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Active Soft Orthotic Ankle Foot (ASOAF) for Gate Pathologies: a Designing Approach

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ABSTRACT:
Ankle-foot orthoses (AFOs) are used by individuals suffers from neuromuskuloskeletal disorders to maintain proper and safe foot drop, in order to achieving a normal gait pattern, Current designs for AFOs provide sufficient support during walking but present stability issues during stair ascent/descent. Resulting compensatory gait patterns in individuals can cause imbalances and pain in other joints. The proposed study to design ASOAF that will provide the target patient with increased mobility, stability, and energy return during normal gait and when negotiating changes in elevation. Design concepts were generated to provide variable stiffness settings and to provide significant energy storage and return capabilities. A prototype of the concept selected was constructed and subsequently evaluated through gait analysis on a test subject while travelling up and down stairs with Redesigned AFO. Analysis of the gait data will shows that an individual's balance when ground walking and ascending/descending stairs. Gait testing with the prototype led to the conclusion that varying the stiffness properties of the hinged AFO with carbon fiber strut facilitates stability. In this paper our study focuses on the rehabilitation performance based on the ankle foot orthotic device. The proposed control system ASOAF consists of Input Module, Digital output module, motor driver, Microcontrollers, solenoid valves, artificial pneumatic muscles, Sensors and a DC motor.
Keywords - Pneumatic artificial muscles, Orthotics, Ankle foot orthosis (AFOs), Neuromuscular mode

I. INTRODUCTION

The ankle foot orthoses are intended to support the ankle with corrective deformities, and prevention from further injuries. Orthotic treatment is the most common method for the foot-drop cases. Since the early 1980's, the idea of an actively powered orthotic device has been explored by using a hydraulic and pneumatic device. In patients, Rehabilitation with neuromuscular disorders such as spinal cord injury (SCI), hemiplegia, cerebral palsy (CP), multiple sclerosis (MS) [1],[2], and muscular dystrophy may create compensatory gait pattern in the patients, and interventions as a physical therapy and bracing with ankle-foot orthotic device (AFOD) helps to normalize the gait pattern. As we consider dropping foot one example. Which due to the damage of the long nerves of brain or spinal cord, the lower leg anterior muscles become weaker when the muscles are become stiffer on the posterior side? Thus the dropping foot in swing phases causing toe strikes instead of heel strikes, which sometimes results in trip and fall. The alternative for drop foot using ankle-foot orthotic device (AFOD) has the potential not only for preventing the development of abnormal gaits over time but also for providing immediate assistance in walking.

Ankle-Foot Orthoses (AFO) braces worn on the lower leg supporting the ankle and foot holding them in the proper alignment with the correct foot drop. AFOs can be rigid or have a hinge at the angle joint depending on the degree of ankle mobility that is required. They are used by children and youth who have medical conditions such as cerebral palsy or spinal bifida, and by adults who have neuromusculoskeletal conditions [3]. This thesis will focus on AFOs used by adults with multiple sclerosis or who have had a stroke.

The most commonly prescribed AFO is rigid and allows for very little dorsi- or plantar flexion, which in turn makes climbing stairs and walking over changes in elevation such as a curb very difficult. Often the individuals need to significantly change their walking patterns to accommodate for the constraints induced by the orthosis. Such changes increase the stress in other joints such as the knees, hips and back, resulting in further pain and discomfort [4]. There is an increasing interest in developing a low-cost AFO which provides adequate stability for ground walking while accommodating for changes in surface elevation, thus facilitating community mobility. The specific goals included:

- Determining the design specifications for ankle-foot orthoses for adults with multiple sclerosis or hemiplegia
- Assessing the current limitations of existing AFOs
- Redesigning the AFO to meet design specifications for the specific Neuromusculoskeletal conditions while accommodating for changes in elevation
- Performing a Finite Element Analysis (FEA) on the redesigned AFO model
- Constructing a prototype of the redesigned AFO
- Performing gait analysis on an able-bodied individual in order to assess the AFO redesign, making recommendations for future work.

II. REVIEW OF THE LITERATURE

The control strategies and the assessment of mechanical concepts actuated by the pleated pneumatic artificial muscles is the proof for the active knee rehabilitation. The special attention is given towards fitting and the concept of adjustability. The proposed experimental setup was used for young adults and elderly people. The EMG signals were used to measure the muscles physiological changes. [4].The primary objective of an ankle-foot orthosis is to restore the rehabilitation function of the amputated knee and ankle joints. These benefits should reduce back and hip pain and should improve mobility to afford the patient a healthier life [4],[5]. By adding the compliant joints and segmented foot to bio- inspired below-knee exoskeleton prevents the human normal walking gaits. A below knee exoskeleton prototype with ankle and toe joints driven by two series-elastic actuators [6].The two experiments are conducted to (1) to show the influence of toes by comparing walking with an without AFO, and (2) clarify the functions of toe during walking by correlating activity of the major muscles controlling the ankle and the toes to shoe sole pressure data during walking. These two experimental results analyze the necessary components and conditions of an ankle-foot model for developing an AFOD [7]. The functional performance of AFOD has been quantified with time and distance measures, such as step length, stride length, walking velocity, cadence, and cycle timing. Time and distance measures along with leg joint kinematic and kinetics are used for quantify portable powered ankle-foot orthosis performance. The straight design requirements of small size, light weight, high efficiency and low noise make the creation of a daily wear assist devices challenging. The author uses the PPAFO, in which carbon composite shank and foot pieces, which actuated by a rotary actuator at the ankle joint powered by portable pneumatic power supply. The device provides and assistance in three regions determined by functional gait requirements: (1) dorsiflexior to prevent foot slap during loading response by foot motion controlling, (2) plantar flexor torque, which is used to provide assistance for propulsion during stance, and (3) dorsiflexior torque to prevent foot drop by maintaining toe clearance while walking. [8].

The microcontroller based realization of gait speed estimation for electronic above knee prostheses was presented by K. Akdogan, A. Yilmaz *et al* presented a low cost system for two dimensional gait analysis in the sagittal plane have been equipped for testing the performances prosthesis and developing the control unit sensing the user intentions and various control conditions. Due to low cost and 'easy to use' structures for prosthesis a gyroscope and accelerometer among standard sensors were selected. For these two sensors the speed estimation algorithms are develops and they uses in microcontroller based control unit of artificial knee [9].

The experimental evolution of a Portable Powered Ankle- Foot Orthosis (PRAFO) proposed by K. Shorter, Y. Li. *et al* which provide both plantarflexor and dorsiflexor torque assistance through a bi-directional pneumatic rotary actuator. The complete system uses an embedded electronics and a portable pneumatic power source (bottle of compressed CO_2) to control foot action during walking. In this study, the PRAFO is used not only to provide functional assistance to control the foot during stance and swing but also measures time and distance along with leg joint to improve the PRAFO performance. The proposed system is lightweight, compact and is capable of providing untethered functional assistance for impaired walkers. The additional DOFs and Sensors for Bio-Inspired Locomotion system is proposed by D. Kuehn, F. Grimminger *et* al which contributes towards the ankle joints[10], active spine and feet for a quadruped robot. The proposed system should effectively improve the mobility and locomotion with the design of biologically inspired structural components. The system completed with the 49 pressure sensors, a 6 DFOs force/torque sensor, absolute position sensor as well as temperature and distance sensors which allow the precise perception of the environment [10]. According to M. Eilenberg, H. Geyer *et al* was proposed a new system which is useful to control of a powered ankle-foot prosthesis based on neuromuscular model utilizes lightweight and passive structure that are designed to present appropriate elasticity during the stance phase of walking[7],[11]. To provide control the advanced composites used in that device permit some energy storage during controlled dorsiflexion and plantar flexion, and subsequent energy release during powered plantar flexion, in the intact human. They also studied the highlights the importance of neuromuscular controller for enhancing the adaptiveness of powered prosthetic devices across varied terrain surface[12].

To understand the neuromuscular control strategies involved in gait, it is necessary to understand the gait cycle, recognised as the fundamental unit of gait, is often studied Within the gait cycle, two distinct phases may be identified: 1) the stance phase, and 2) the swing phase (see Figure 2.1). Stance phase begins when the reference foot contacts the floor (heel contact) and ends when the reference foot lifts off the ground (toe off). Stance phase is typically 60% of the normal adult gait cycle. The swing phase begins when the reference foot lifts off the ground and ends when the reference foot contacts the floor. This phase typically occupies 40% of the normal adult gait cycle[13].

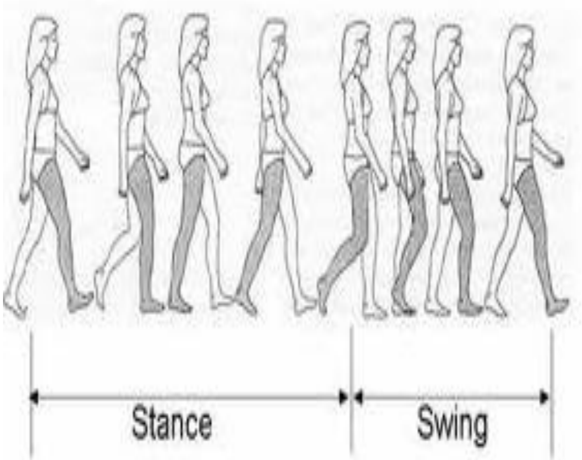

Fig.1. Gait Cycle for Stance and Swing Phases

Above fig. shows that the experimental result includes periods of initial contact to foot that don't correlate with the walking speed. In addition the patients having a dysfunction of the ankle, means that the patients suffering from polio or peripheral nerve palsy, have more difficulties in controlling their ankle movements (shown fig.2).The ankle joint is a hinge that allows the foot to move up (dorsiflexion $10\text{-}30^0$) and down (plantar flexion $20\text{-}30^0$)[14]. The ankle joint is a synovial joint, meaning that it is enclosed in a joint capsule that contains a lubricant called synovial fluid.

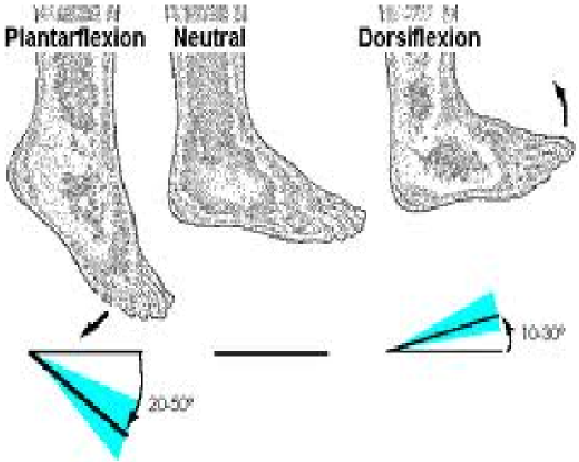

Fig.2. Dorsiflexion and plantar flexion of ankle joint

Anterior impingement may feel like ankle pain that continues long after an ankle strain. The ankle joint sometimes may feel weak, like it can't be trusted to hold steady during routine activities. Even when anterior impingement comes from ligament irritation, tissue thickening and pain are usually felt in front and slightly to the side of the ankle. This is the area of the AFTL. The pain worsens as the foot is forced upward into dorsiflexion. If the ligaments have irritated are synoviam of the ankle joint capsule, swelling and throbbing pain from inflammation (synovitis) may also be felt in this area.

This causes "drop foot" or a lack of dorsiflexion of the ankle during the swing phase. Sometimes such patients are unable to prevent themselves from catching their toes on the ground and stumbling, even when taking small steps. In other way, these patients tend to incline their bodies more than do healthy persons because of the motion required to prevent stumbling.

III. DESIGN APPROACH

In this paper we propose an autonomous adaptive device for actuation, data acquisition and control of an active ankle-foot orthosis during normal level walking using the tactile sensors and the monitoring system for gait analysis. The device is used to help or rehabilitate persons with control disorders and weaknesses of the ankle foot complex.

The complete autonomous system consists of four primary components– sensing, data acquisition, communication and friendly oriented software for interpretation of the data.

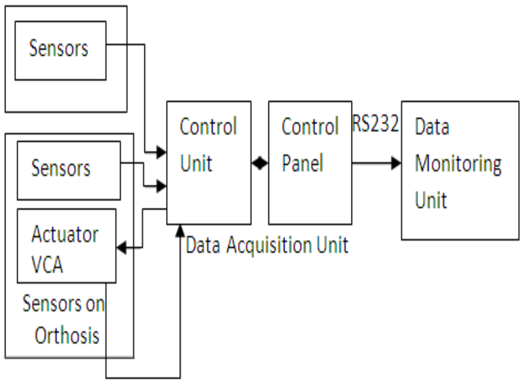

Fig.3.Autonomous control and monitoring system with active ankle-foot orthoses

The sensor system is mounted into two basic components: insole for the healthy leg and ankle-foot orthoses. The acquisition unit gathers and digitizes the information from the sensors during the walking. That data is transferred through the RS-232 lines to a monitoring data unit for visualization and interpretation in monitoring mode.

IV. SYSTEM OVERVIEW

4.1 Sensors:

As the basic idea of this project is to develop active ankle foot orthosis. To achieve and build this system, accurate signals for the gait cycle and human walking should be measured in order to use these signals to operate the actuating system. And to choose the most suitable sensors, which can measure all gait cycle cases, several options are available such as: Force sensors and Pressure sensors, which have been used before in previous projects. Below, is the description of the procedures used to choose sensor type in this project.

4.1.1 Sensor Selection:

The general criteria to choose any type of sensor for an application are as follows:

Range: The sensor should be able to measure the full-scale range of the event. Sufficient margin should remain at the upper end of the range so the measured event should not exceed the range of the sensor and cause damage.

Frequency response: The frequency response of the sensor is the range of frequencies over which the sensor gives an accurate response. It should be able to measure the full range of frequencies expected from the experiment.

Sensitivity: The sensitivity of the sensor is defined as the ratio of the change in sensor output to a change in the input to be measured.

Accuracy: Accuracy refers to how close the output of sensor is to the actual event. Environmental conditions; such as temperature, humidity, water and other should be considered while choosing a sensor.

Cost: The cost of a sensor is an important factor and depends on the standard of the project.

4.1.2 Sensor used in AFO:

Force Sensors:

As its name implies, force sensors are used to measure the force. Depending on its application, it can also be used to measure the weight or mass. Force sensors can be integrated into an orthosis or prosthesis to measure ankle/wrist forces, moments and loads. It can also be used in gait analysis to measure ground reaction forces and loads exerted by a strap or pad in an orthosis.

Pressure Sensors:

To measure pressure, an electrical signal must be generated in response to a pressure input. Pressure is measured either by deflect or strain. This strain can then be measured in a variety of ways, using capacitive, PR and PE as well as other techniques to measure displacement. The use of these sensors was limited, due to there size, same as the force sensors, non linearity signals , which need some signals analysis before it will be entered into the control system. And the use of this sensor in foot orthosis will be limited for measuring some points under the foot, which maybe changed from one foot to another.

4.1.3 Strain Gauge Sensors:

These sensors normally used to measure the stress or strain in materials depends on their amount of bending due to applied force. So this bending will be proportional to the change in sensor resistance, and voltage value applied.

4.2 Control Circuit:

The sensors signals will be transferred to the control kit Which consist of a PIC Microcontroller, analog and digital input/output ports, power supply.

All these components; circuits, amplifying and filtering circuits, Microcontroller kit and power supply for electronic circuits and MR damper will be mounted inside one box on the foot orthosis. The patient will wear the foot orthosis and be able to walk with it anywhere[15].

4.3 Data Monitoring Unit:

In Data Monitoring Unit, receives all the data from the sensors and provide the appropriate signaling to the required action to be happened.

V. CONCLUSION

In this paper, we studied the different existing system approaches in order to provide the human gait assistance focuses on the ankle-foot joints. The various techniques were used to improve locomotion and mobility while dropping the foot. Some of the existing techniques are inexpensive but having much bulky and not surely specified the restricting angle while sitting. The system overview shows that the various components in the ASOAF used.

In order to overcome the above disabilities or orthotic design, we want develop a system which is more comfortable without restricting angle while sitting. The prototype will be flexible and awareness with the gait pathologies disorders by using different types of sensors. The results of the system is in the process, here we just placed the design approach for the ASOAF system.

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