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Acute Muscle Response Sensing Using SEMG Applied To Orthopedic Support Structures

Sidharth Ramachandran[1], R. Senthil Kumar[2], Yashovardhan Katare[3], Anirudh Anupam[4] & Praveen Kumar K[5]

[1,2,3,4,5] *SRM University, Kattankulathur, Chennai-603203, Tamil Nadu, India.*

Abstract

Foot drop is a neurological problem, which makes the muscles in the foot become weak. This atrophy of the muscles causes the foot to "drop" i.e. fall when walking. The aim of the project is to design, analyse and to fabricate a device which will help patients having this disease, by providing Dorsiflexion based on gait cycle time. The device is to be automated. The project involves analysing the walking gait of the patient and designing a control timing based on the gait. The device will be proto-typed for a standard leg of size "Nine" the World standards of adult human. The scope of the project is to allow the patients to move and walk normally and to provide a degree of comfort for the patients. The device will rise above the existing rigid solutions, which constricts the walking of the users.

Keywords: Peroneal nerve injury, gait cycle, dorsi-flexion, electromygraphy, noise reduction, pattern recognization.

INTRODUCTION

Also known as Foot Drop or drop foot is a condition which causes the patients suffering from it, difficulty to lift the foot above the ground. This is due to the weakening of the muscles known as "Dorsiflexor" the muscle responsible for allowing the ankle to flex upwards.The cause of this problem is mostly neurological in nature. A patient acquires this syndrome when he either gets a brain-injury or a stroke or an ankle injury cutting the nerves to the Dorsiflexor. Due to the above reasons the electrical impulse to the leg via the nerves is either very low or is completely stopped. Hence the actuation of these muscles is stopped. Hence the actuation of the foot is stopped.

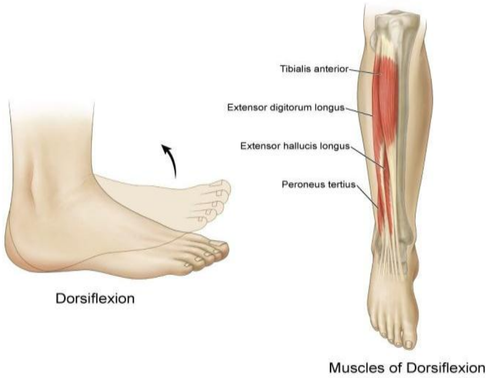

Figure 1.1: Muscles involved in dorsiflexion

This shows the muscles involved in Dorsiflexion. The most important muscle involved in dorsiflexion is the Tibialis Anterior Muscle. All the muscles end in what is known as “Tendons”. The tendons are fibrous tissue that usually connects a muscle to the bone.

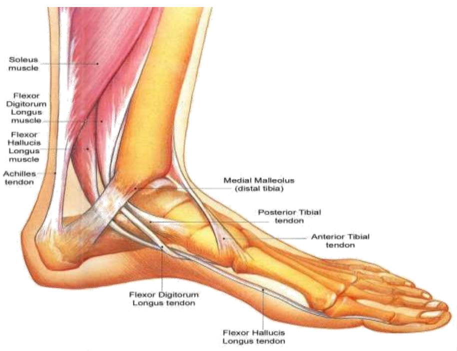

Figure 1.2: Bisectional view of the foot:

In this figure, we can see the bisectional view of the foot and where the anterior tibia pulls up the foot and follows it up with the relaxing movement.

BIOMECHANICS OF THE HUMAN FOOT

A. Gait

The walking cycle consists of only two movements namely Dorsiflexion and Plantar Flexion explained previously.

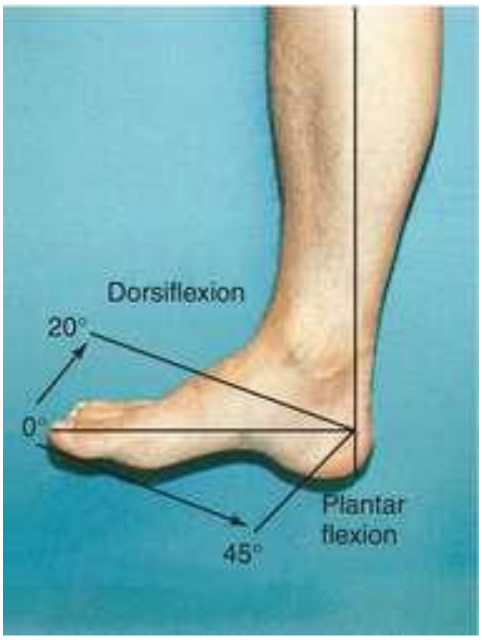

Figure 1.3: Angle involved in dorsi and plantar flexions

The above figure 1.3 shows the angle measurement of the range in which plantar flexion occurs and the range associated with dorsiflexion.

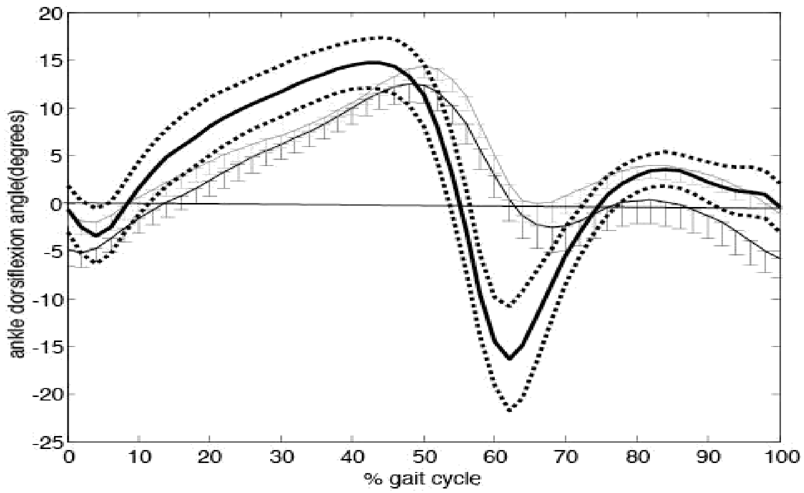

Figure 1.4 Graph plotting the Angle of Dorsi and Plantar flexions while walking

While walking it has been established that the Dorsi flexion angle is between the range of 10.2 to 13.35 Degrees and Plantar Flexion has an angle motion range of -6.35to -8.6 Degrees. All the angles have been mentioned with reference to the ground.

The figure 1.4 shows angle involved in the various stages of the walking cycle for 12 patients. The black-line shows the mean and the dotted lines show the range.

The biomechanics and the angles associated is an important part to measure the correctness of the setup. If the device achieves actuation in the said range then an important criterion has been met.

The term “Gait” refers to the pattern of movement of the legs of a human being when he walks on a solid surface. The most commonly used gait is the “Walk Gait”. The typical steps involved in a Walk-Gait are:

Lift one leg off of the ground ;Using the leg in contact with the ground, push your body forward ;Swing your lifted leg forward until it is in front of your body ;Fall forward to allow your lifted leg to contact the ground.

Foot drop condition will bring about alterations into a person’s walking gait. The Foot-drop syndrome causes the foot to scrape the floor when walking. To prevent this, a patient may lift the leg above the hip with a rolling action, similar to one’s gait on a staircase. This gait is called as a “Steppage Gait”. Or another common action is to swing out the leg across the body at an angle and this gait is known as “Swing-out Gait”. By performing these altered gaits, the patient gets the required clearance that they require to prevent the leg from hitting the floor.

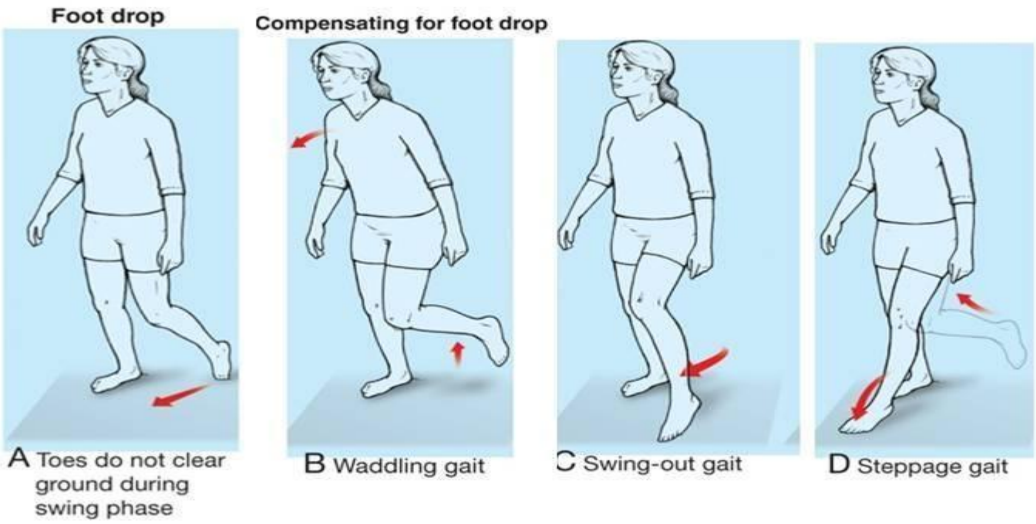

Figure 1.6: Compensation gait for foot-drop affected patients: The figure above represents the abnormality of the inability of the patient in question follow a normal gait but having the difficulty to put up any kind of motion against gravity but has to use the motion and momentum from the previous step to carry out one step.

B. Proposed solution

By means of using a muscle sensor (SEMG module), Arduino Uno and servo motors in combination with each other, we can emulate the human walking gait even in situations where the patient's muscular response may not be good enough to initiate movement by themselves. This enhances the patient's movements and hence enabling them to flex dorsally, have a better walking gait, and help them with their "rise" phase against gravity in the gait cycle.

SURFACE ELECTROMYOGRAPHY

Surface Electromyography Signal (SEMG) is the bioelectric signal which sent by the neuromuscular activities from the surface of the body, recorded by an electrode on the surface of skeletal muscles. It reflects the functional status of nerves and muscles. Muscle action mode recognition is a critical feature in the application of surface electromyography signal in servo motor initiation or any other impulsive interaction to initiate any other device. With the development of research on neural network, a lot of recognition methods on the shin and ankle action based on neural network have been proposed by experts in India and abroad. Electromyography is a relatively easy method, that can be carried out relatively fast and the results are consistent, measurable and more than one muscle and can be analyzed at the same time.

A. Structure of Skeletal Muscles

The skeletal or striated muscles are responsible for the locomotion of the body and are very integral. Muscles are anchored to the bones by connective tissue called tendons. The outer sheath of the muscles is called epimysium and contains the fascicles.

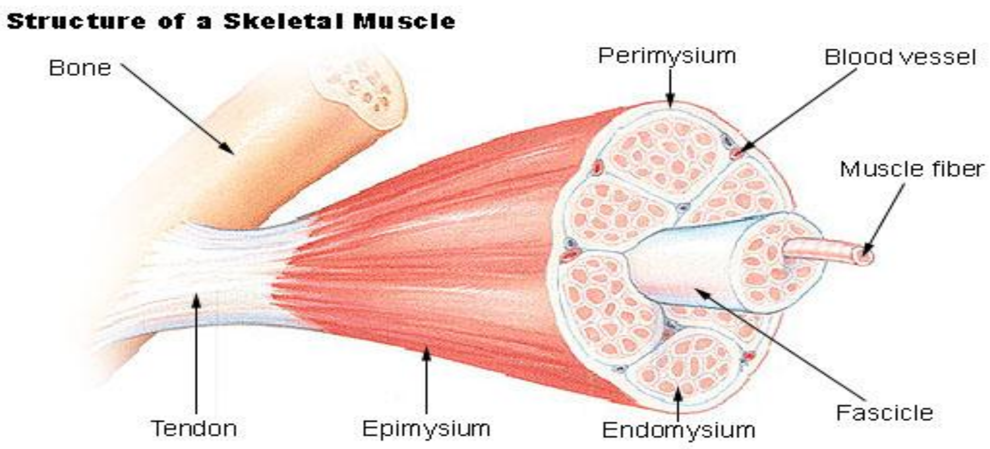

Figure 1.6: Structure of the skeletal muscle.

Fascicles are a bundle of muscle fibers bounded together by the connective tissue perimysium. Muscle fibers are surrounded by endomysium : they are the muscle cells with loss of nuclei. These muscle cells contain myofibrils which are further divulged into sarcomeres. These sarcomeres are composed of actin and myosin, which are myofilaments responsible for the contraction of muscles. There are two types of muscle fibers: type I red and type II white fibers. Type I fibers contain more myoglobin, their contraction is slower compared to type II fibers, hence the contraction holds on for a longer period. Type II muscle fibers fatigue rapidly but they are stronger than type I fibers. Type II muscle fibers can be classified into two sub groups: type II a and type II b.

There are two types of proprioceptive sensory receptors in the skeletal muscle: muscle spindles and Golgi tendon organs. Muscle spindles are located in the belly of the muscle and detect changes in the length of the muscle. They play an important role in the stretch reflex. Golgi tendon organs can be found in the tendons near at the beginning of the muscles and are an important part of the tendon reflex.

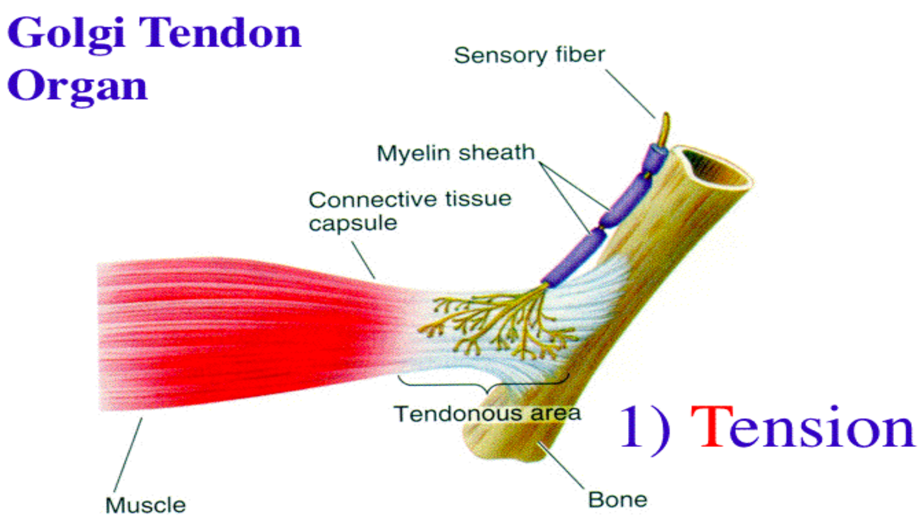

Figure 1.7: Golgi tendon organ.

B. Motor Unit

The motor unit is the smallest functional unit of the neuromuscular system and can be conciously activated.

The parts of the motor unit include the motor neuron in the ventral horn of the spinal cord, the axon of the motor neuron in the peripheral nerve and the muscle fibers innervated by the axon terminals of the motor neuron.

The size of the motor units may also vary within the same muscle. Small motor units are activated in the begining when some movements are performed, the bigger motor units are then activated at larger voluntary effort. This phenomenon is called the Henneman's size principle. The muscle fibers of the same motor unit contract more or less at the same time. A slight a synchronicity can be observed due to the different length of the axon collaterals of the motor neuron, hence the action potential reaches the muscle fibers indifferent time delays

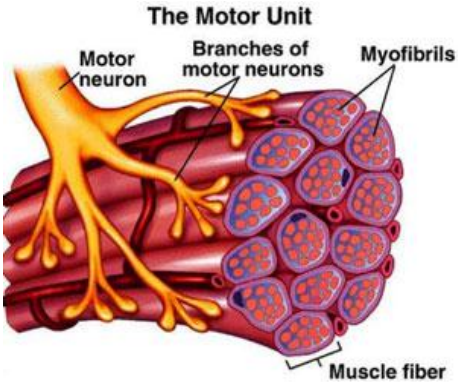

Figure 1.8: The motor unit and the neural connectivity.

C. Feature extraction

Here, the feature extraction is done by wavelet analysis. Wavelet analysis is a frequency-time based technique that involves a high dimensional feature vector. Due to this factor, the number of parameters involved for this method is larger and hence selecting an appropriate dimensionality technique is essential in order to get a proper output or rather the required range of output. The main advantage of the wavelet transforms is generation of the useful subset of the frequency components of the signal under scrutiny.

Wavelet transform method is divided into two types: discrete wavelets transform and continuous Wavelet transforms. Generally, discrete wavelet transform is used for the analysis of discretized EMG data. The discrete wavelet transform, transforms the EMG signal with a compatible wavelet base function. In this the original EMG signal is passed through a low-pass filter and a high-pass filter to obtain the approximation coefficient and a detailed coefficient subset at the first level. In order to obtain multiple-resolution subsets, repeated transformation is performed. This process is repeated until the desired final level is obtained. These coefficients works as the features of the EMG signal.

INTEGRATION

Having understood about the concepts of SEMG and a reasonable understanding of how the muscle anatomy works, their integration would seem a lot more simpler to understand as it involves the synchronization of the muscle response i.e., the feature extracted and the servo motors that control the dorsiflexion of the foot in the device.

A. Arduino Uno and Control

Arduino Uno is an open source device that provides a creative platform for various purposes ranging from automation of robots and pneumatics to working on Ethernet shields and advanced system control designs. The Arduino’s versatility is commendable and will work as our control unit in this case.

The feature extracted by means of a surface electrode is taken to the Arduino and processed upon as it’s wavelets are accordingly pulse width modulated depending upon the intensity of the incoming signal i.e. the amplitude of the signal and hence the degree of rotation of the servo motor is controlled by this intensity of the incoming signal.

The Arduino acts as the intermediate between the motion and the actuator. This control center is very important and is coded to facilitate the corrective range of motion as per requirement to help the patients improve their gait when they walk .

B. Muscle sensor

As described earlier, the muscle sensor `collects or extracts the key feature for the process to be initiated and hence is the input device that rigs up the muscle response however weak it may be and hence enabling the patient to have movement.

Surface electrodes are made from silver/silver chloride or tin/tin lead alloy. These type of electrodes are 1-6 mm in diameter. They are used when we want to record motor units that discharge synchronously. They are useless when we want to estimate the shape and duration of single MU potentials or analyzing muscles in deeper regions. In addition, the high frequency signals are lost due to the high resistance of the tissue between the skin and the electrode.

C. Servo motors

The servo motors here are our choice of motors in use as they provide a better resolution when it comes to step angle and hence the closeness to the actual foot flexion is achieved.

Although stepper or reluctance motors can be implemented, the supporting structures to facilitate the motion or rather rotation of these motors is more than what the servo motor can manage with and also, mounting the servo motor is a lot more simpler and sits well in line with the foot and does not allow it to drop.

The servos are placed on either side of the ankle at a specific angle based on the patient's foot dimension and extent of dystrophy. The weight of the foot of the average human is about a kilo to 1.5 kilos and the torque required would be somewhere along the lines of 2-3 N/m^2. The TowerPro servos that we're using in this case have a torque of 13 newton per meter square. Hence, the force against gravity is also overcome efficiently.

CONCLUSION

From what we have devised we can conclude that a more precise and a lighter solution for muscular dystrophy ort the inability of the muscle fibers to communicate with the motor unit can be effectively reduced to a great extent my means of this method through which we extracted the feature response to activate the servos and hence controlling the motion and allowing the patient the ease of dorsiflexion. The preexisting solutions provide pre-installed solutions to the problem whereas in this case, the patient is allowed the ease and magnitude of flexion based on the response of his/her own muscle fibers and how they contract and relax.

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