Chapter 3

Bio Signal Based Control
Design for Active AFO

3.1 INTRODUCTION

Biomechanics of human movement can be defined as the inter-discipline which describes analyses and assesses human movement [35]. To design the control system for active AFO, it is very much necessary to understand the ankle joint movements in the different phases of the gait. In most of the active AFO developments [32] one out of the following alternatives is chosen (a) The desired motions are recognized by force sensors between the human and mechanical construction (b) Bio signal are taken directly from the subject

Skeletal muscles are the active force generators, called as actuators within the locomotor system. The electrophysiological process of stimulation and contraction of skeletal muscles can be taken as being the transformation of information contained in a train of electrical impulses. The electrical processes of propagation of the action potential in a neuron and then in muscle fiber leads to the realization of a muscle twitch with a few milliseconds (latency time). A twitch is the time change of isometric force [36].

Electromyography (EMG) is a technique of acquiring and recording electrical activity generated by muscles. Electrical activity is due to functional variations in muscle fiber membranes [26, 27]. The EMG signal is widely used as a suitable means to have access to the
physiological processes involved in producing joint movements. The information extracted from the EMG signal can be used to control rehabilitation devices or to study the biomechanics and motor control of musculoskeletal system during different movements of the upper and lower extremities. In the case of biomechanical research, important information about the natural and pathological functioning of the neuromuscular system can be obtained in order to assess posture and movements in able-bodied and disabled persons. To detect the muscle contraction levels the raw EMG is compared with the fixed threshold.

With EMG signal it is possible to track the intended movement even in the presence of obstacles or lack of sufficient muscle power. If the EMG sensors are placed carefully on the subject, the intension will be available ahead of time. The reason for this is that EMG signals are detectable slightly before the actual movement is performed, because muscles take some time to produce the force after having received the activation signal [36, 37]. EMG records differ between individuals, and differ for a single individual according to variables such as walking velocity.

This chapter discuss about the study of muscle activity for the ankle foot joint movement using sEMG signals. The EMG amplifier circuit is designed using instrumentation amplifier and filters. The real time control of active AFO using compact Reconfigurable Input Output (cRIO) system is presented in this chapter.

3.2 STUDY OF MUSCLE ACTIVITY USING SURFACE ELECTROMYOGRAPHY

3.2.1 Design of EMG Amplifier circuit

The preferred method of amplification of EMG signal is differential amplifier using a bipolar electrode and instrumentation amplifier. The main specification that must be considered while selecting an instrumentation amplifier for this task is its common mode rejection ratio (CMRR). When the input signals are subtracted and the difference amplified, there is a residual signal amplified that is common to both inputs. The CMRR, represented in dB, is the measure of the ratio of the amplified signal to the amount of amplification of the signal common to the inputs. In the case of EMG amplification the common signal is most commonly noise so this specification plays a critical role in acquiring an accurate signal. A
reference electrode is used to create a common body reference signal which will increase the amplifiers ability to remove the unwanted commonalities of the inputs. The designed EMG amplifier circuit design and circuit are shown in Figure 3.1 and Figure 3.2 respectively. The corresponding gain calculations are shown in Table 3.1.

**TABLE 3.1 EMG AMPLIFIER GAIN CALCULATIONS**

<table>
<thead>
<tr>
<th>Instrumentation Amplifier</th>
<th>Band Pass Filter</th>
<th>Variable Gain Amplifier</th>
<th>Overall gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_g = 575 , \Omega )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_1 = 1 + \left( \frac{50K\Omega}{R_g} \right) )</td>
<td>( R_1 = 330 \Omega )</td>
<td>( R_4 = 100 , \Omega )</td>
<td>( A_1 \times A_2 \times A_3 )</td>
</tr>
<tr>
<td>( = 87.99 )</td>
<td>( R_2 = 1.77K\Omega )</td>
<td>( R_5 = 2.45K , \Omega )</td>
<td>( = 88 \times 5.36 \times 24.5 )</td>
</tr>
<tr>
<td></td>
<td>( A_2 = -\frac{R_2}{R_1} )</td>
<td>( A_3 = -\frac{R_5}{R_4} )</td>
<td>( = 11.56K )</td>
</tr>
<tr>
<td></td>
<td>( = -5.36 )</td>
<td>( = -24.5 )</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.1 EMG amplifier circuit design

**Instrumentation amplifier**

An instrumentation amplifier is a type of differential amplifier that has been outfitted with input buffers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional
characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high CMRR, and very high input impedances. Instrumentation amplifiers are used where great accuracy and stability of the circuit both short- and long-term are required. INA 128 is used as an instrumentation amplifier. It offers a CMRR of 120dB at G ≥ 100. It operates with power supplies as low as ± 2.25 V and quiescent current is only 700 µA.

**Band-pass filter**

An active filter is a network composed of resistors and capacitors built around an op-amp. Here we design a band pass filter to ideally extract the EMG signal from the range of 10Hz to 900Hz. A band pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside the range. The bandwidth of the filter is simply the difference between the upper and lower cut-off frequencies. The lower and upper frequencies are given by the expression shown below. The band pass filter used in this project has the calculated lower cut-off frequencies of 21.9Hz and upper cut-off frequencies of 899Hz.

\[
\omega_L = \frac{1}{R_1C_1} \quad \omega_H = \frac{1}{R_2C_2}
\]

R1= 330Ω, R2=1.77KΩ, C1=22µF, C2=0.1 µF

**Variable gain amplifier**

After the initial amplification and filtering stage the signal is amplified further. Further amplification is needed due to the small magnitude of the signal being acquired. The signal can be in the microvolt range so an amplification of 10k or more is in the desired range. Operational amplifier can be made variable gain amplifier simply by using a potentiometer on the output of a fixed gain op-amp circuit. Here the gain is given as= - (R4*R5)/R3. The output can be further varied by using the 4.7kΩ pot. On increasing the 4.7kΩ pot the analog output also increases and on decessing the output decreases.
3.2.2 EMG signal for planataflexion and dorsiflexion movements

In this study, EMG is taken while normal walking from the gastronemious (GA) and tibialis anterior (TA) muscles which are bulky and surface electrodes can detect the muscle activity easily [2, 12, 29, 30]. Figure 3.3 shows the placement of electrodes on these muscles to extract the signal. Silver chloride (AgCl) electrodes were used to extract the signal. The reference electrode is placed on the bony area where it is not influenced by the muscle signal. The EMG signals of respective muscles are shown in Figure 3.4 and Figure 3.5. The x axis gives the number of samples per second (1800 samples/sec) and y axis is the amplitude of the signal in volts after amplification. The EMG signal amplifier is designed for 900 Hz. The signal is then rectified and filtered to get the useful information [26]. The average feature is computed for a subject both online and offline. Hence, feature set is taken for multiple subjects to find the average value which can be used to control the orthosis.
Figure 3.4 (a) Raw and (b) filtered EMG from gastrocnemius muscle

Figure 3.5 (a) Raw and (b) filtered EMG from Tibialis anterior muscle

Figure 3.6 (a) shows the rectified and filtered EMG of the subject’s plantarflexion movement. GA muscle is responsible for plantar flexion movement. When subject is asked to performs plantar flexion movement, the EMG is obtained at GA muscle and there is no signal
from TA muscle. When dorsiflexion movement is performed, EMG of TA resulted and no signal from GA, as TA is the responsible muscle for dorsiflexion movement. Figure 3.6 (b) shows the rectified and filtered EMG of the subject’s dorsiflexion movement.

![EMG Graphs](image)

(a)  
(b)  

Figure 3.6 Filtered EMG a) plantar flexion b) dorsiflexion movements

### 3.3 REAL TIME CONTROL OF AFO USING ELECTROMYOGRAPHY

In present years more focus has been put on the development of biomechanical robots, robotic arms and exoskeletons or powered orthosis, which are controlled with the help of EMG signals [12, 19-21, 37-39]. Out of developed systems personal computer is mainly used as a controller thus making the system huge and not portable. The issue of portability is one of the major factors that limit the application of active orthoses outside of clinical therapy [1, 4, 5]. The work focussed on design of an intelligent, un-tethered device for control of active ankle-foot orthosis which can be used for assisting and rehabilitation in cases of pathological ankle-foot complex. In the designed active AFO the aim is at embedded system to control the actuator.

A standalone embedded system for active AFO is developed where in National Instruments cRIO system is used as a main hardware. The control of AFO is done using sEMG signals. DC motor is used as an actuator for plantar flexion/dorsiflexion movements.
It is a battery operated system for data acquisition and actuation. The cRIO is an embedded system, features an industrial 400 MHz Freescale MPC5200 processor that deterministically executes the LabVIEW Real time application program on the Wind River VxWorks real time operating system [40].

The control system model for AFO using sEMG signals is as shown in Figure 3.7. The surface EMG signals which are responsible for the ankle movement are acquired to cRIO with the help of analog input module. The algorithm required for analysing acquired sEMG and implementing control method is developed in NI LabVIEW. Then it is deployed to cRIO which controls the motor for realizing ankle movements. The motor driver and digital output module are connected to cRIO.

3.3.1 Compact reconfigurable input output system

NI cRIO is an advanced embedded control and data acquisition system which can be reconfigured according to the requirements. It consists of an embedded real-time processor, a high performance FPGA and I/O modules which are hot swappable. Each I/O module is directly connected to the FPGA, providing low level customization of timing and I/O signal processing. The FPGA is connected to the embedded real time processor via a high speed PCI bus. LabVIEW contains built in data transfer mechanisms to pass data from the I/O modules to the FPGA and also from FPGA to the embedded processor for real time analysis. Its main purpose is to execute real-time application with high performance and reliability.

The Compact RIO embedded system features an industrial class processor that reliably and deterministically executes Real-Time applications. It uses built-in LabVIEW functions to build multithreaded embedded system for real-time control, analysis, data
logging, and communication. The controller also features a 10/100 Mb/s Ethernet port for programmatic communication over the network. The reconfigurable chassis is the heart of NI Compact RIO embedded systems, containing the RIO FPGA core. This user-defined RIO FPGA is a custom hardware implementation of the control logic, input/output, timing, triggering, and synchronization design. The RIO FPGA Chip is connected to the I/O modules in a star topology, for direct access to each module for precise control and unlimited flexibility in timing, triggering, and synchronization. A local PCI bus connection provides a high-performance interface between the RIO FPGA and the real-time processor [40].

The integrated configuration combines the embedded real-time controller and chassis containing the FPGA in a single unit. This configuration provides all of the functionality of the modular controller and chassis, and has been optimized for cost which makes this system ideal for high volume applications. The cRIO 9073 Integrated 266 MHz Real-Time Controller 2M Gate FPGA chassis is shown in Figure 3.8.

![Figure 3.8 Integrated Real-Time Controller and FPGA Chassis](image)

NI Compact RIO 9073 is used as a main hardware in the AFO implementation model. NI 9201 and NI 9401 are used as hot-swappable I/O modules for Compact RIO. NI 9201 is an 8 channel, 12 bit analog I/O module which has a maximum sampling rate of 500 kS/s. The input range of NI 9201 is ±10V. NI 9401 is an 8 channel 5V TTL high speed bidirectional digital I/O Module [41-43]. Amplified signals are acquired to Compact RIO at a rate of 1800 samples/sec with the help of NI 9201 module using LabVIEW. Acquired signals are rectified and then filtered using band pass filter with a cut of 10- 500Hz. Frequency response of the filter is as shown in Figure 3.9.
3.3.2 Feature extraction of sEMG

The raw EMG signal must be processed before it can be used for most scientific purposes [10]. The Root-Mean-Squared (RMS) value provides a measure of a physical property of the EMG signal that is the energy of the signal. This makes it a more useful way of conceptualizing the EMG signal than other mathematical functions which have been used in the past, such as the mean rectified value and the integrated value. It is the most common method for characterizing the signal [44-47]. The RMS gives the linear relationship with muscles power generated [48] and is mathematically expressed as

$$\text{RMS value} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} v_i^2}. \quad (3.1)$$

where $v_i$ is the voltage at $i^{th}$ sampling and $N$ is the number of samples in a segment. Here 1000 samples are used in a segment. The data is read continuously while walking (real time data).

3.3.3 Implementation and programming

Analog and digital I/O modules are connected to cRIO. The cRIO is programmed with NI LabVIEW, in such a way to acquire sEMG signals in real time from the TA & GA muscles with the help of analog Input Module NI9201 and to control the DC motor for giving desired movements of ankle foot joint. The control inputs are given to motor driver through NI9401 digital output module.

The digital output module NI 9041 is TTL compatible and gives a voltage output of 5V and hence to drive the DC motor, the motor driver L293D is used which can drive the motor in dual direction. The direction of DC motor which is connected to pin3 and pin6
which is shown in Figure 3.10 depends on the digital inputs given to pin2 and pin7 from DO0 and DO1.

![Motor driver interface with the digital I/O module NI9401](image)

Figure 3.10 Motor driver interface with the digital I/O module NI9401

The Table 3.2 shows the directions of the motor with inputs at pin2 and pin7.

<table>
<thead>
<tr>
<th>Pin2</th>
<th>Pin7</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
<td>Stop</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
<td>Turn right</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
<td>Turn left</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>Stop</td>
</tr>
</tbody>
</table>

The control system is developed for a hemiparesis case i.e with the consideration that only one of the limbs is affected and other one works normally. The sEMG sensors are connected to normal limb. The plantar flexion or dorsiflexion movements are decided with the changes in RMS value of EMG signal with time. This indicates when the swing is happening and in which direction the affected leg should move during the swing for corrected gait. The actuator is used to vary the ankle position during the swing phase so that the foot does not slap on the ground and toe drag does not happen.

The sEMG electrodes connected to normal leg are used to calculate the swing phase for directional control of actuator. As shown in Figure 3.11 whenever a TA/GA cycle occurs it indicates dorsiflexion/plantar flexion has occurred for normal leg i.e. for the defective leg.
the opposite should occur and thus it changes the direction of actuation. The dc motor moves clock wise or anti clock wise depending upon the direction control. A counter is included in the LabVIEW code to check for odd or even gait cycle. Odd cycle indicates the normal leg is in the swing phase (dorsiflexion movement). Thus an even cycle indicates that the affected leg is in swing phase. The actuator action i.e. gait correction is done in this time interval and hence actuator is enabled.

The control flow diagram for real time motor control is shown in Figure 3.12 and the experimental prototype is shown in Figure 3.13. The real time signals acquired through analog input module which is connected with cRIO are compared with a fixed threshold. The threshold is set such that sEMG signal (normalized) is just above the noise level. It is fixed after taking number of trials from different subjects. In this system, personal computer (PC) is used only for signal analysis, visualization of data and to deploy the code on the cRIO. After programming the cRIO the whole AFO system can be used as a standalone embedded system without intervention of computer for process of signals and control of motor.
Figure 3.12 The control flow diagram

Figure 3.13 The complete experimental setup
3.4 CONCLUSION

A prototype of stand-alone embedded system for an active AFO is developed. National Instruments Compact-RIO is used as an embedded processor. In the designed prototype, the dorsiflexion or plantarflexion movements are controlled using sEMG signals. The control signal is based on the extracted RMS value of sEMG signals. An average threshold value for sEMG signals of TA and GA is calculated by taking different subjects into consideration. DC motor is used as an actuator. The actuator enable and direction control are made based on the gait analysis and signal classification with sEMG signals.

Ag/Cl surface electrodes are used in the experiment to acquire the EMG signal. The placement of electrodes shall be accurate to acquire the sEMG signal. The EMG amplifier circuit is designed using an instrumentation amplifier INA128. Since EMG signal is of low amplitude and high noise, it requires an advanced, compact EMG electrode with pre-processing and filtering circuit embedded in it. But it is not economical.

The major limitation in this prototype design is the oscillation of motor. It is because of continuous input data from either TA or GA muscle while walking. The complete knowledge of speed control and amount of displacement is also required for the actuator to control the AFO. Gyroscope is selected for this purpose. To add the smooth movement in the controller design, Fuzzy logic is adopted which will be discussed in the next chapter.