Abstract—In the field of providing mobility for the elderly or disabled the aspect of dealing with stairs continues largely unresolved. This paper focuses on presenting continued development of the “Nagasaki Stairclimber”, a duel section tracked wheelchair capable of negotiating the large number of twisting and irregular stairs typically encountered by the residents living on the slopes that surround the Nagasaki harbor. Recent developments include an auto guidance system, auto leveling of the chair angle and active control of the front-rear track angle.

Index terms—stairclimbing, wheelchair, tracked operation, automatic guidance.

I. INTRODUCTION

This paper focuses on the further development of the Nagasaki Stairclimber [1].

Two common approaches to negotiating stairs are shown in Figure 1 (a) carrying the person on one’s back and (b) carrying the person in a lightweight wheelchair1, the recommended means being one person at each side of the wheelchair.

Carrying elderly or disabled persons on one’s back represents a very efficient and cost effective approach however it also presents high risk of injury for both persons, usually back injury2 and / or the risk of suffering a fall.

II. BACKGROUND

Nagasaki is built on the slopes surrounding the beautiful Nagasaki Harbor, while the view from the hillsides is magnificent difficulty in negotiating the slopes has gradually left many elderly 3  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 4  victims) [2]. While the stairclimbing 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 immediate vehicular access.

Figure 1. Stairclimbing – current techniques

(a) (b)

Figure 2. Typical Nagasaki hillside (Suwa area)

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1 two persons are typically sufficient for a patient under 80Kg
2 typically associated with long term care – despite using all the “right” lifting techniques
3 20% of Nagasaki Hillside residents over 65 as at 1999, cf National average of 17% of Japanese persons over 65 [2]
4 Stroke - Cerebral apoplexy, often resulting in partial paralysis
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. The Nagasaki Hillside Association\(^5\) is one such support group. Other support groups include the Nagasaki Aging Society Research Group\(^6\), 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 area where access is difficult. Nagasaki is a city built around a harbor, commercial areas use most of the flat land leaving mainly the steep hillsides for residential use. The result has been that parts of the housing areas are accessible only by large numbers\(^7\) of roughly twisting and/or irregularly shaped stairs. This phenomenon regarding terrain is quite common around the world particularly regarding more established residential areas\(^8\).

A typical Nagasaki hillside is shown in Figure 2 (Suwa suburb). Access to the average residence consists of a network of concrete paths and stairs weaving between the properties, the paths often start (that is nearest point of vehicular access) at the bottom of the hill.

The main reason for access difficulties to given suburbs in Nagasaki is the presence of stairs. These stairs eliminate most current mobility technologies. At the time this problem was initially investigated only a single track stairclimbing vehicle was commercially available (refer to figure 6). This vehicle was purchased and put to use on the slopes of Nagasaki. However a common complaint from persons transported was “it’s scary\(^9\)”, when asked specifically what was scary persons explained when the stairclimber was tilted over the first step to begin the descent, this condition is illustrated in figure 4c. While the stairclimber 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\(^10\) is perhaps exaggerated by the passenger not being able to see where they are going. This situation prompted research at Nagasaki University in conjunction with local industry\(^11\) and a number of special research groups to look into the wider aspect of transportation of the elderly and or disabled on the Nagasaki slopes.

### III. METHODS

#### A. Stair climbing – single section track operation

Work on the development of a vast variety of fascinating mechanisms has been the subject of study of many laboratories [3], [4] for many years. Climbing a set of stairs presents 2 central issues, firstly the actual climbing of each single step, and secondly providing stability for the overall mechanism while on the stairs. In the case of a wheelchair a constant seat angle is preferred and is outlined in the following section (the Nagasaki stair-climber).

![Figure 3. Wheelchair to single track stair-climber transfer](image)

![Figure 4. Stairclimbing operation](image)

![Figure 5. Stair-climber to wheelchair transfer](image)

A simple approach to climbing a set of stairs is the single stage tracked wheelchair shown diagrammatically in figures 3 to 5 and photo shown in figure 6 (large tire is a local modification for non-stairclimbing high speed operation).

This type of stairclimbing wheelchair became commercially available in Japan around 1995\(^12\). Advantages

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5 Nagasaki Hillside Association [http://www1.odn.ne.jp/nha/](Japanese only as at May 2001)
6 consisting largely of retired engineers
7 approximately 200 stairs to the nearest road (worst case)
8 particularly areas built originally before the 1900s.
9 the actual Japanese word being “kowai” meaning “I’m afraid” or “It’s scary”
10 tilt angle equals stair angle typically 25 to 35 degrees
11 Kyowa Electric Industry Corporation
12 Sunwa Ltd., Tokyo, Japan. StairChair CDM-2.
of the single stage tracked stair-climber include operational independence to the type of stairs, curbs or slopes encountered. This aspect is central in stairclimbing in the Nagasaki area as it is no doubt in any steep hillside areas developed over one hundred years ago. In these regards a single section stair-climber has been used very effectively on the hillsides surrounding Nagasaki.

Dedicated tracked stairclimbing vehicles do however have some negative attributes. The low operating speed becomes frustrating with many areas in Nagasaki where the stairs are interleaved with 5 to 20 meter sections of sloped pathways. Commercially available track based stair-climbers are typically 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 figure 6). This function is essential to move the stair-climber about efficiently in barrier free environments, but such functionality namely the reduction of braking or motive ability is often inappropriate on a slope. This specific problem has been dealt with on the commercial stair-climber at Nagasaki University by equipping the chair with 30 cm pneumatic wheels which are connected to the track drive train, as shown in figure 6. The modification provides inherent high speed operation when operating on a flat surface and yet maintains full control of the vehicle.

Figure 6. High speed operation modification (pictured wheelchair Sunwa, CDM-2)

Single stage tracked vehicles are also commercially available in non-powered forms typically provided for emergency escape purposes. Single section track stairclimbers are also available that simply provide a platform on which a manual or powered wheelchair can be wheeled onto, refer to patents [5] and [6].

B. Stairclimbing – dual section track operation

The Nagasaki stair-climber code-named “Sakadankun” is shown in operation in Figure 7. 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 slope or stairs”. This stair-climber represents a 3rd generation of two stage tracked stair-climber developed by Nagasaki University in conjunction with local industry.[1]. The concept of the two stage stair-climber is shown in figure 8. 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 are 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 avoid the instability inherent in the single stage design at the beginning and end of climbing a set of stairs.

Figure 7. The Nagasaki stairclimbing wheelchair KSC-A-11

Table 1. KSC-A-11 Stairclimber main specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum stairclimb angle</td>
<td>35 degrees</td>
</tr>
<tr>
<td>Stair climb speed (max.)</td>
<td>6m/min</td>
</tr>
<tr>
<td>Stair descent speed (max.)</td>
<td>10m/min</td>
</tr>
<tr>
<td>Operating range (time)</td>
<td>40 minutes cont. operation</td>
</tr>
<tr>
<td>Size length, width, height</td>
<td>1,170x540x1,240mm</td>
</tr>
<tr>
<td>Power source (battery)</td>
<td>12Vx2</td>
</tr>
<tr>
<td>Drive motors</td>
<td>110W x2</td>
</tr>
<tr>
<td>Max. passenger weight</td>
<td>80Kg</td>
</tr>
</tbody>
</table>

Figure 8. Stairclimbing operation

Some additional features have also been added to the basic two stage mechanism. The initial pivoting mechanism was passive, that is naturally pivoted (gravity based), certain

(Japanese only as at May 2001)
situations however caused abrupt pivoting, particularly at the top of a set of stairs. This was improved by providing hydraulic damping. Table 1 outlines the main specifications of the Nagasaki Stairclimber.

C. Stairclimbing – dual section track, controlled pivoting, automatic seat leveling and guidance system

A number of the Nagasaki Stairclimbers outlined in section b have been put into operation around the Nagasaki area. This has provided significant feedback regarding its performance or more specifically aspects that require improvement. Figure 9 shows a side elevation of the automated stairclimber and main specifications are listed in table 2.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum stairclimb angle</td>
<td>35 degrees</td>
</tr>
<tr>
<td>Tracked op. speed (max.)</td>
<td>6m/min (stair operation)</td>
</tr>
<tr>
<td>Wheeled op. speed (max.)</td>
<td>50m/min (barrier free op.)</td>
</tr>
<tr>
<td>Operating range (time)</td>
<td>~40 minutes cont. operation</td>
</tr>
<tr>
<td>Size length, width, height</td>
<td>1,260x821x1,368mm</td>
</tr>
<tr>
<td>Power source (battery)</td>
<td>12VAx2</td>
</tr>
<tr>
<td>Drive motors</td>
<td>200W x2</td>
</tr>
<tr>
<td>Vehicle weight</td>
<td>~250Kg</td>
</tr>
<tr>
<td>Max. passenger weight</td>
<td>80Kg</td>
</tr>
</tbody>
</table>

Overall the dual section tracked wheelchair has performed well, aspects requiring improvement include providing better control of the pivoting mechanism. The pivoting mechanism between the two track sections despite being hydraulically damped occasionally pivot when not required, that is it follows contours that it would be best not to follow. Secondly overall operation of the wheelchair was fully manual and therefore requires operator skill. While the skill level required is not significant one of the goals in the design is to make the stairclimber operable by any person, for example a mobile spouse, or an acquaintance. It must be noted that while operation by the user is possible this mode of operation is not planned or advised on the slopes of Nagasaki, given the typical users.

The initial aspect requiring improvement was that of resolving the problem of controlling the pivoting mechanism, this has been resolved by replacing the hydraulic damping mechanism with active control of the pivot angle using an electric power cylinder.

The aspect of improving user friendliness is the focus of the remainder of this paper.

Operation of the wheelchair outlined in section B is fully manual, thus requiring some operator skill, specifically the operator must judge and adjust seat level, 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 adds to the potential control complexity.

1) Wheelchair control system

In order to simplify the Nagasaki Stairclimber’s operation a control system has been implemented. An overall schematic of the control system is shown in figure 10.

Figure 9. Automated stairclimber, Side elevation

Figure 10. Dual section tracked wheelchair control system diagram

The goal of the automation based on the local needs is to provide a series of buttons defining possible destinations, somewhat likened to predefined bus or train stops. The purpose of the operator is to choose the destination eg. A, B, C or D and to press start or stop buttons as appropriate. In order to preprogramme the vehicle it is operated once by a skilled operator in record mode, the vehicle follows a line for basic directional information which is supplemented with additional information as required. Additional information includes 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 are provided to deal mainly with unexpected problems, children enroute etc.
Central in the automated control is the aspect of directional guidance. This has been achieved via a CCD video camera at both front and rear of the stairclimber. The video camera in use is based on direction of travel. The camera data is processed in real time. A yellow line is provided on the path to provide basic guidance and special marks to provide additional information. Figures 12 and 13 show the stairclimber following the line on stairs and in a barrier free environment respectively.

Basic operation of the guidance system is shown in figure 11. Figure 11 shows actual image data from the CCD video camera as seen on the screen of a notebook computer along with resulting image analysis data, 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 illuminance traces” shown in figure 11. The center of the peak shown is obtained and considered the center of the yellow line. The input signal is 29.97 frames per second (fps) but after calculation time results in an 8 fps output. This frame rate is considered adequate for 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 figure 11, 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. Some robustness is provided in the control program to minimize false readings, this includes the ignoring of secondary peaks that occur outside of given boundaries, and an “ignore and wait” when otherwise. When multiple peaks persist the vehicle automatically stops.

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15 actual trace data has been redrawn in solid black for clarity
16 the boundaries are based on continuous line data from initialisation

D. Mobility administration

This paper 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 has been shared
by a number of volunteer groups. However more recently the aspect of mobility has been taken up at a Prefectural Government level and assistance is provided for persons certified eligible for the “Mobility Assistance Service”\textsuperscript{17}. The person requiring mobility assistance makes a single phone call and one or two persons come to assist, a small fee is payable about 1US$\textsuperscript{18} for one assistant for under 30 minutes or 2US$ 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 as in figure 1b, up or down stairs as necessary to then board one of the taxis\textsuperscript{19}, again a small extra surcharge is added to the taxi fee for this service but is mainly covered by the Health Insurance.

IV. CONCLUSION

A dual section tracked stairclimbing wheelchair “the Nagasaki Stairclimber” has been developed in Nagasaki. The wheelchair has been used in the Nagasaki area to assist the elderly and disabled whose local terrain has led to mobility difficulties or being housebound. A control system has been added to the proven dual track mechanism wheelchair. The control system provides for automation of all aspects necessary in the control of the wheelchair including a guidance system.

This provision of “hardware” has been balanced with the provision of the administrative side of making mobility assistance available to those who need it and thus overall raising the Quality of Life of elderly and disabled persons living on the Nagasaki Hillsides.

Future work includes the continued development of the control system with regard to improved automation, safety and general robustness. Further refinement is also required on reducing the weight of the overall stairclimber.

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REFERENCES


\textsuperscript{17} IsouSaenSa-bisu in Japanese

\textsuperscript{18} 80 Yen as at May 2001

\textsuperscript{19} a minimum of 20 stairs has been decided upon to make use of this service

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