Lower Limb Rehabilitation Using Motorized Therapeutic Training for Paraplegia

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Abstract - Gait recovery is an essential part of rehabilitation of the patient affected by the lower limb disorder result in loss of motion. This is caused due to paraplegia results in impairment in the motor function or the loss of the sensory function of the lower extremities that would affect the trunk, legs and it is additionally termed as leg paralysis. The disorder is also seen in the children and if it is not treated at the initial stage it would cause the loss of muscular activity in the lower part of the body which includes both the legs. Treatment would consist of rehabilitation that is used to restore the functional ability of the lower limb. The concept of the body support harness is implemented to enhance the locomotion rehabilitation. The rehabilitation is carried out by the motor controlled foot pedal that prepares or trains the muscles that is associated with the movement. At the start of the training passive movement is given to the lower limb muscles at slow speed and decrease spasticity. The automated robotic device is designed to move along with the patient inside the frame. It would eliminate the patient restricted to specific zone of training. The result of the gait rehabilitation training aims to bring the daily activity in the paraplegic person and furthermore it helps to regain the independent walking ability towards the end of the rehabilitation training.

Index Terms: paraplegia, body support harness, locomotion rehabilitation, passive movement, spasticity.

I. INTRODUCTION

Paraplegia is caused due to the impairment in the motor function or the loss of the sensory function of the lower extremities that would affect the trunk, legs
result in the loss of movement and locomotion. It is caused due to spinal cord injury and damage in the nervous system which causes the loss of the lower half of the body that include the legs. The thoracic, lumbar and the sacral segments of the spinal cord are damaged. In paraplegia condition the arm function is normal but the legs and the pelvic region is affected depending upon the level of the injury in the spinal column. Signals to and from the lower part cannot reach as a result not only the movement is affected the sensation is also lost such as tingling sensation. Children with such disorder should be given special care and a different method of rehabilitation process has to be adopted because it is the stage where psychological and social development takes place. These children are socially isolated because of their inability to move from one place to another that would affect their life due to stress and other barriers. Over 69.8% of spinal cord injured (SCI) paraplegics totally rely upon a wheelchair to move and for the locomotion that would result in mental and physical stress and cause additional issues [1]. Gait training is an important for the rehabilitation process which helps to restore the ability to walk independently. There are many ways by which the rehabilitation is done for the lower limb that is used to train the muscle in order to walk.

A. Gait Cycle:

It is necessary to understand the concept of the gait cycle before selecting the method for the rehabilitation of the lower limb. The gait of the human is done by the coordinated work of the muscle and the joints of the lower limb. There are two major phases of the gait cycle namely the stance phase where the part of the foot is in contact with the floor and it is about 60% of the gait cycle and the swing phase where the foot is not in contact with the floor and it contribute the remaining 40% of the gait cycle. Nearly 80% of the gait cycle the body is supported by a single limb. The events in the stance phase are heel contact or heel strike, foot flat, mid stance, heel off, toe off.

The events of the swing phase include acceleration or early swing phase, initial swing, mid swing and the deceleration or the late swing. The angle of the normal knee during walking is about 0 to 70 degree. When the leg is in the contact the knee is in 5° flexed position [2].
B. Gait Rehabilitation

Walking is one of the daily routine activities of the human being. The devices aid the people with disabilities also said to improve their quality of life and also said to increase the average lifetime of the disabled person. Gait rehabilitation is more efficient by the use of rehabilitation robotics that is used to mimic the function of the therapist. The devices used for the gait rehabilitation unload certain weight and speed adjustment has to be provided depending upon the level of the disability \(^1\). Rehabilitation robotics is the application of robotic device that is used to provide support during therapeutic training and improve the patient suffering from motor impairment. One of the risk factor during the rehabilitation is the spasticity that is caused during the training as a result of sudden contraction of the muscle and this factor has to be eliminated to improve the gait rehabilitation. Spasticity is also said to increase the joint resistant and adds further drawback to the training process. In some approach the muscle spasm or the level of spasticity is detected by measuring the EMG signal and lowering the speed helps to eliminate the condition. There are various robotic device that are used for rehabilitation of the lower extremities such as walk trainer, Nature-gait that are used to improve the efficiency of the lower limb rehabilitation and also to reduce the work effort of the physical therapist\(^4\).

This paper describe the conventional methods that are used for the lower limb rehabilitation and also discuss the new approach of rehabilitation robotic device that is used to restore the ability of walking in the person with paraplegia. The design of the motorized therapeutic training robot also utilizes the body support harness used to support the patient during training. This is used to eliminate the fear of falling of the patient during the rehabilitation process and also used to reduce the percentage of body weight on the lower limb that would provide better recovery and helps them to attain independent walking ability.
II. EXISTING METHODS

A. Over Ground Gait Training

There are different methods that are adopted for the lower limb rehabilitation. One of the most common technique is employed is the over ground gait training method \(^5\). In this method the patient is allowed to walk on the floor with a physical support and it does not involve high technology aids. The patient is made to walk with or without the application of the body weight support system. For this type of training the trainer or the physical therapist move the legs of the patient according to the walking pattern. But the drawback of the technique is that it is not sufficient to determine the effects of the training on restoring the gait function. It also takes time for the recovery of the proper function of the lower limb in a disabled person.

Lower limb exoskeleton are been designed that enable the patient to walk and it also improve the mobility. This exoskeleton are worn around the patient that would provide 105° in flexion and 30° extension to the hip joints and 105° flexion to the knee joint \(^6\). This is used to provide support during walking in the paraplegic. The training is done where the user is allowed to walk on the floor with the exoskeleton and the disabled person can also use the parallel bars provided for additional support during the gait rehabilitation process.

B. Rehabilitation Robotics

Rehabilitation robotics was then employed for the lower limb rehabilitation and plays an important role in restoring the normal walking pattern of the paraplegic or a gait disabled person. Rehabilitation robotics technology is the utilization of the robotics gadget that is used for bringing the motor function back to normal. These robots are utilized to provide the therapeutic training and support the patient during the process of gait recovery. Rehabilitation robotics is the efficient way to provide the training for the patient suffering from the motor disability. For the design of the rehabilitation robotic device it is necessary to understand the application for which it is employed. The outcome of the rehabilitation should restore the disabled parts back to normal and should also bring the day to day activities in the individual freely. Treadmill based rehabilitation system is the ideal way for the gait rehabilitation. There are different types of treadmill based rehabilitation system and it has gained much consideration among the experts such as the researcher and the specialist. The key segment of the treadmill based training is the usage of body weight support (BWS) system. This is used to remove the percentage of the body weight during the training and permits the patient to walk with the disabled legs. Research has demonstrated that the usage of the body weight support in the treadmill based rehabilitation enhance recovery process. It also reduces the patient fear of falling during the training and improves the patient involvement towards the system and provides
faster recovery. The body support system may be passive or active \[7\]. It would consist of the external frame where the support harness is attached to the main frame. The patient is first made to walk on the treadmill at slow speed and the speed is increased depending upon the period of recovery. The result of the training with the body support and without the body support shows significant differences. This examination demonstrates that stride preparing on a treadmill with BWS is a powerful approach since it brings about better locomotion capacities \[8\][9]. This concept of BWS could be also implemented in the other rehabilitation techniques. Enhanced version of the treadmill based training implement split belt that would comprise of two belts. Each belt is independently regulated by a DC motor and different speed mode is given to the belt of the treadmill \[10\]. Restoring the gait pattern with the body weight support prove better result in the training than the individual with no support who bear the total body weight on the disabled legs. Both the kinetic and kinematic factor was improved during the training \[11\].

III. METHODOLOGY

A. Simulation Model

Before developing the mechanical model for the gait robot a simulation model is designed using solid works software which is used for virtual modeling by the application of computer aided design. The simulation model is represented in Fig.

B. Mechanical Design

The use of robotics design to facilitate the process of rehabilitation of the lower limb is dealt under the field of rehabilitation robotics. During the training of the paraplegic subject the design should be in such a way that it is user friendly and the patient is comfortable throughout the training period. The paraplegic children should be supported by adapting the concept of body support system with a harness that is attached to the top of main frame in the rehabilitation robot \[12\]. The material required for the construction of the external frame work is made of a material that could withstand the load of the patient and should also support the whole system. Certain mechanical properties like tensile strength, compressive strength; hardness of the material is analyzed for choosing the right material to fabricate the design. Tensile strength and compressive strength denotes the resistance of the material under tension and compression when it is
This paper deals with the robotic setup that is fabricated using iron material which would satisfy the mechanical properties mentioned. The base of the system is constructed using square iron pipe of sufficient thickness that would increase the weight bearing capacity of the design. The raw materials are cut to the required dimension as mentioned. The next process is to manufacture the design. The pipes are welded as per the design and it the important part of fabrication. The base is then attached to the wheel with the help of the bearing.

The wheel is provided in order to move the robotic device with the help of motor control. This is done to eliminate the barrier of the patient subjected to a particular area of training and would also improve the user involvement to the system. The wheels are attached to the rods by using bearing. The bearing is bolted to the base and the wheels are attached on the either sides of the rod. The pedal which is used to provide cyclic movement to the lower limb is attached to the center of the base. The pedal is designed to evenly distribute the weight of the patient on the lower limb. The patient foot is attached to the footpad or the pedal by the strap provided. The footpad is attached to the sprocket at the center of the base part as shown in Fig.3. A roller chain is then used to connect the sprocket with the footpad and the wheel rod. This is because when the motor is used to drive the wheel rod the rod would rotate that would provide the movement of the robotic device and simultaneously it would rotate the foot pedal because both are connected with the help of roller chain. The foot pedal is used to promote the gait training while the wheel movement increases the user involvement towards the system.

The external framework is also constructed by square iron pipe and it is bolted to the base. The body support harness is hooked to the center of the frame by using strong elastic material. The implementation of the body support harness provides additional feature to the system. It is used to unload a percentage of body weight of the subject in the lower limb during the training. The harness is used to support the patient during the training and it would eliminate the patient fear of falling. The handle is provided so that the patient can hold it which would provide additional support.

Fig. 3 Mechanical model of base with attached pedal used for lower limb rehabilitation
Table 1 Dimensions Of Mechanical Model

<table>
<thead>
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<th>S.NO</th>
<th>TITLE</th>
<th>PARAMETER</th>
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<td>1.</td>
<td>Base</td>
<td>Length</td>
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<td></td>
<td></td>
<td>Width</td>
<td>1 m</td>
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<td>2.</td>
<td>Frame</td>
<td>Height</td>
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<td>3.</td>
<td>Bearing</td>
<td>Length</td>
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<tr>
<td></td>
<td></td>
<td>Width</td>
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<tr>
<td></td>
<td></td>
<td>Diameter</td>
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</tr>
<tr>
<td>4.</td>
<td>Iron Rod</td>
<td>Length</td>
<td>1.15 m</td>
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<tr>
<td></td>
<td></td>
<td>Diameter</td>
<td>17 mm</td>
</tr>
<tr>
<td>5.</td>
<td>Foot Pedal</td>
<td>Height</td>
<td>28 cm</td>
</tr>
<tr>
<td>6.</td>
<td>Wheel</td>
<td>Diameter</td>
<td>32 cm</td>
</tr>
</tbody>
</table>

A. Block Diagram Description

Fig. 5 explains the electronic design that is incorporated with the mechanical parts. The electronic part of the system is divided into two parts. One part deals with the power that is used to drive the motor and the circuit and the second part deals with the speed control unit of the motor. The power supply to the system is chosen as the AC source and it is given to the primary side of the step down transformer or the input. The speed of the motor is controlled using pulse width modulation which is used to control the power delivered to the load i.e. motor. Pulse width modulation is mainly used for the control of the speed of DC motor by providing series of pulses used to drive the motor during the duty cycle. The speed of the rotation of the motor is controlled and a switch is provided to the patient so the training is given when the switch is pressed.
The DC motor shown in Fig. 6 is attached to the base and is mechanically connected to the wheel rod. The wheel rod and the pedal are interconnected by sprocket and the roller chain. When the motor is activated it would drive the wheels and the foot pedal simultaneously. The foot pads are used to provide the therapy to the lower limb and facilitate the rehabilitation process. The wheel rotation would carry the whole system along with the patient inside supported by the support harness. It would eliminate the disadvantages of the patient restricted or confined to particular area of training and the movement would improve the overall rehabilitation process and increase the patient involvement.

### Table 2 DC Motor Specification

<table>
<thead>
<tr>
<th>S.NO</th>
<th>CATEGORY</th>
<th>SPECIFICATION</th>
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<td>Voltage</td>
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<tr>
<td>2.</td>
<td>Current</td>
<td>2.7 A</td>
</tr>
<tr>
<td>3.</td>
<td>Torque</td>
<td>0.14 Nm</td>
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<tr>
<td>4.</td>
<td>Revolution Per Minute</td>
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<tr>
<td>5.</td>
<td>Shaft</td>
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</tr>
<tr>
<td>6.</td>
<td>Type</td>
<td>DC Motor</td>
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<tr>
<td>7.</td>
<td>Model Number</td>
<td>BCI 63.25</td>
</tr>
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</table>

**B. Body Support System**

The training is supported by a harness is used to reduce the part of the body weight on the lower limb and adds faster recovery period since the patient need not concentrate in balance during gait and can only focus on the movement of the lower limb. The gait training system improves the balance and better walking pattern than the training which involve the patient bearing full load of the body weight on the affected limb. The patient would withdraw from the training if body support is not provided as the patient would develop fear of falling during the training as it might lead to injury. In this new method of training subject would actively participate in the rehabilitation process.
without withdrawing from the course of training since the concept of support system is incorporated. Gait training with the body support system provides better result of lower limb rehabilitation. By reducing the weight of the patient on the lower limb it enhance the restoration of the gait pattern. The body support harness technique used for the gait rehabilitation is used for two purposes. The support system is used to reduce the body weight or the load to the foot that facilitate less weight on the lower limb. This would improve the gait restoration process. The body weight support is also used to support the patient in the training. The support system is provided with the adjustable straps so that it could be used for different person with different body dimension. It would reduce the patient fear in risk of falling and would also increase the patient involvement towards the system. The body support harness is represented in Fig. 7.

C. Lower Limb Rehabilitation

The lower limb rehabilitation robot is equipped with foot pedal in which the paraplegic children are made to stand on it. They are supported by body weight support system which would support the patient during the training. Free movement can be easily provided to the lower limb without causing stress due to body weight support provided. It would also improve the period of recovery and increase the efficiency of the system. Fig. 8 shows a musculoskeletal model of the patient during the gait training provided by the foot pedal. The rotation of the foot pedal is controlled by motor driven circuit. The DC motor is employed for this purpose. The motor is attached to the roller chain which is attached to the sprocket and the foot pedal. When the motor is made to rotate the pedal also rotates which facilitates training the leg muscle. The rotation of the pedal is in such a way that it provide full degree of movement to the lower limb. The training would improve the positive feedback to the lower limb rehabilitation.

IV. CONCLUSION

The pedal based rehabilitation of the lower limb is a new concept and this would provide full range of motion to the lower limb. It would improve the strength of the muscle that is required for standing and walking and also the coordination of the lower limb with better balance recovery. The foot of the patient is firmly attached to the pedal and it would help to keep the legs with the pedal. This system would reduce the patient stress since they are not confined at one location of training. The slow speed rotation at the start and the end of the training should
be given to ease the muscle relaxation and to reduce the muscle spasm. The speed of the footpad is adjusted depending upon the patient recovery. The activity of the muscle could be checked by acquiring the EMG signal repeatedly during the training. This is done in order to check the improvement of the muscle activity of the lower limb after the period of training. At the end of the rehabilitation training the patient must recover their normal gait pattern with a good posture, stability and also the balance during walking.

The training is supported by a harness is used to reduce the part of the body weight on the lower limb and adds faster recovery period since the patient need not concentrate in balance during gait and can only focus on the movement of the lower limb. The gait training that is provided with the body support improves the overall effectiveness of the rehabilitation. The gait training system improves the balance and better walking pattern than the training which involve the patient bearing full load of the body weight on the affected limb.

This technique of gait training is a best approach with a faster period of recovery. This rehabilitation system would also reduce the work load of the therapist. However they are still needed to make sure about the effectiveness of gait therapy and should also monitor the progress of rehabilitation of the lower limb. Depending upon the improvement the speed of the training can also be increased and training sessions could be carried for longer period. Furthermore the training strategy could be given continuously when compared to manual training method since it may be difficult for therapist to work for long period.

Walking is an important factor responsible for performing daily activities. It is necessary to restore the gait in paraplegic individual without making them confined to wheelchair. The rehabilitation should restore the function of the lower limb and make the paraplegic lead independent lives. This approach is an effective way to regain the normal function of the lower limb through rehabilitation.

REFERENCES


