaki is outlined in Appendix D. A system whereby eligible persons can call a single phone number to request one or two persons to assist in regard to mobility. This service being provided at a small charge to the user. This simple and yet very effective means of meeting mobility needs could be introduced anywhere. The initialization of such a system requires very little infrastructure and no significant capital investment.