# Design of Walking Assistance Lower Limb Exoskeleton for Paraplegic Patients

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**Abstract** - *This paper reviewed different lower limb exoskeleton system which provides assistive torque at both hip and knee joints to supply gait assistance to spinal cord impaired person. Every year around 2,50,000 to 5,00,000 people suffer from spinal cord injury. Of these at least 44% result in paraplegia. Loss of mobility is the one of the most important impairment resulting from the paraplegia. Already available lower limb exoskeleton systems are so much costly. Design of simple and low cost exoskeleton system is required.*

***Key Words***: **Assistive technology, lower limb exoskeleton, paraplegia, powered orthosis, spinal cord injured (SCI).**

## 1. INTRODUCTION

Loss of mobility is the one of the most important impairments resulting from paraplegia. Moreover to impaired mobility, not able to stand and walk lead to severe physiological effects, including decreased bone density, skin breakdown issues, tightness of muscles, damaged lymphatic and vascular circulation, reduced digestive operation, muscular atrophy, urinary tract infection and reduced respiratory and cardiovascular capacities.

Various lower limb orthoses have been built and explained to repair some degree of legged mobility to persons with paraplegia. Orthoses that were developed specifically for restoration of mobility in paraplegic persons are being targeted in this review. To repair legged mobility to paraplegics several passive orthoses have been built. Long-leg braces that include a pair of ankle-foot orthoses (AFOs) are the simplest form of passive orthotics.

lower Extremity Exoskeleton which provides features like non intervention between the structure and human body, large load bearing capacity, comfortable and easy to wear, safe and reliable. DARPA Program Exoskeletons which is also known as Exoskeletons for Human Performance Augmentation (EHPA).

## 2. GAIT ANALYSIS

Fig-1 shows the gait analysis of normal human walking. Gait cycle can be split into single support, double support with one redundancy. Fig-2 shows the angular displacement of each joint in a gait cycle.

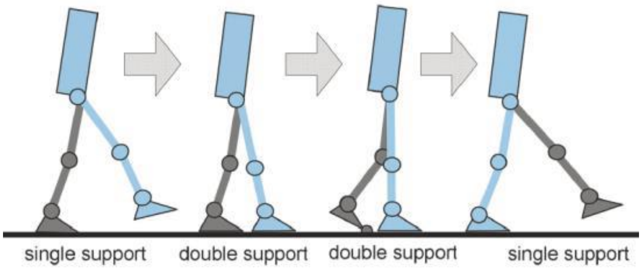


**Fig-1:** Gait Cycle

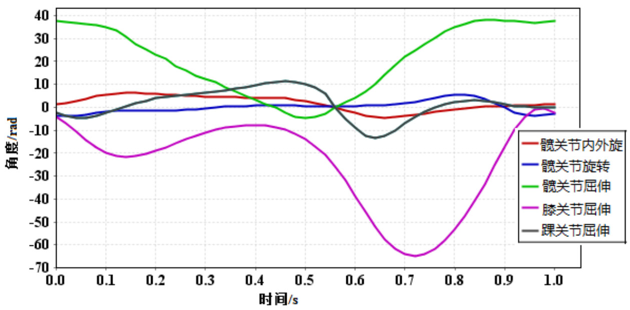


**Fig-2:** Angular Displacement of Each Joint

## 3. MECHANICAL DESIGN

### 3.1 Active Orthosis

Quintero, Hugo A., Ryan J. Farris, and Michael Goldfarb, Authors have developed powered lower limb orthosis shown in fig -3 designed to provide powered assistance to both hip and knee joints. Brushless DC motor is used in this powered orthosis with a gear reduction of 24:1, gives maximum constant torque of 12 NM and shorter duration maximum torques of almost 40 NM.[3]

**Fig-3:** Powered Orthosis

In the condition of a power failure the knee joints remain locked because of electrically controllable normally locked brakes. Each brake integrate a spring-loaded solenoid which, gives torsional resistance in a drum brake design. In the stance phase of gait the brake remains locked. The hip joints degree of motion is 105° in flexion and 30° in extension, while the degree of motion for the knee joints is 105° in flexion and 10° in hyperextension.[3] The orthosis is designed to be worn in concurrence with a standard ankle foot orthosis (AFO), which provides support. The total orthosis mass is 12 kg. Using two thigh straps instantly above the knee joints, and by the orthosis hip segment the orthosis is prevented from sliding down the body.[3] A mass breakdown of the orthosis is given in Table I.

**Table -1:** Mass Breakdown of Orthosis

| **Component** | **Mass(kg)** | **Mass Distribution** |
|---|---|---|
| Joint Actuation | 3.57 | 30% |
| Thigh Frames | 4.08 | 34% |
| Hip Brace | 2.10 | 17% |
| Shank Frames | 1.09 | 09% |
| Battery | 0.68 | 06% |
| Electronics | 0.50 | 04% |
| Total | 12.02 | 100% |

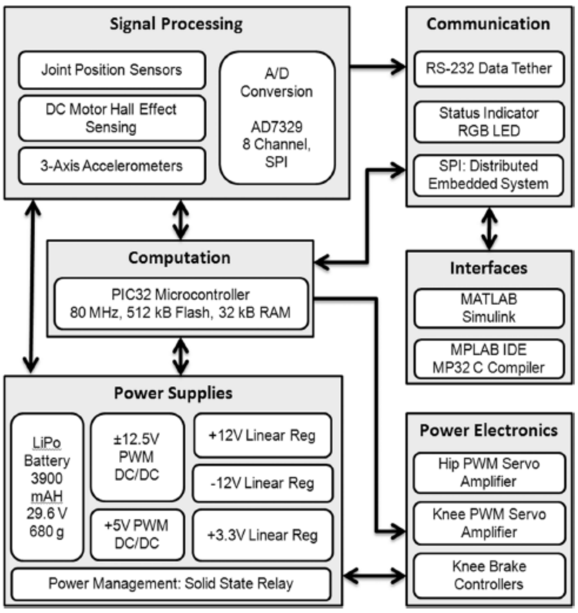


**Fig-4:** Embedded system framework.

Fig-4 shows the functional diagram of the Distributed Embedded System (DES). The DES is powered by a 29.6 V, 3.9 A h lithium polymer battery, consist of power supply module, a computation module, interface module, power electronics, and communication electronics to interface components within the DES and between the DES and a host computer.[3]

### 3.2 lower Extremity Exoskeleton

The main purpose of lower extremity exoskeleton to co-operate human body movement, so that it can walk for long period of time.[8] Following functions are provided by lower extremity exoskeleton: large load bearing, non intervention between the structure and human body, comfortable and easy to wear, safe and reliable, etc.[8] Fig-5 shows the design of lower extremity exoskeleton.

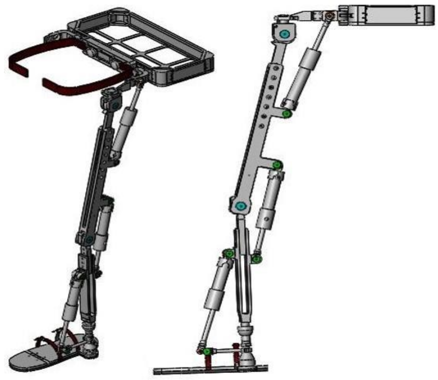

**Fig-5:** Mechanical design prototype

Table 2 Mechanical prototype technical parameter

| Structural parameter | Technical indicator | Structural parameter | Technical indicator |
|---|---|---|---|
| Mono-limb DOF | 7 | Hip-abduction /adduction angle | ⍰ 15° |
| Supply voltage/V | 24 | Hip-rotation angle | ⍰ 15° |
| Adaptation height/m | 1. 6-1.8 | Hip-flexion angle | -9°~115° |
| Carrying quality/kg | ⍰ 40 | Knee-flexion angle | -126°~5° |
| Ankle-flexion angle | -20°~15 | | |

Design includes mainly back load carrying system, hip joint, thigh structure, knee joint, lower leg structure, ankle joint and foot structure.[8] Batteries, controllers, and electronic components are installed in back load-carrying structure. Waist belt used for connecting with human waist, and the width adjustment structure is used for adjusting the space between the legs.[8]

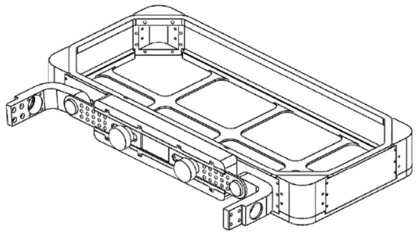

**Fig-(a):** Back-bearing structure

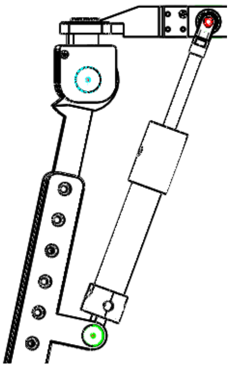

**Fig-(b):** Hip joint structure

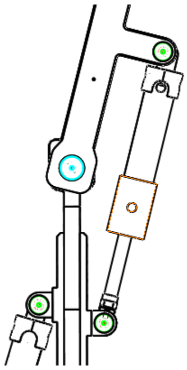

**Fig-(c):** Knee joint structure

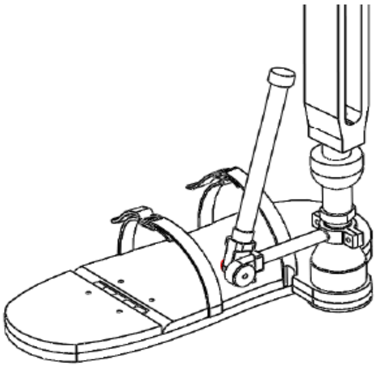

**Fig-(d):** Foot and ankle joint structure

**Fig- 6:** Mechanical design structure details

### 3.3 DARPA Program Exoskeletons

DARPA also known as Exoskeletons for Human Performance Augmentation (EHPA). The main vision of the DARPA exoskeleton is to increase the capabilities of soldiers.[7] DARPA focus on enhancing the execution of soldiers during load-carrying, enlarging the size of the load that can be carried, and decreasing the tiredness on the soldier during the load-carrying task.[7]

#### 3.3.1 Berkeley Exoskeleton (BLEEX):

Berkeley Lower Extremity Exoskeleton (BLEEX) is one of the famous exoskeleton of DARPA. It carries its own power source.[7] Developers of the BLEEX claims that, it is the first load-bearing and energetically autonomous exoskeleton. 3 DOFs at the hip, 1 DOF at the knee, and 3 DOFs at the ankle is provided by BLEEX.[7] Among these, hip flexion/extension, hip abduction/adduction, knee flexion/extension, and ankle flexion/extension are actuated and ankle inversion/eversion, hip rotation and ankle rotation are unactuated.[7] Different feature of the BLEEX exoskeleton is rotation of the hip, because of that it does not intersect with the person's hip joints.[7]

#### 3.3.2 Sarcos Exoskeleton

A full-body Wearable Energetically Autonomous Robot (WEAR) was invented by Sarcos Research Corp. under the DARPA EHPA program.[7] Sarcos exoskeleton carries its own power supply, it is energetically autonomous, same as Berkeley exoskeleton, Sarcos has advanced a hydraulically actuated exoskeleton conception. Rotary hydraulic actuators are used in the Sarcos exoskeleton as an alternative of linear hydraulic actuators.[7] The Sarcos exoskeleton gives structure supporting entire load of 84 kg, walking at 1.6 m/s while carrying 68 kg on the back and 23 kg on the arms, walking through 23 cm of mud, as well as twisting, squatting, and kneeling.[7]

#### 3.3.3 MIT Exoskeleton

The MIT exoskeleton take on a quasi-passive design without using any actuators.[7] Instead, exoskeleton uses energy stored in springs during the walking.[7] Based on an analysis of the human walking, quasi-passive elements were chosen in the exoskeleton.[7] The 3 DOF hip keeps a spring-loaded joint in the flexion/extension direction which stores energy during extension and releases during flexion.[7] In the flexion direction, the user can freely swing their hip due to spring mechanism.[7]

**Fig-7:** MIT exoskeleton

## 4. CONCLUSION

After reviewing the Active Orthosis, lower Extremity Exoskeleton, DARPA Program Exoskeletons, we conclude that servo motors can be used instead of brushless DC motor because its provide angular movements and inbuilt locking mechanism. low cost material like ABS (Acrylonitrile-Butadiene-Styrene) can be used, and cost of the whole lower limb exoskeleton system can be reduced.

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