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Adaptive Dorsiflexion and Plantar flexion in Active Ankle Foot Orthosis

Sumitkumar V. Dhule[1], V. V. Shete[2], Sunil B. Somani[3]

Student, Department of VLSI and Embedded, MITCOE, Pune, India [1]

Professor, Department of VLSI and Embedded, MITCOE, Pune, India [2, 3]

Abstract: Impairments of Ankle foot is caused by spinal cord injuries, multiple sclerosis, cerebral palsy, and polio. Foot slap and foot drag during swing movement of leg are the problem faced during gait. To support such ankle foot impairments orthotic devices are used to achieve the proper gait movements. Currently there are Ankle Foot Orthosis (AFO) which provide assistance for gait which are majorly of passive type. Active AFO is current trend of research. There are many Active AFOs which are recently developed which provide fix dorsiflexion and plantar flexion movement. This paper propose methodology to achieve adaptive dorsiflexion and planter flexion movement of impaired ankle foot depending upon the healthy ankle foot movements.

Keywords: Adaptive Dorsiflexion, Planter flexion, Active Ankle Foot Orthosis, untethered.

I. INTRODUCTION

Walking is a basic need of one's daily routine and it affects the quality of living. Gait cycle of human is symmetric and requires coordination in muscle movements. The ability to walk is impaired by numerous neurological and muscular pathologies or because of injuries. These include trauma, spinal cord injuries, polio, stroke, muscular dystrophies, multiple sclerosis, and cerebral palsy. AFO is used to treat the impairment of subjects with neurological pathology and also used for rehabilitation aid for ankle injuries in accidents.

Due the ankle impairment caused by the various reasons subject is unable to perform the dorsi flexion and planter flexion movements, so an orthotic device supports the movements of the ankle joint. Foot slap and foot drag is the problem faced by the subject due to the weak Doris and planter muscle of the ankle foot. Human gait cycle is symmetric, each joint and limb segment goes in cyclic pattern of movements. Two major part of gait are stance and swing phase. Ankle joint and muscles plays part in normal gait, so impairment of ankle affects total gait. An abnormal gait leads to energy loss during walking. Due to the impairment and abnormal gait, most the subject faces problem of low self-esteem and lack of confidence. AFOs are classified in passive AFO and active AFO. Currently there are no active AFOs which can provide efficient and commercial solution for providing Doris flexion and Planter flexion movements of impaired ankle joint.

II. BACKGROUND

Many researches has been carried out in design of active AFO. Kanthi et al. [1] proposed system design which can aid plantar flexion and dorsiflexion movements. To control the position of the actuator microcontroller is used. Force resistive Sensor (FSR) is used to measure the forces during the gait. According to output obtained by the sensors, microcontroller generates the pulse width modulation signals to control the servo motor. The soles of orthotic device and a healthy leg consist FSR sensors. During each gait cycle the microcontroller executes the algorithm using that the actuator controls the motion of ankle joint. Solution proposed by the author provides 20 degree of dorsiflexion and planter flexion movements, which is considered to be a drawback there is no intelligence involved in calculation of these angle. Developed system has performance limitations since algorithm based on threshold values for event detection.

Kenneth Alex Shorter et al. [2, 3] over viewed the biomechanics of gait, existing active and passive AFO devices, and discusses the key enabling technologies required to meet this challenging human scale application. Various passive, semi-active and active AFOs are reviewed by the author and fair comparison is made among all existing AFOs. Some of the active AFO discussed by the authors are Osaka University AFO, Halstead University AFO, MIT Active AFO, Arizona State Robotic Tendon AFO, Bionic Walk Aide, and NESS L300. All discussed cases are bulky in nature and not capable of providing dynamic dorsiflexion and planter flexion function.

Peng Zhang et al. [4] proposed a solution using Planter Pressure Sensor , which contains novel design of active AFO for hemiplegic and amyotrophic patients, proposed mechanical design and mainly analyze mechanism design of device and made simulation on Solid works. In this design author used pressure sensors and acceleration sensors. The major drawback of this system is that the designs weigh 2240 g. Also this work does not quote about Doris flexion and planter flexion movements and its control angles.

Yong-Lae Park et al. [5] described the design of an active ankle foot orthotic device powered by pneumatic artificial muscles. The design is inspired by muscular structure human leg. Device is fabricated with flexible and soft materials. Developed device provide assistance in all possible freedom at the ankle joint. Assistance during dorsi flexion as well as inversion and aversion is possible due to

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three pneumatic artificial muscles. The AFO is equipped with various embedded sensors which help for gait pattern analysis and training. The drawback of system is that it relies on air source connection for pneumatic muscles so it does not allow complete untethered operation. Exiting work in Active AFO does not quote about dynamic dorsi lexion and planter flexion movements and its control angles [1-11].

Presently majority of ankle foot impairments are treated with passive AFO as Active AFOs are not able to provide power efficient and proper gait movements. Active AFO designed to treat the impairment is worn on the impaired foot only. Majority of Active AFO does not take reference gait from healthy foot, so dorsif lexion and planter flexion movements provided by such AFOs are questionable. As dorsi lexion and plantar flexion angle of human gait depends on walking speed and physical parameters of subject.

III.METHODOLOGY

Human gait cycle is symmetric, Doris flexion and plantar flexion movements produced during gait are synchronized. As shown in figure 1 each limb moves in cyclic movement. Using this principle we can mirror the movements of impaired ankle foot from the healthy ankle foot. Every gait cycle starts from heel strike and foot goes in swing phase as toe is off. So generally gait is divided in stance phase and swing phase. For a plane terrain the pressure on limbs during gait is symmetric. In daily life walking and staircase traversal are general task performed. Proposed methodology is able to achieve these goals. During gait ankle movements between the heel-strike and toe-off are very important as balancing of gait is depend on this movement and foot drag is also observed in this phase.

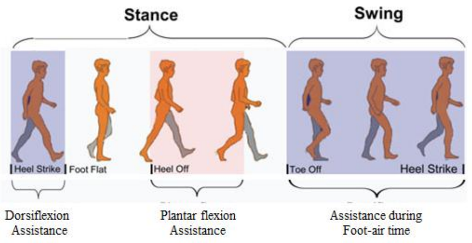

Fig.1: Human gait

A. Block Diagram

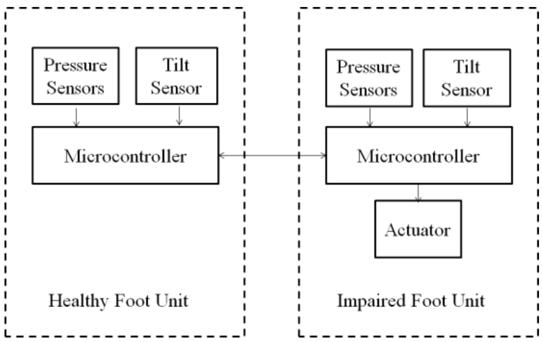

Fig.2: Block diagram

Proposed system consist of two units, one will be in healthy foot and other will be in impaired foot. Fig 2 shows the block diagram of system which is under devolvement. Both impaired foot and healthy foot will consist of pressure sensors and accelerometer for tilt sensing. Communication between both units will be established so that system will operate in close loop to achieve the accurate resulting gait.

B. Algorithm

Both healthy foot unit (HFU) and impaired foot unit (IFU) will be active during the gait. Pressure sensor and accelerometer will sense real-time readings. Gait starts with heel strike of healthy foot. Healthy foot continuously monitor the change in angle of ankle and respective change in pressure readings of healthy foot. When toe-off of healthy foot is reached then all data will be sent to the impaired foot. Data obtained from healthy foot is processed in impaired foot and actuator comes in action to drive ankle foot. At same time pressure and angle readings are monitored and sent to healthy foot for error correction for next gait cycle. Fig. 3 shows the generic flowchart of algorithm.

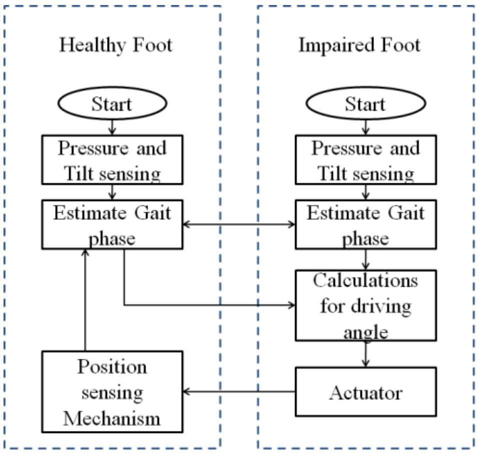

Fig.3: Generic flow chart of algorithm

C. Experimental Setup

To conduct the experimentation an embedded system is designed. Designed system is used for taking samples of gait. System consist of following hardware components.

Devolvement Board: For fast prototyping Arduino Mega 2560 is used. As it is AVR processor based processor having computational and functional capacity for required task. As it has three hardware serial ports the simultaneous communication with other unit and data analysis through serial port is possible. Both units consist of this devolvement board.

Pressure Sensors: Location of pressure sensor is in sole of the foot. As thin and small sized sensor requirement is full filled by Force Sensitive Resister (FSR). FSR has good resolution and it directly used to calculate the force by simple voltage division principle. Each unit consist of two pressure sensors.

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Bluetooth Devices: Communication between the both healthy and impaired foot should be wireless to provide complete untethered operation. So Bluetooth module HC-05 is used in both units. Both Bluetooth modules are paired and binded using AT commands, so as the units are powered on communication link will be established automatically.

Actuator: Ankle with impairment has to be driven by external force. For this purpose servo motor is used.

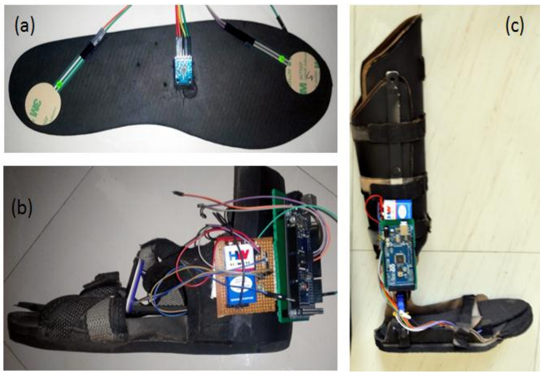

Fig.4: (a) Sensor locations (b) Healthy foot unit (c) Impaired foot unit

Accelerometers: For tilt angle calculation ADXL345 is used. It is very low power consuming and accurate sensor. Each unit has accelerometer mounted in sole.

Fig. 4 shows experimental and hardware setup. Both HFU and IFU are battery driven. For programming and data analysis open source Arduino IDE is used. MATLAB is used to perform the graphical analysis of the serial data obtained from Arduino development board.

IV. RESULTS AND DISCUSSION

Human gait has specific pattern which is repeated, graph of pressure at heel and toe for respective angle movements of the ankle foot are shown in Fig. 5. The experimentation is conducted on healthy male candidate with 181 cm height and 73 kg weight. From Fig. 5 can see that as heel is strikes the pressure on heel increases rapidly and same time pressure at toe is zero. As gait progress pressure at heel decreases gradually from peak and pressure at toe increases gradually. Before swing phase pressure at toe decreases rapidly and after that foot goes in swing phase where pressure on toe and heel are zero. Maximum pressure on heel and toe is approximately 143 N and 118 N respectively. Figure 5 shows 100 samples of gait from the heal strike, four gait cycles of healthy foot are considered in analysis. Each sample is taken after 60 ms. From heel-strike to toe-off it takes approximately 20 samples. In this 20 samples approximate ankle foot angle is 30º. Foot remains in air for 8 samples. During the first cycle total angle deviation including hip and knee flexion is 132º for discussed case. Data from HFU to IFU is transferred successfully; actuation of servo motor according to healthy foot is achieved.

By observing the gait waveforms of healthy foot, it is clear that calculation of driving angle must be done before the healthy foot toe-off is achieved. The angle changes between heel-strike and toe-off are the critical and must be driven accurately for impaired foot to achieve healthy gait of ankle foot impaired subject.

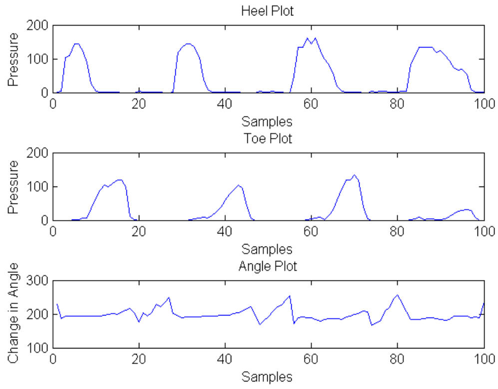

Fig.5: Foot pressure and respective angle movements

V. CONCLUSION

A novel algorithm is proposed for adaptive Doris flexion and plantar flexion movements of the ankle foot. From the healthy foot analysis ankle foot angle can be calculated to drive the impaired foot. In human gait dors flexion and plantar flexion angle are dependent on the gait speed and physical parameter of the subject. Adaptive change in ankle foot angle can be detected from the experimentation. Current work laid foundation for developing the adaptive active ankle foot orthosis. The measure performance parameters for this orthotic system are Doris and plantar angles, energy efficiency, torque during Doris and plantar movements and weight of the device. In future work a compact untethered active AFO is to be developed with adaptive dors flexion and plantar flexion, capable of forces comparable to healthy individuals.

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BIOGRAPHIES

Sumitkumar Vasudevrav Dhule received B.E. degree in Electronics and Telecommunication from Savitribai Phule University of Pune, India, in 2012. He currently pursuing M.E. degree in VLSI and Embedded Systems from MIT College of engineering, Pune. His area of interest are robotics and biomedical.

V. V. Shete is Head of Department of E&TC, MITCOE, Pune, affiliated to SFPU, Pune. He published numerous scientific papers in various domains. His areas of interest are soft computing, signal processing and communication.

S. B. Somani received the M.E. degree in Electronics and Telecommunication Engineering. He has been in the teaching field since last 20 years and specialized in areas such as Advance communication, Microwave engineering and Mobile communication. He is currently working professor at MIT College of Engineering, Pune, India.