Robotic Mobilizer for People with lower Limb Paralysis

A Project Report

Submitted by

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to

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Abstract

The Sit-to-Stand (STS) is an activity most people perform numerous times daily. Standing up deals with the transition from two postures, which is sitting to standing, with movement of all body segments except the feet(lower part of leg). During the STS, the body's Center of Gravity (COG) is moved upward from a sitting position to a standing position without losing balance and requiring a good coordination of many muscles. Three main phases of the STS movement can be recognized. A subject begins to stand up by moving the upper body forward, which moves body mass toward the feet in order to maintain balance after lifting from chair(seating position). Prior to leaving the chair, hip and knee extensor muscles are activated to provide the necessary antigravity support for these joints, this action is commonly referred to as weight shift. Finally, after leaving the chair, the leg and trunk joints are straightened to achieve upright stance. In this paper a detailed procedure for the design of assisting devices to be used for the STS in paraplegic subjects is suggested. In particular, an experimental procedure is described firstly to track and record points and the orientation of the lower and upper leg during the STS. This analysis is then used to get information for the design of assisting devices. A proposal and simulation results are presented for a novel assisting device. The experimentation involves both assisted and unassisted STS transition and related anthropometric data is collected to identify the efficiency of the novel assisting device.
Keywords: Biomechanics, Antepulsion, Retropulsion, Stability Analysis, Assistive Technology

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Chapter 1

Introduction to Sit to Stand Transition

1.1 Introduction

There is a high motivation for elderly people with a motion disability to perform basic daily-living activities independently. Therefore, nowadays it is of great interest to design and implement safe and reliable devices that are able to help end-users and provide them a better quality of life[1]. Medical staff are more busy with daily living tasks such as escorting the patients or assisting them during transfer. Due to the disparity between the member of the medical staff and elderly people, a lot of patients are not assisted and stayed in an inactivity leading to the loss of the walking function.Among several daily-life activities, Sit-to-Stand (STS) can be considered as one of the most common, it can be defined as a movement in which the base of support is transferred from the seat to the feet[2]. Then the feet begin to accept the weight first by downward pressure through the heels as the pelvis rolls anteriorly. The weight then moves to the front of the feet as the trunk moves forward and the pelvis lifts from the surface. The trajectory of the Center of Gravity (COG) is then characterized by a movement forward and then backward with simultaneous vertical displacement.

Consequently, it is clear that the entire movement requires a strong coordination between posture and movement, but due to several reasons, it may represent a problem for elderly or people with a motion disability.

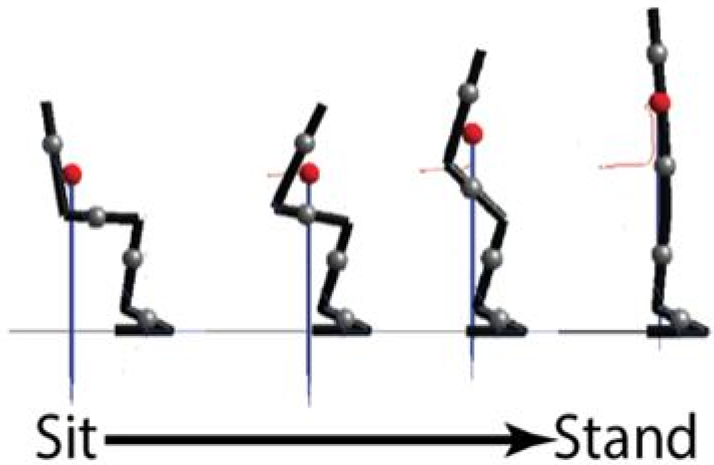

Figure 1.1: Sit to Stand Transition[1]

1.2 Factors affecting STS Transition

1.2.1 Coordination of lower limb muscles

There are basically 8 lower limb muscles that are activated during an STS transition. For this transition to be a successful one each of these muscles will have to undergo a series of flexion and extension[5]. Muscle force, muscle length and muscle contractile velocity determine the pattern of sit to stand transition. The roles of each of these 8 lower limb muscles are as follows: m. iliopsoas (hip flexion), mm. glutei (hip extension), hamstrings (hip extension and knee flexion), m. rectus femoris (hip flexion and knee extension), mm. vasti (knee extension), m. gastrocnemius (knee flexion and ankle plantar flexion), m. soleus (ankle plantar flexion) and m. tibialis anterior (ankle dorsi flexion). To develop an index for exercise or rehabilitation to improve the performance of a sit-to-stand movement, it was examined and found that the minimum required joint moment for a sit- to-stand task and reported that the total of the peak hip and knee joint moment is an appropriate index[11]. They also found that the minimum required value is 1.53 N m/kg. Their finding, represented in terms of joint moment, is convenient for practical uses such as physical rehabilitation and exercise prescription, since joint moment is used as the index of muscle strength in many muscle strength tests.

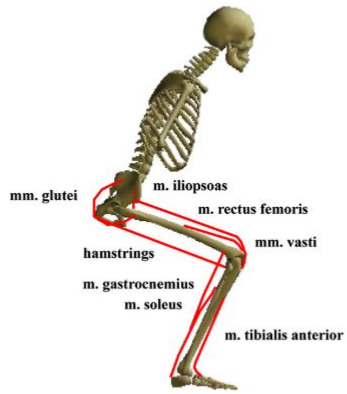

Figure 1.2: Location of eight muscles implemented in the musculoskeletal model[3]

From experimental studies and anthropometric data it was noted that elderly people(>75years) found it difficult to complete their STS transition successfully. The main reason for this problem was the weakness noted in their lower limb muscles[3].

1.2.2 Balance control of the body

The STS transition is a condition during which the body transfers its weight from a static and stable position to a quasistatic position or a position which will be stable in the near future[10]. It is already discussed that for the STS transition to be successful we need proper coordination of 8 lower limb muscles. But for a successful STS transition a proper reception of information from the nervous tissues is also required. The neurological department of a normal and healthy person does this job excellently but when it comes to people with neurological deficiency, ex. Parkinson's Disease patients it becomes tiresome. These patients looses their balance during the transfer of weight from seat to feet. This results in either Retropulsion or Antepulsion movement.

During the STS transition the body torques can be calculated by dividing the entire body into 5 segments which consists of 4 joints. So, during this transition joint torques is being generated at these joints. When the joint

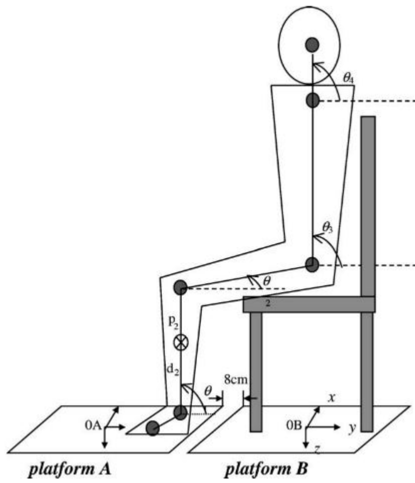

Figure 1.3: Schematic description of the four-joint, five-segments presentation of the human body, including the feet, lower legs (shanks), upper legs (thighs), trunk and head[2]

torques of Normal and PD subjects were compared it was noted that there is a significant difference in hip flexion of PD subjects[6]. It is noted that PD subjects displayed 40% reduction in hip flexion compared to normal subjects.

Chapter 2

Sit to Stand Transition Assisting device

2.1 Need for STS assisting devices

STS transition in most elderly people is a tiresome task because after a certain age lower limb muscles tend to be weak and this makes them dependent on others to carryout their daily activity. For patients diagnosed with PD or other lower limb motor impairments find it difficult to balance their body during STS transition. These factors affect the subjects physically and mentally[7]. These people become physically idle and mentally isolated from rest of the world. STS transition assisting device help these people to do their daily chores without any external assistance and thereby making them self reliable and confident.

Design considerations for the STS assisting device should always include factors like relative effort. Relative effort is defined as the ratio of body weight to the capacity of muscles to accomodate this body weight[15]. The design should be make the subjects self reliable and confident which will influence change their approach towards the deficiency. Overall cost of the assisting device should be restricted by utlizing the proper combination of actuators and fasteners.

2.1.1 Design Considerations for STS transition assisting device

For elderly people, as discussed earlier they suffer from weak lower limb muscles. Considering this factor, a design should accommodate the support for all joints that might be weak during the STS transition. Normally all joints that take part in STS transition have 6 DOF, i.e, 3 translation and 3 rotation. But during STS transition these DOF of joints are restricted to just 2[17]. During this transition, the Center of gravity(COG) tends to be concentrated in and around the hip. So, proper consideration for hip support should be given while considering a design for assisting device. In the case of neurologically deficit people overall stability of the mechanism should be subjected for proper examination. Any meager imbalance in posture or device will result in an unsuccessful STS transition.

2.1.2 Novel Assisting Devices for Sit-to-Stand Transition

In the study of the STS it must be noted that there is enormous variation of motion patterns, that include differences in the anthropometric data of individuals[9]. The changes are due to the unique style of movement as distinctive as his/her personality, but also according to the age and weight strength in muscles. The value of ratio of body weight to capacity of muscles(Relative Effort) plays an important role in designing an assisting device.

Chapter 3

Procedure for the Design of Sit-to-Stand assisting devices

3.1 Initial Specifications

The design procedure should consider some initial data, which refer to the working area in sagittal plane, type of actuators and control, main dimension of the mechanical part of the system, for the starting of the design procedure[14]. More specifically, design requirements of an assisting device can be summarized as follows: the device should posses 2 DOFs in sagittal plane to accomplish the requested trajectories, which may vary according to anthropometric data of the subject, but also due to his/her physical conditions. In addition, the orientation of the trunk during the movement depends on the height of the seat and physiological factors.Therefore, an additional DOF may be considered to provide a suitable orientation for the trunk support.

3.2 Selection of Mechanism and Types of Joints

According to the above initial specifications, the designer should determine the topology of the kinematic chain underlying the mechanical structure, indeed choosing among serial, parallel or hybrid structures. Since the requested motion is obtained in sagittal plane, a planar mechanism instead of spatial one can be considered. Then, a decision is to be made in terms of the type of joints, most commonly, revolute and prismatic. Recently, one additional type has been recognized to equally useful, the P-joint that is, the four links

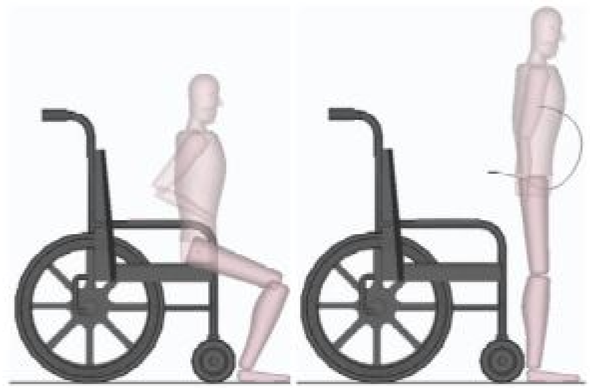

Figure 3.1: STS simulation of model of human body[6]

form a parallelogram four-bar linkage, it is used either for serial and parallel architectures. Then the dimensional synthesis should be performed. It consists in determining the geometric dimensions of the various links defining the mechanism. Finally, structural dimensioning of the links and joints should be performed according to the forces and torques that are acting on the system during its operation. The mechatronics design deals with actuation and transmission system definition and the control part has to be developed.

3.3 General requirements of STS assisting devices

The assisting device can be designed to be installed either frontally or posteriorly to the seat. If the device is placed in front of an individual, he/she should grab the handles and pulls slowly to reach the standing configuration while preventing retropulsion. If the assisting device is placed backward, it should push him/her while preventing any possible fall due to antepulsion. Furthermore, the device should not be bulky or heavy to be easily used in domestic environment and also to be portable (e.g. transported in a city car). It is worth noting the majority of the commercialized solutions for the STS and even those prototypes for research activity are bulky and not transportable, therefore their main use is directed to clinical environment but not for the home care. Then, there is the need to design systems that can be efffctively used in home environment, even additionally folded when they are not needed. Finally, additional 1 or 2 DOFs can be considered to accomplish the walking operation, if requested.

Chapter 4

A Proposal for a mechatronic Sit-to-Stand assisting device

4.1 Proposed System

According to the requirements obtained by experimental tests and considerations reported in previous sections, we designed a mechatronic system for the STS as shown in fig. 4.1 We chose to consider a planar mechanism to be installed in front of an individual having two DOFs in order to reproduce any desired trajectory in sagittal plane. At this first stage we considered a fixed orientation of the trunk. In future developments, the orientation of the trunk and special features (e.g. non symmetrical behavior of the body during the standing) can be taken into account by considering a 3 DOF parallel architecture, which can be also used for orientation purposes. In order to reduce production costs revolute joints may be selected because they can be manufactured at relatively low-cost. In addition, we chose a mechanism scheme to obtain a quasi-Cartesian behavior that drastically simplifies the control to set the requested trajectory.

4.2 Limitations of Existing Systems for assisting STS transition

It is worth to note that for this first model the system is built in a skeleton form, and the various mechanical parts could be further covered or encased.

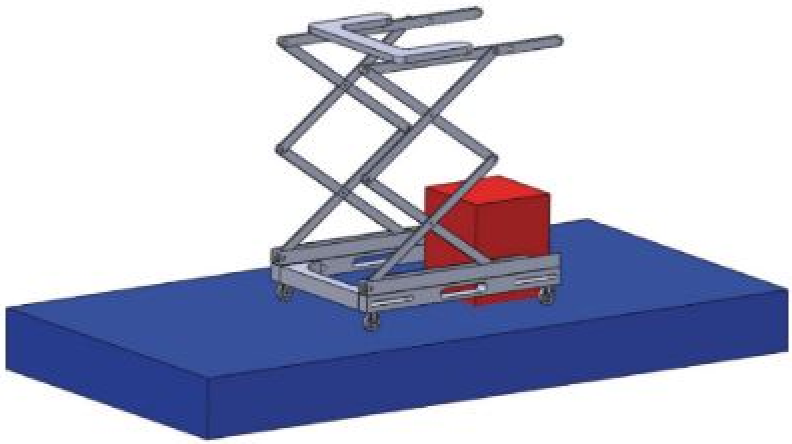

Figure 4.1: The proposed system for the STS[14]

No such covering or encasement has been shown at this stage since it would merely obscure the operation of the working parts. Furthermore, it was assumed that the interaction of the system with the end-user takes place through the armpit, then an interface similar to a crutch can be configured. Off course wrap around belts are also provided to hold the torso and prevent antepulsion and retropulsion, even if in this simulation they have not been explicitly reported.The model can only be used by elderly and people neural deficiency. People with other motor impairments especially lower limb paralysis find it difficult to use this device as there is no supporting structures for lower limb. The STS was analyzed from the point of view of point trajectories and trunk orientation of the human body in order to identify suitable requirements and provide useful considerations for design purposes. Results of an experimental trial obtained by young adult volunteers were compared with those numerically obtained by a suitable model of the human body. The results were used to derive an efficient procedure for the design of the assisting devices. In particular, the above-mentioned results and procedure can be used to test assisting devices during the design and simulation phases, to customize a system according to the end-user needs, and further use data from experimental trials to drive the actuation system of a real mechanical device to assist the STS.

Chapter 5

STS assisting Mechanism

5.1 Design for restricting joint torques at lower part of body

As the proposal of design is for lower limb paralyzed subjects it is obvious for the design to be restricting any motion whatsoever for the lower limb. The 2 major segments that should be restricted while proceeding a STS transition is the lower leg and upper leg. These segments have 2 joints namely ankle and knee. These joints are restricted in the proposed design.

5.2 Center of Gravity of Human body

The COG of the human body is studied to be concentrated in and around the hip of the body. So while assisting the STS transition for lower limb paralyzed patients maximum support should be given for the hip av s this will help in providing an efficient uplift of the patient.

The proposed design is intended to provide both Sit to Stand assistance and also aims in providing mobility for the patients. This mechanism stimulates the walking or mobility of the lower limb paralyzed patients. The stability of the entire system is to be studied and analyzed so that suitable ergonomic changes can be incorporated so as to accommodate people with different physical conditions.

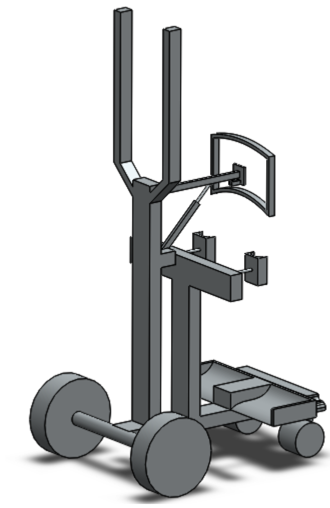

Figure 5.1: Proposed Design for Mobility Vehicle for Lower Limb paralyzed patients

5.3 Actuation Force

During the STS transition, the actuation force required by the human being is provided by the upper leg with the aid of 8 lower limb muscles of which each muscle has a specific muscle length, muscle contractile velocity and muscle force. But in the case of paraplegic subjects, their lower limbs are completely paralyzed which creates a deficiency of upper leg actuation force. So, when designing an assisting device for paraplegic subjects, the actuation force factor should be considered. The proposed design intends to mechanically imitate the natural action of sit to stand. Two actuators each of 6" stroke is used for the purpose. The fig. 5.2 shows the actuator used for providing the actuation force and shows the direction of actuation.

5.4 Prototype Development

The fig. 5.3 shows the first and revised prototypes of the proposed Sit to Stand assisting device. A medical team lead by Dr. P S John (HOD, PIMSRC) and Dr. Varghese Thomas (Assistant Professor, PIMSRC) evaluated

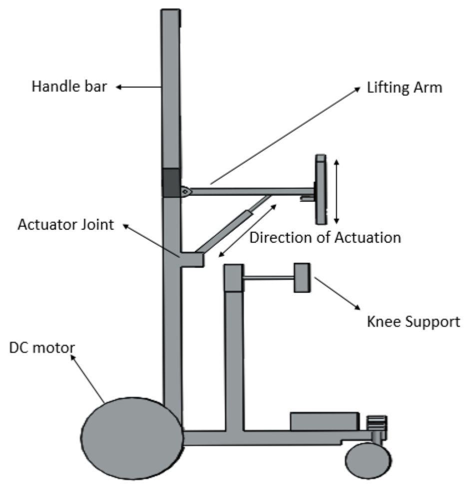

Figure 5.2: Direction of Actuation

the fist model to give some valuable feedback which were implemented to develop the second and final prototype. All the data subjected for revision was prepared in consultation with the medical team who identified the factors that may influence the overall efficiency and accuracy of the device design. Proper relation with the corresponding anthropometric data was important in identifying the possibilities of design enhancement in future.

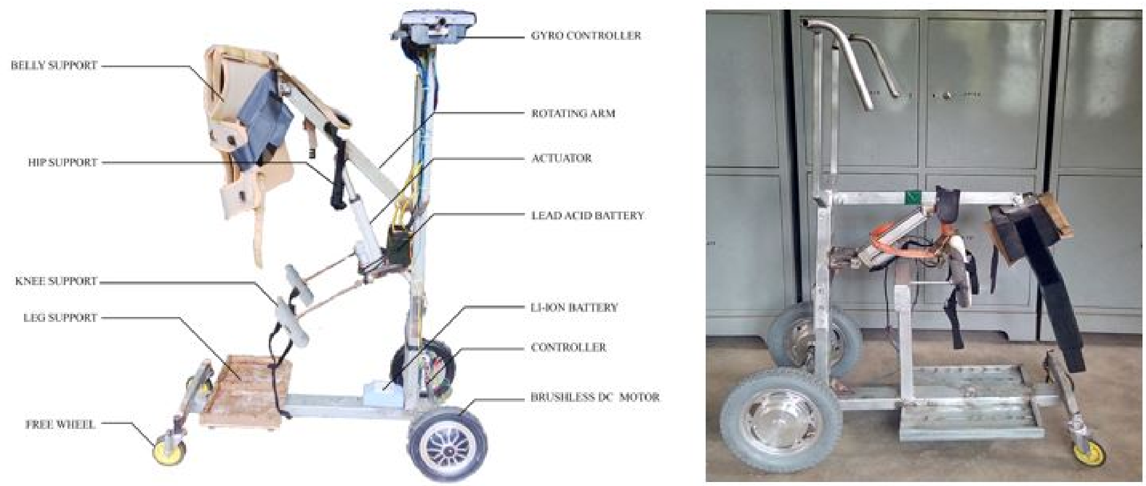

Figure 5.3: (a) First Prototype (b) Second Prototype

Chapter 6

Experimental Study of Sit to Stand Transition

In this experimentation setup, assisted and non assisted STS transition is studied and this data is compared with the optimum anthropometric relations available. In order to conduct the experimentation, 4 points on the body of a subject are considered. fig. 6.1 shows the line diagram illustrating different segments of the body. Apart from the points considered three joint angles i.e., hip, knee and ankle angles are also considered. The distance between the identified points are used to find the anthropometric relations of different segments of the body.

6.1 Normal Sit To Stand Transition

The fig. 6.2 shows the line diagram of the normal, unassisted STS transition. The three phases of the transition is illustrated. The first phase of transition begins with flexion at hip and ankle joints. The flexion is followed by an extension at the same joints. During the second phase,the subject transfers the body weight from the ankle to the toes. And in the final phase the weight of the body is completely accepted by the feet.

6.2 Assisted Sit to Stand Transition

In assisted STS transition, the subject uses the aid of the mobility vehicle fabricated for paraplegic patients. In assisted transition, The initial phase of

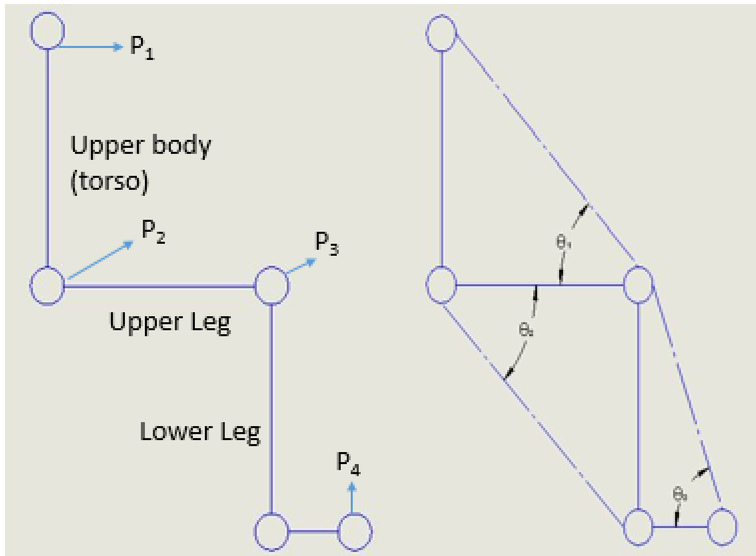

Figure 6.1: (a)Segments of Human Body (b)Anthropometric angles

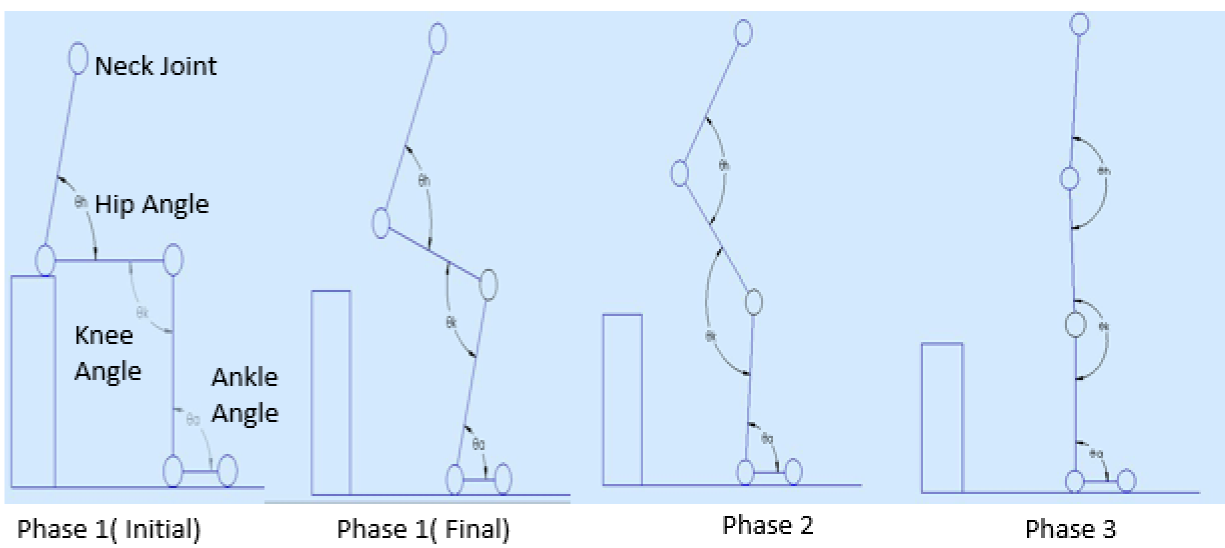

Figure 6.2: Phases of Unassisted STS transition

Figure 6.3: Phases of assisted STS transition

the transition is integrated (i.e., flexion and extension). Fig. 6.4 shows the phases of assisted STS transition.

Chapter 7

Locomotion Mechanism for Mobility Vehicle

7.1 Choosing the Correct DC Motor for a Specific Application

Design engineers are often faced with having to determine the best DC motor choice for a given functional requirement or design parameter. A typical example might look like this: Functional Requirement: DC Gear head motor capable of accelerating a 300 lb, two-wheel drive robot with wheel diameters of 12 inches at a rate of 3 ft per sec. Top speed required will be around 4 feet per sec.
Design Parameters: Supplied Voltage = 12Volts, Motor size limited to an overall diameter of approximately 2inches and an overall length of not more than 4inches (Less the output shaft length.)

Type and No. of motors	DC motor (2 no.s)
Operating Voltage	12V
Motor Length	2.25 inches
No Load Speed	2000 rpm
Wheel Diameter	12 inches

In order to reduce the speed of the motor a reduction gear is attached to the mechanism. This ensures the ideal speed for the mobility vehicle.

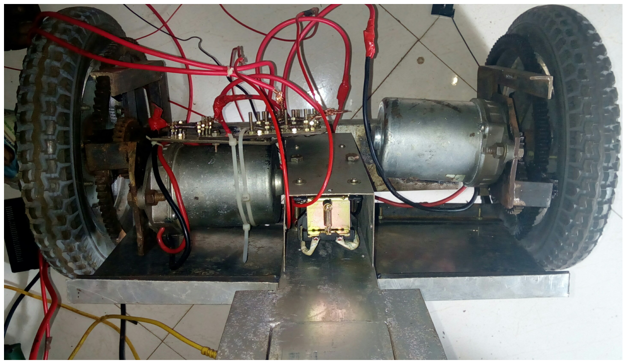

Figure 7.1: DC motor intergated with 12 inch wheels for Mobility Vehicle

Figure 7.2: Reduction gear used to reduce speed from the drive

Chapter 8

Results

The anthropometric data for normal human being is collected for different age group, height and body weight. An average value of the optimum hip, knee and ankle angles are calculated[19]. Table 1 shows this optimum data.

Table 1 Optimum Anthropometric Data [19]

	$\theta h(in degrees)$	$\theta k(in degrees)$	$\theta a(in degrees)$
Phase 1 (Flexion)	72.1	90	90
Phase 1 (Extension)	77.9	90	71.8
Phase 2 (Intermediate)	102.8	132.1	82.4
Phase 3	173	181.5	90

The angle data for hip, knee and ankle is also collected for assisted and normal STS transition. These data are collected by measuring the distance between the points that were identified on the subject's body.

Table 2 Unassisted STS Transition Data

	$\theta h(in degrees)$	$\theta k(in degrees)$	$\theta a(in degrees)$
Phase 1 (Flexion)	73.85	90	90
Phase 1 (Extension)	78.7	90	72.4
Phase 2 (Intermediate)	104.2	134.26	85.6
Phase 3	173.9	182	90

Table 3 Assisted STS Transition Data

	$\theta h(indegrees)$	$\theta k(indegrees)$	$\theta a(indegrees)$
Phase 1 (Flexion)	77.61	90	90
Phase 2 (Intermediate)	97.68	126.66	90
Phase 3	170.21	185.29	90

8.1 Data Comparison

From the Table 1 and 2 it is quite evident that flexion stage of of unassisted STS transition is similar to the optimum data available from references. This shows that the anthropometric data is relatable over a different factor range and the experimentally obtained data is fair enough to justify the optimum anthropometric data obtained from references.

8.2 Phase 1 Anthropometric Angles

The two sections of phase 1 are flexion and extension. In assisted STS transition, it is nearly impossible to replicate the motion of flexion and extension simultaneously. So, a design provision was made so as to skip the extension section of phase 1. This provision was made by altering the length of the bar used to lift the subject. Apart from this alteration in phase 1, the hip angle for both assisted and unassisted STS transition showed a small deviation from mean value.

8.3 Phase 2 Anthropometric Angles

Experimentally it was observed that the second phase of STS transition is the most unstable phase. The theoretical reason for the same instability is the transfer of weight from the upper legs to the feet or the lower leg. This transfer of weight actuates the shift of the center of gravity (COG) of the body.From the experimental setup it was observed that the subject's hip angle reading varies indefinitely from reading to reading. This huge variation of hip angle is expected to be happening due to the instability factor of second phase. It is significantly noted that the major deviation of values when comparing assisted and unassisted transition the second phase produces the maximum value.

8.4 Phase 3 Anthropometric Angles

The third phase of STS transition is commendably the most stable and accurate phase for anthropometric data collection. When experimentally studied, the assisted and unassisted STS transition data of the third phase is approximately similar. The ankle angle in case of assisted STS transition is limited to 90 degrees, as the lower part of legs is constrained to the mobility vehicle.

Chapter 9

Conclusions

The STS assistance mechanism of the proposed mobility vehicle is efficient to produce hip angle in the range close to that produced normally. The mechanical imitation of the STS assisting device provides a more efficient and reliable lift for the subject by reducing the chances of retropulsion or antepulsion. In the case of paraplegic subjects, the lower segment of the legs are constrained so as to avoid the slip away of the lower legs. This constrain provides a smoother lift and all the supports used for lifting were carefully designed to facilitate the free flow of blood through blood vessels. The COG (Centre of Gravity) of the body tends to shift from the hip region to the torso during the first phase of STS transition. After the completion of the second phase, the COG of the body comes back to the hip region. The design ensures this change of COG as the entire weight of the body seems to be concentrated around the COG.

Chapter 10

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