KINEMATICAL ANALYSIS AND SIMULATION OF TRANSFORMABLE WHEELCHAIR MECHANISM

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Disabled people with different level of impairment and limitation need proper assistive technology. Hence, this research is intended in the development of a new transformable wheelchair design which is able to transform from chair into bed form, and also transform into a sturdy standing position. The work had focused on designing, scaled prototyping, modeling and simulation for the new wheelchair using CAE tools. Design using AutoCAD result in a 3D virtual model of wheelchair with dimensions and detail profile. Scaled prototyping of early wheelchair concept was conducted to ease characteristic inspection of the model. The completed model was tested using kinematic simulation and virtual reality simulation. The final outcome of this research is the design of new transformable wheelchair, with three state modes with independent actuator at each joint to ease the user in obtaining a comfortable position. It is equipped with anti-tilt frame to maintain user in horizontal position while moving on slope. It also has a single bed size shape when transformed into sleeping state. Kinematic simulation using SimMechanics and Simulink toolbox from MATLAB was developed to verify the design with respect to skeletal dimension problem among actuators and frames. Virtual reality simulation verified the design to avoid unexpected parts collision during transformation. Vrealm Builder, Simulink, and Virtual Reality toolbox from MATLAB were utilized for virtual reality simulation. Major issues in developing the product are the kinematic geometry and collision avoidance since the product has detail profile. These were resolved using kinematic and virtual reality simulation technique.

Keyword: Wheelchair design, Scaled Prototyping, SimMechanics, Virtual Reality.
CHAPTER I

INTRODUCTION

Advance motorized mechanisms have enabled the transformation into different configurations from its original shape. Basically, the transformed mechanism experiences rotational movement, flips, or maybe slides. Another important transformation is resizing, also called dilation, contraction, compression, enlargement or even expansion. The shape can become bigger or smaller.

Wheelchairs are developed to enable daily movement for disabled people who are unable to walk due to sickness or injury. Wheelchairs have become multifaceted to be more than just moving from one place to another but enabling handicapped individuals to have a degree of control over their own movements.
1.1 Motivation

Disabled people with differ assistive technology. Disease which handled by many people studying for their own personal wheelchair development.

Without an accessible transport system, the freedom to move beyond their immediate environment would obviously make travel easier (DLF, 2006).

Malaysia Government at 2009 started the “Dementia People” project. A group of researchers from Universities together with several industrial partners worked under the project to build an integrated system to handle dementia patient. The main product of this project would be a new advanced wheelchair. Hence, this research is to be part of the project.

1.2 Aim of Study

The study is about developing a new design concept of transformable wheelchair, and it is focused on transformation of mechanism. The development consisted of model design, kinematical modeling and simulation methodology, which employ certain software.
1.1 Motivation

Disabled people with different level of disability and limitation need a proper assistive technology. Disabled Living Foundation, an organization in United Kingdom which handled disabled people society declared in factsheet that there are many people studying different aspects of disability as part of their course work or for their own personal development. Recently, some of their works are focused in wheelchair development.

Without an accessible transport system, many disabled people are deprived of the freedom to move beyond their immediate environment. Accessible vehicles would obviously make travel easier (DLF, 2006).

Malaysia Government at 2009 started the “Dementia People” project. A group of researchers from Universities together with several industrial partners worked under the project to build an integrated system to handle dementia patient. The main product of this project would be a new advanced wheelchair. Hence, this research is to be part of the project.

1.2 Aim of Study

The study is about developing a new design concept of transformable wheelchair, and it is focused on transformation of mechanism. The development consisted of model design, kinematical modeling and simulation methodology, which employ certain software.
1.3 Objective of Study

This research is conducted to develop:

a. A new transformable wheelchair design that enable in obtaining three function modes (sitting, standing and lying).

b. Wheelchair can provide single bed size when performing lying state mode.

c. Anti-tilt frame is installed in wheelchair to maintain the user position under slope effect operation.

d. Mobile platform is developed in raw model. It is only representing a wheelchair base. Further development can be carried out in future work.

1.4 Scope of Study

The scope of this research includes design process that produces a transformable wheelchair model, complete with dimension and detail profile in 3D. Raw scaled prototyping of the model is made to obtain constructive feedbacks which can be useful for detailing the design. Kinematical analysis and virtual reality technique are carried out to perform transformation of the model. The simulation is done to assure working function and collision avoidance of the wheelchair model. The issues above are resolved using several software includes AutoCad, Simulink, SimMechanics and Virtual reality (MATLAB).
1.5 Thesis Arrangement

The organization of the rest of the thesis is as follows. Chapter 2 contains reviews of researches conducted on difficulties faced by the disabled people, existing wheelchair, anthropometry considerations and leverage mechanisms. Chapter 3 describes the proposed technique in obtaining the product. Chapter 4 describes the process of current work. Results of the research are shown and discussed in Chapter 5. Finally, the conclusions and recommendations for future work are described in Chapter 6.
CHAPTER II

LITERATURE REVIEW

This chapter explains several key elements with relation to disabled people, and specific assistive technology which is could be useful to help them in doing daily activity. Some existing wheelchairs, actuators, and human anthropometry are also explained.

2.1 Disabled People

Human with limited condition or disabilities need to be cared, since they could not do normal activities unassisted. There are several ways to define disability. The two most widely used definitions are the medical model and the social model (Disabled Living Foundation, 2006). Based on social model, disabled people are group of society whose are restricted from having an equal opportunity to take part fully in all
aspects of life. World Health Organization in early 1980s term of disabled in relation to impairment, disability and handicap as follows:

- **Impairment**: loss or abnormality in structure or function.
- **Disability**: inability to perform an activity within the normal range for a human being because of impairment.
- **Handicap**: inability to carry out normal social roles because of an impairment/disability.

This research specifically looks at disabled people who have disability caused by impairment. Without an accessible transport system, they are deprived of the freedom to move beyond their immediate environment. Disabled people who lack in mobility like walking and standing is where this research concerned on. Accessible technology such as wearable device and wheelchair are common and developing significantly nowadays. Wearable device means a well-suit device which is worn by a human. Marketable wearable device is usually a powered skeletal structure and used to support disabled in moving their impairment body.

Here, the research strictly focused on developing new concept of powered transformable wheelchair mechanism as main issue of the research which may participate to help disabled people in obtaining better condition. Observations and investigations on several existing powered transformable wheelchairs with those features and disadvantages are done to result a new design of powered transformable one.

2.2 **Wheelchairs**

Wheelchairs were actually first developed thousands of years ago, but they did not begin to take a standard design until the beginning of the twentieth century (Disabled
Wheelchairs can be basically broken down into manual wheelchairs, electric wheelchairs, or mobility scooters (Wikipedia, 2010).

Many wheelchairs in market offer advance technologies and features than a conventional manual wheelchair. Powered or electrical or propelled wheelchair has an electrical motor in generating a wheel rotation (Permobil Inc., 2008).

(a) Propelled outdoor; (b) propelled indoor; (c) adjustable powered.

Other wheelchairs with adjustable functions are also available in market nowadays. This type of wheelchair gives more freedoms to the user in adjusting chair positions. Chair can be transformed into lying position (rest/sleep), and also assist user in obtaining a standing position. Further, users are eased by using a joystick and button to adjust the desire position of the chair, Figure 2.2. Below is sample of Power 4x4 wheelchair specifications and features.

Figure 2.3: Adjustable electrical wheelchairs obtain lying position. (Source: http://en.wikipedia.org/wiki/Wheelchair)
<table>
<thead>
<tr>
<th>No.</th>
<th>Product</th>
<th>Feature</th>
<th>Specification</th>
<th>Material</th>
<th>Power</th>
<th>Power source</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Sit</td>
<td>Stand</td>
<td>Lie</td>
<td>Base Tilt (degree)</td>
<td>Height (cm)</td>
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<tr>
<td>1</td>
<td>Adventure 10 (Ulrich GmbH, 2008)</td>
<td>√</td>
<td>-</td>
<td>-</td>
<td>25° Upward</td>
<td>98</td>
</tr>
<tr>
<td>2</td>
<td>C 300 Corpus (Permobil Inc, 2008)</td>
<td>√</td>
<td>-</td>
<td>√</td>
<td>10° Upward</td>
<td>112</td>
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<tr>
<td>3</td>
<td>(2008)</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>12° Upward</td>
<td>119.38</td>
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</tbody>
</table>

This is motorized wheelchair, able for indoor and outdoor operations. It has enough ground clearance, so able to be operate through staircase, eventhough still need second person hand for this situation. Power configuration offers longer wheelchair operation for mobility purpose. The wheelchair has only sitting mode, and safe for handling the user under 25° ascending floor. Wheelchair operation is controlled using joystick.

Wheelchair with dual functions which may provide sitting and lying positions. Ascending floor negotiation is safe under 10° degrees, and low ground clearance made this type is suitable for indoor operation. It has comfort padding chair suitable for longer operation above the chair. User also able to rest on this chair although it could not transform into single bed size shape in lying position. Hydraulic actuator was not supported for failsafe condition. Wheelchair operation is controlled using joystick.

Motorized wheelchair with triple functions. This is the upgrade of wheelchair type which is mentioned in number 2 above. The wheelchair supports standing position and use the mobile platform as a counter weight when achieving standing mode. It is equipped with safety belt for maintain the user. Wheelchair operation is controlled using joystick.
<p>| No. | Product | Sit | Stand | Lie | Base Tilt (degree) | Height (cm) | Width (cm) | Length (cm) | Weight (kg) | User (kg) | Material | Motor (Watt) | Chair actuator | Power | Power source |
|-----|---------|-----|-------|-----|-------------------|-------------|------------|-------------|-------------|-----------|-----------|-----------|--------------|----------------|-------|--------------|
| 4   | 4Power4 (4P4, 2009) | ✓    | -     | -   | 40°               | 156         | 67         | 181         | 210         | 131       | Stainless steel | 300W    | -           | 6V, 110 Ah, lead gel battery |
|     |         |     |       |     | Upward 35°       |             |            |             |             |           |           |            |              |       |              |
|     |         |     |       |     | Downward 25°     |             |            |             |             |           |           |            |              |       |              |
|     |         |     |       |     | sidewalk         |             |            |             |             |           |           |            |              |       |              |
|     | This type is dedicated for user who needs outdoor operation. It has 4 motors on each wheel, which enables the user to operate through terrain. The wheelchair is safe for operation through ascending, descending, and also slope ground, which only use the base as counter weight. It is also equipped with higher amount of battery, for longer outdoor operation. Wheelchair operation is controlled using joystick. |
| 5   | Q 6000 (Quantum, 2008) | ✓    | -     | ✓   | -                | 65.72       | 93.98      | 112         | 150         | Stainless steel | 200     | Linear DC motor | 12V, 24Ah, lead gel battery |
|     |         |     |       |     | -                |             |            |             |             |           |           |            |              |       |              |
|     | This type is suitable for indoor operation which could be seen from mobile platform design. It has dual function for sitting and lying position only. Chair frame can not provide bed shape for supporting lying state, mean that user still may take a rest above the chair in short time. Linear DC motor selection is considered for handling failsafe condition. |
| 6   | TDX spre (TDX, 2008) | ✓    | ✓     | ✓   | -                | 100.33      | 64.77      | 89.53       | 131         | 150       | Stainless steel | 200     | pneumatic     | 24V, Optional, lead gel battery |
|     |         |     |       |     | -                |             |            |             |             |           |           |            |              |       |              |
|     | This wheelchair has similar functions, and features with previous wheelchair which is described in number 3. The difference is on mobile platform design, where this type is expected has more maneuverability purpose. |</p>
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<thead>
<tr>
<th></th>
<th>Model</th>
<th>Drive Type</th>
<th>15°</th>
<th>Upward</th>
<th>90</th>
<th>64.51</th>
<th>106.68</th>
<th>70</th>
<th>150</th>
<th>Stainless steel</th>
<th>200</th>
<th>Pneumatic</th>
<th>12V, 24Ah, lead gel battery</th>
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<tr>
<td>7</td>
<td>Levo compact</td>
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<td>80</td>
<td>58</td>
<td>90</td>
<td>25</td>
<td>um Tube</td>
<td></td>
<td></td>
<td>27Ah, lead gel battery</td>
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<td>(LEVO AG, 2008)</td>
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<td></td>
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<td>Non-motorized wheelchair type which may provide standing support for user. It is designed for simplicity purpose, for ease the transportation. It is foldable which can be entered into car. Power supply is equipped only for actuator operation. It use button for controlling the actuator.</td>
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<td>8</td>
<td>Jazzy 1400</td>
<td>√</td>
<td>-</td>
<td>√</td>
<td>15°</td>
<td>Upward</td>
<td>90</td>
<td>64.51</td>
<td>106.68</td>
<td>70</td>
<td>150</td>
<td>Stainless steel</td>
<td>200</td>
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<tr>
<td></td>
<td>(Pride, 2009)</td>
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<td>This type is suitable for indoor operation which could be seen from mobile platform design. It has dual function for sitting and lying position only. Chair frame can not provide bed shape for supporting lying state, means that user still may take a rest above the chair in short time. It is designed to be simple because cost consideration. Hence, low income people are expected able to buy this product.</td>
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<td>Bounder plus</td>
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<td>90</td>
<td>65</td>
<td>95</td>
<td>90</td>
<td>112.5</td>
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<td>220</td>
<td>Hydraulic</td>
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<td></td>
<td>(21st century</td>
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<td>Motorized wheelchair with triple functions. The wheelchair supports standing position and use the mobile platform as a counter weight when achieving standing mode. It is equipped with safety belt for maintain the user. Wheelchair operation is controlled using joystick. This is the simplest wheelchair than previous samples. The product is suitable for indoor operation.</td>
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</table>
Some existing wheelchair information from market sources, factsheets, brochures, which are collected and resumed in Table (2.1). Information describes among powered wheelchair feature, specification (dimension and weight), actuator type, material structure, and power source.

There are also some patented wheelchairs having a triple functions feature. Technical MFG Group at 1968, shown in figure 2.4 designed an adjustable wheelchair device which support triple functions.


An adjustable wheelchair device is provided with a first actuating mechanism for adjusting a plurality of pivotally connected chair elements relative to one another so as to provide a range of sitting, standing or recline positions, and a second, mechanism is provided for tilting the entire chair assembly about a horizontal axis of a base frame to which the chair assembly is connected. Then second mechanism operates through hollow framing members of the base frame so as to provide a safer more stable operation of the chair device (Technical MFG Group, 1968).
Figure 2.5: Power Stand-up and Reclining Wheelchair. (Source: Dale, P.(1994).
_Power Stand-up and Reclining Wheelchair._ U.S. Patent 5, 366, 036)

In 1994 Perry Dale from United State, also patented his wheelchair by title _Power Stand-up and Reclining Wheelchair_ (U.S. Patent 5, 366, 036), which is shown in Figure 2.5. Perry’s wheelchair is designed and built to meet user’s demand in achieving a triple functions also. It is powered by single positioning actuator to obtain sitting, standing and recline state. A programmable controller is selected as main control for wheelchair operation. In order to eliminate skin irritation for user, it is designed having a sliding back frame. Perry stated that rear payload weight and by shifting foot rest behind the front wheel axis when standing position is activated, will not cause the user tilt forward.

LLYOD Linden Inc in August 2006 patented his wheelchair by title _Wheelchair with Self Raising Seat_. The chair has two rigid frames, each connected to a separate wheel. It is powered using a pneumatic actuator to transform the chair base into a standing support, by generating coupled linkages. Leg rest part, is extendable, by using motorized and rack pinion gear train. This chair has no feature in supporting user obtain a recline position. The design is shown in Figure 2.6.
Reference which is used as guidance in designing a new concept wheelchair, come from *Humans Factors Design Standard 2009*. It is subtitled *Anthropometry and Biomechanics* and displayed in Figure 2.7. Dimension stated in inch and millimeter length. Another reference is *Wheelchair Homes Design 2007*, written by South East London Partnership which contains guidance in design a disabled people home.
2.2.1 Wheelchair Actuator Technology

As mentioned previously, this research is looking at adjustable powered wheelchair. Powered wheelchair is actuated by specific motorized actuator. It has battery power source to energize actuator and other electrically equipment, like installed sensors.

An actuator is a mechanical device that is used to move or control a simple or even a complex mechanism. It takes energy from a source, and converts that into some kind of motion. The power source could be created by electricity, vibration, air, water, etc. Actuators can manipulate a linear motion, rotary motion, or oscillatory motion.

Many type electrically-powered actuators are developed with specific function and need. DC motor for example, might be implemented on low level toys to a high-precision industrial application. Pneumatic and hydraulic actuators are fluidic powered. Pneumatics use compressed air, while hydraulic using compressed oil to actuate the mechanism. DC motor convert power into rotational force (torque), whereas pneumatic and hydraulic create a linear translational movement (pull and push force).

2.2.2 Linear DC Motor

Mobile robot platform or wheelchair base is equipped with DC motor. It can be a brushless or brushed motor. Most of powered wheelchairs have two motors installed, at right and left side to actuate wheels. They use differential drive steering so the chair can be maneuvered based on user demand. Figure 2.8 shows sample of brushless DC motor which is installed on wheelchair.
Figure 2.8: Sample of wheelchair motor. (Source: TDX, (2009). Product Manual- TDX Family. Canada: Brochure)

Brushless Motor has better performance that brushed one, hence it has rather expensive price. Another reason is that brushless has longer lifetime, since has no mechanical contact inside, during operation.

This research will not take a deep investigation for mobile robot performance. The design is assumed to build a mobile robot platform which is installed with common wheelchair motor. Further, mobile robot performance investigation can be done for future research.

Wheelchair with adjustable function is actuated by type of actuator. It could be single or even double, depend on product requirement. Most of wheelchairs use pneumatic, hydraulic, or linear DC motor since they have enough power to establish transformation of wheelchair compared with their dimension.

Linear motion is much in demand in all sectors of industry and the linear actuator is one of the responses. Linear actuator is a device that develops force and motion, from an available energy source, in a linear manner, as opposed to rotationally like an electric DC motor. The linear actuator is generally less cumbersome than a cogged belt, simpler than a rack and pinion and more economical than a ball screw.
There are various methods of achieving linear motion. Several examples are mechanical actuators, hydraulic actuators, piezoelectric actuators, electro-mechanical actuators and linear motors. In the majority of linear actuator designs, the basic principle of operation is that of an inclined plane. The threads of a lead screw act as a continuous ramp that allows a small rotational force to be used over a long distance to accomplish movement of a large load over a short distance. Figure 2.9 shows a conceptual design of a basic linear actuator and Table 2.2 displays specifications of one marketable linear DC motor product.

<table>
<thead>
<tr>
<th>Model Type</th>
<th>DTG24-100</th>
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</thead>
<tbody>
<tr>
<td><strong>Length L (mm)</strong></td>
<td>240mm</td>
</tr>
<tr>
<td><strong>Input Voltage</strong></td>
<td>12-24VDC</td>
</tr>
<tr>
<td><strong>Stroke Length(mm)</strong></td>
<td>100mm</td>
</tr>
<tr>
<td><strong>No Load Speed at 12V</strong></td>
<td>4mm/sec ±10%</td>
</tr>
<tr>
<td><strong>No Load Speed at 24V</strong></td>
<td>6mm/sec ±10%</td>
</tr>
<tr>
<td><strong>Maximum Thrust at 24V</strong></td>
<td>4000 N</td>
</tr>
<tr>
<td><strong>Limit Switch</strong></td>
<td>Built-in (Factory Preset)</td>
</tr>
<tr>
<td><strong>Mounting Hole Diameter (mm)</strong></td>
<td>8.3mm</td>
</tr>
</tbody>
</table>
The system converts rotary motion (in the form of a DC motor) to linear motion. When an electrical source is applied to the motor, the threaded shaft is driven and the nut rides up and down in the corresponding direction. This action provides an extension and retraction capability for tasks requiring a linear displacement. Note that in this example the nut and red tube do not rotate, merely "ride" the threads on the spinning shaft up and down. Ride distance of red tube is called stroke length.

Important performance specifications to consider when searching for linear actuators include stroke, maximum rated load or force and maximum rated speed. Stroke is the distance between fully extended and fully retracted rod positions. The maximum rated load or force is not the maximum static load. The maximum rated speed is the maximum actuator linear speed; typically rated at low or no load.

2.2.3 Pneumatic and Hydraulic actuator

Pneumatic is mechanical actuator that deals with gas properties such as pressure, density, and applies the principles to use compressed gas as a source of power to solve engineering problems. The most widely used compressed gas is air, and thus its use has become synonymous with the term pneumatics (Beater, P. 2006).

Pneumatic cylinders are used for several reasons:

- A pneumatic cylinder can produce a force typically 20 times as large as the maximum force of a solenoid with identical diameter.
- The cylinder force remains almost constant throughout the stroke.
- Solenoid strokes are very limited, typically equal approximately to the solenoid diameter. By comparison, cylinders have strokes up to 15 times the piston diameter.
• There is nothing to burn out inside the compressed air in producing a force
• The piston speed can easily be regulated, by placing adjustable restriction (needle valves) in the exhaust lines.

Figure 2.10: Pneumatic work. (Source: http://bostitch.co.uk/products/tools/how-pneumatic-tools-work/index.php)

Pneumatic and Hydraulic actuator have some disadvantages that may to be considered due to wheelchair application. Transformation on wheelchair for example standing or lying position will rely on actuator movement. Hence, actuator plays important role to keep the user safety in every position.
Disadvantages Pneumatic and Hydraulic:

• Higher density, higher losses, more inclination to cavitations
• Limited operational temperature < 55 °C
• Worse lubrication characteristics, reduction of maximum load
• Worse de-aeration characteristics
• Sometimes chemically aggressive against sealing materials
2.2.4 Pneumatic Air Muscle

Several types of pneumatic actuators e.g. cylinder bellows, pneumatic engines and even pneumatic stepper motors are commonly used to date. A less well-know type is that of the so-called Pneumatic Artificial Muscle (PAMs) or Air Muscle. These are in fact inverse bellows, i.e. the contract on inflation. Their force is not only dependent on pressure but also on their state of inflation, which make for a second source of spring-like behavior (Daerden, 2005).

They are lightweight because their core element is membrane, and yet, they can transfer the same amount of energy as cylinders do, since they operate at the same pressure ranges and volumes. For these reason they carry a great potential to be used to power mobile robots, where they have additional advantages, such a direct connection, easy replacement and safe operation.

The Shadow Robot Air Muscle is a simple yet powerful device for providing a pulling force. It behaves in a very similar way to a biological muscle. When actuated with a supply of compressed air, it contracts by up to 37% of its original length. The force it provides decreases as it contracts, and the first few percent of the contraction is very powerful indeed. The simplest use of a muscle is to move a lever. One muscle will pull the lever in one direction, and a spring can return it. Two muscles will allow the lever to be pulled in either direction, with considerable force. Because the muscle contracts over a known distance, it can be used to provide a safe movement. There is no need to ensure that the lever is not going to be rotated beyond its end-stop, since the muscle will only move the lever to its set up angle.

Figure 2.11: 6mm Air muscle Shadow Robot Company, UK. (Source: http://shadowrobot.com/airmuscles/pictures.shtml)
Figure 2.11 shows an air muscle with 6 mm length from Shadow Robot, has ability to pull 4.6 Kg Load, within 4 bars air pressure and 11% contraction from its initial length. Air muscle has many better features than pneumatic cylinder. Its weight between 10g and 150g, for example the 30mm Air muscle weight is 80g. Unlike pneumatic cylinders, air muscles have no 'stiction', and an immediate response. This results in a smooth natural movement. Air Muscles is flexible, since it needs no precise aligning. Air muscles powerful because can produce forces up to 700 N at pressures of only a few bars.

Pneumatic cylinders produce a small force over a long movement. Air muscles, on the other hand produce very high forces, but pull relatively short distances. Therefore cylinders and air muscles are used in different ways, and are generally for slightly different applications.

Important information need to be considered since using air muscle actuator to produce linear translation is the characteristic of muscle's contraction. The contraction may be vary depend on loading condition, even same pressure is supplied. Achieving a specific stroke length by increasing a pressure did not make any solutions, but it will reduce the life of muscle. Hence, pressure limitation is stated by Shadow Robot Company. Recommended pressure to maintain the muscle condition from breaking is between 0 – 4 bars.

Figure 2.12: Contraction characteristic due to various loading. (Source: Shadow Robotic. (2008). Product Manual- 30 mm Air Muscle. United Kingdom: Brochure)
The graphs in figure 2.12 and 2.13 shows the dynamic contraction condition of the 30 mm muscle as the pressure is increased to 3.5 bar (lower line), then decreased back to 0 bar (upper line), under several static loads.

![Graphs showing contraction vs time](image)

Figure 2.13: Speed contraction characteristic due to various loading. (Source: Shadow Robotic. (2008). *Product Manual- 30 mm Air Muscle*. United Kingdom: Brochure)

In a typical situation, a muscle requires two pneumatic valves to operate. One valve lets air into the muscle, the other lets air out. By controlling the opening of each valve, it is possible to set the desired contraction of the muscle. The throughput of the valves, the pressure of the air supply, the bore and length of tube used, will all affect the speed of the Air Muscle.

![Diagram of Air muscle setup](image)

Figure 2.14: Air muscle setup. (Source: Shadow Robotic. (2008). *Product Manual- 30 mm Air Muscle*. United Kingdom: Brochure)
If maximum speed of contraction or extension is required, should select high 
throughtput valves, and attach the valves as close as possible to the muscle, using the 
largest bore tube possible. Typically, user can expect the muscle to contract within 
about 0.5s, depending on conditions. If conditions are optimal, it is possible to 
achieve contraction times as low as 0.1s.

Achieving a slower stroke, or more controlled movement, should consider 
adding air restrictors into the tubes. This way, it is possible to slow the movement to 
anything, down to a standstill. One great advantage of Air Muscles is their ability to 
move extremely smoothly, even at very slow speeds.

Flexibility and lightweight consideration are reason air muscle is applied on 
many bio-mechanic rehabilitations. We developed a powered ankle–foot orthosis that 
uses artificial pneumatic muscles to produce active plantar flexor torque 
(Figure 2.15). The purpose of this study was to quantify the mechanical performance 
of the orthosis during human walking (Gordon et al, 2005).

![Figure 2.15: Air muscle for powering an ankle–foot orthosis. (Source: Gordon, et al. (2005). Mechanical performance of artificial pneumatic muscles to power an ankle–foot orthosis, Journal of Biomechanics, Elsevier)](image)

This research carried out design approach which is listed in Table 2.1 number 
6, TDX SPRE brand. This type of wheelchair has selected as product benchmark
comparison since it has the most advantaged feature than others. Pros and cons of this wheelchair are:

Pros:

1. Can provide triple function (sitting, standing and lying state).
2. Able to handle the payload (user weight) up to 150 kg.
3. Motor wattage is lower than others (200 Watt).

Cons:

1. Could not provide a single bed size in lying state
2. Wheelchair was not equipped with anti-tilt frame to compensate slope effect.
3. Pneumatic or hydraulic actuator was not installed with failsafe mechanical support. Hence, actuator failure may cause danger to the user.

Further, this research is focused in developing a new transformable wheelchair with more advanced feature than existing ones. The new wheelchair design offers:

1. Provide triple function modes
2. It has single bed size form in lying position.
3. Anti-tilt frame design to maintain user position under slope effect during mobility operation.
4. Using linear DC motor actuator, since the mechanism support failsafe condition.

2.3 Anthropometric Data and Asian Hospital Bed Size

Humans vary significantly in size and build. In some situations, it is sufficient to design for the smallest or largest likely dimension. In other situations, adjustable benches, chairs or devices are required for the full range of people (Human Factors Design Standard, 1996).