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A SYSTEMATIC APPROACH TO CONTROLLING THE PROSTHETIC LEG USING AN EMG (ELECTROMYOGRAPHY)

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ABSTRACT

This paper proposes new methodology to build a system for control and actuation of a prosthetic leg. The method described in this paper involves online control of a prosthetic leg by analysing EMG (Electromyography) signal inputs from a normal leg and thereby actuating the prosthetic leg. The EMG (Electromyography) pulse inputs are taken from specific set of muscles in the leg to form a signal pattern library of active and inactive states of the muscles for every specific movement. During real-time operation the inputs from the normal leg is taken and actuation of motors in done by processing those input signals.

Keywords: EMG pulses, online actuation, prosthetic leg.

1. INTRODUCTION

Prosthetics play a vital role in assisting the people affected during trauma by loss of their limbs. The control system plays a major role in the prosthetic system architecture.

The control system needs to be efficient, quick in response and intelligent. Besides above considerations, the prosthetic system should be rugged and reliable. Any malfunction of prosthetic system will cause a mishap to the person using it.

A prosthetic control system, like any other control system requires physical computing components like sensors, actuators and a processor. In this case, there are two possible ways of controlling the pseudo body part. One method is through offline control, where the motor actuation parameters are pre-programmed. Second method is through online control, where the controller directly runs the prosthetic motors with inputs from sensors, through a continuous feed of inputs from the sensor to the controller which breaks down these signals and processes them for further actions.

This paper is devoted to develop an online control system, where EMG (Electromyography) sensors are used to get inputs from a healthy leg. The outputs from these sensors are processed in an 8-bit microcontroller, and then actuation signals are given out to the motors.

2. COMPONENTS OF THE ARCHITECTURE

a) The prosthetic leg

The prosthetic leg used here consists of triple link and double joint mechanical system. The top link and the link below it are joined by a free running shaft. The movement of lower link is arrested by a screw which is controlled by a servo motor which is used to control the entire system.

The second link is connected to the bottom most link, which is the third link. The third link acts as the ankle of the prosthetic leg. The ankle link is not powered, and the motion is arrested by a certain angle to allow little movement so as to enable putting down the leg on the ground.

The motor used in the system is a geared motor. The geared motor functions as a normal DC motor, except that there is a gear coupling between the load and the motor. This allows for proper torque output; however, this may induce backlash in the system. If inertia of the gear is reduced, it in turn reduces overall backlash. The transfer function for this system is illustrated below.

Transfer function of the model

$$\frac{\phi_1(s)}{T(s)} = \frac{1}{(0.133s^2 + 243s + 2535)}$$

The Simulink model of a prosthetic leg is as shown below in Figure-1. The model is an estimated vibratory model of a healthy leg.
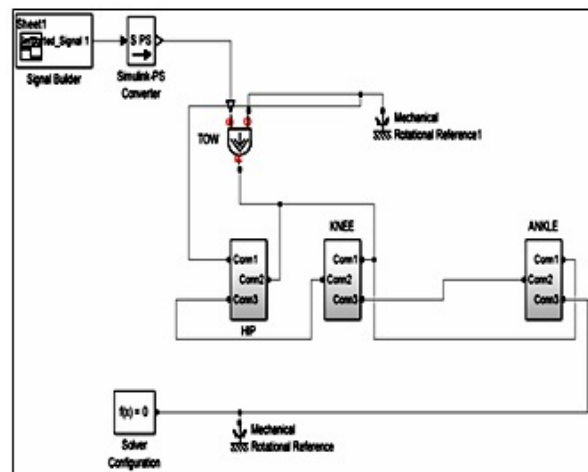

Figure-1. Simulink model of the leg analogy as a vibratory model.

Here each block is an individual representation of various parts of the leg viz., Hip, Knee and Ankle. All these blocks have similar connections with the other and hence one of them is shown here, namely the knee joint. The individual block is as shown Figure-2 below.
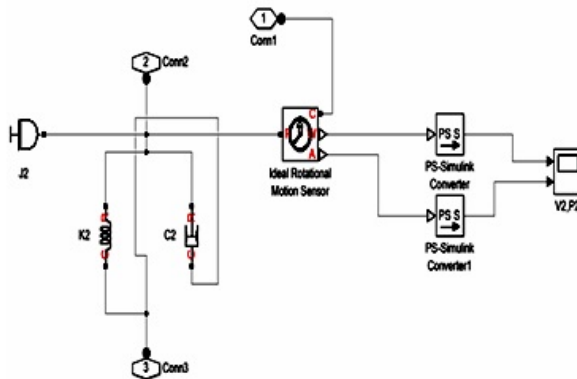

Figure-2. Showing the simulink model of the individual block, Knee.

b) EMG (Electromyography) signals

EMG (Electromyography) are a train of signals that can be picked up from specific points on the surface muscles from different parts of body. The train of electric discharges are called Motor Unit Action Potentials (MUAPs). Usually EMG (Electromyography) electrodes are placed at different points on the skin. A general muscle anatomy is easily available easily, where spots on skin can be marked up and patched for signal acquisition.

Electromyography instrument detects the electrical impulses that are passing on the information from one muscle to another.

Normal pulses range from 1-100/sec

- EMG plots the graph by rectifying the raw data.
- EMG is used to identify when a particular muscle is activated in a particular movement.
- EMG is used measure Muscle Fatigue.

Usually, three types of electrodes are used for EMG signal acquisition. 1. Needle type; 2. Fine Wire; 3.Surface EMG. Needle type electrodes are the best ones to be used. But, surface EMGs are popular among enthusiasts. The surface EMGs however do not give proper signals and are very complex to analyse.

The special algorithms used by the method described in this paper avoids the need to use the more painful Needle type electrodes. The surface patches are non-invasive electrodes. Although they don't give out signals of the best quality, the number of them used here suffice the need of this experiment.

Fundamentally the signals acquired are decomposed. The decomposition of the signals is done using specialized algorithms. One popular decomposition algorithm used is MTLEMG automatic decomposition program by Florestal and Mathieu.

In this paper innovative algorithms are described, which avoids the need to use EMG decomposition. A special C code is used to record and analyse eight different channels of incoming signals. Special algorithm is described in the next section, which uses the array of signal data acquired from the eight sensors. The signals acquired however need to be passed though high pass filter first to remove the noise from the source.

Figure-4 is the surface EMG patches used for the conduction of experiment and Figure-3 shows the EMG signals acquired.
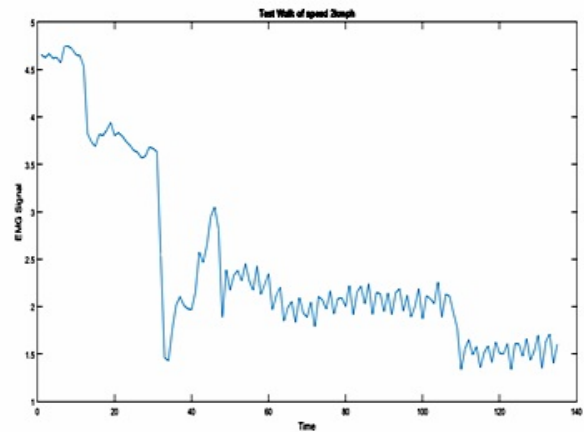

Figure-3. Graph of EMG signal vs time.

Figure-4. Surface EMGs, EMG patches.

c) Algorithm

The algorithm described below uses comparison of the acquired vector of signals with a pre-programmed library as opposed to the usual method of signal decomposition. The algorithm used in this experiment is termed as 'Index algorithm.'

The basic purpose of the index algorithm is to check the quality of match of the local input data to the reference data of the library and predict the amount of match in terms of the percentages. This will be used to predict and trigger the outputs for the actuator activation. The amount of match is quantized in the scale from 0-100 a best match is 50% to 100% if the match is below the 50% then it is called as the dead index and the algorithm will again search in the library. This continuous process named as approximation and triggering. If the person has no reference leg to train, then the reference library will serve as the base, if the person has one leg then the

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indexing algorithm will come into account. The time complexity of the algorithm is of order $O(N^2)$. Basic steps in the algorithm, Get the local signal array and Search for the same signal in the library. If the match was found, then proceed with the respect to the command coded. Else search for the nearest match. If match is greater than or equal 50% to then proceed with the command. Else search for the next possible match or Continue until match is greater than or equal to 50%. Figure-5 describes the flow process of Indexing Algorithm.
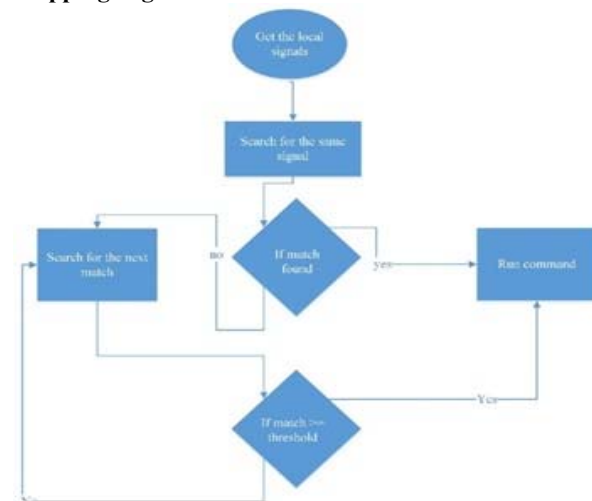
Mapping engine

Figure-5. Showing the flow chart of the indexing algorithm.

Mapping engine is the basic look up table with the pre made coded array which we address them as the master codes. The main purpose of this engine is to search for the best possible match and send it to the indexing algorithm. So we can also call it as the search engine as in our internet application. The following Figure-6 gives the basic idea how this engine works.
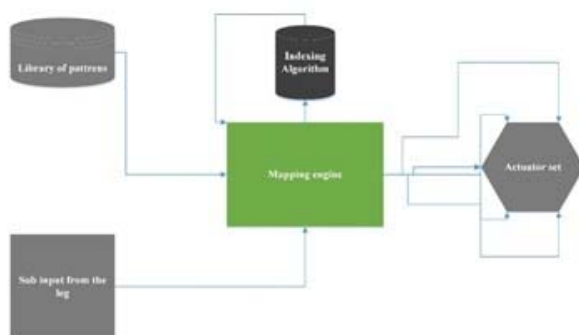

Figure-6. Showing the flow chart of the mapping engine.

The local input form the client is taken with help of the individual EMG signals and they are clubbed together so as to form an array of individual signal. This is

sent to the mapping engine and mapping engine will try to find the best match possible and this best match array is sent to the indexing algorithm along with the local input signal and index is calculated if the algorithm rejects the results again the loop continues until the best match is made. This signal array is sent to the specific targeted actuators for the specified actions.

The modular and flexible algorithm helps the user set his desired threshold values of percentages in the controller itself. The number of channels used also plays a vital role in the quality of system control. The user can, with minute changes in the setting of the above system, change the number of signal inputs and thresholds. The example of the visual mapping of the algorithm is shown in bellow. Consider the following dummy look up Table-1 which gives the address of the muscle and the activity of the leg.

Table-1. Showing the activity look up table.

Muscle Sl no.	Voltage Signal from EMG (while)			
	Walking	Sitting	Running	Standing
1	1	0	1	0
2	1	0	0	1
3	0	1	0	1
4	0	1	1	1
5	1	0	1	0
6	0	0	1	1
7	1	1	0	0
8	0	1	0	1

Consider the following Table-2 which is taken from a local client giving the outputs from the EMG.

Table-2. Showing the local client input walk cycle data.

Muscle Sl no.	1	2	3	4	5	6	7	8
Voltage Signal	1	1	0	0	0	0	1	0

Then the algorithm compares the two signals as shown in the Table-3.

Table-3. Comparison between the reference library and input.

	1	2	3	4	5	6	7	8
REFERENCE	1	1	0	0	1	0	1	0
LOCAL	1	1	0	0	0	0	1	0
DECISION								
WEIGTAGE	12.5	12.5	12.5	12.5	000	12.5	12.5	12.5
INDEX	87.5 %							

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So the mapping engine will send this signal to their respected actuator set.

3. GAIT CYCLE

Gait is a pattern that describes an individual's walking style. The Gait cycle of a person is greatly affected by the injury or a disease condition he has.

A gait has two phases. One phase is when the leg is in contact with the surface, which is called stance phase. The second phase is when the leg is in the air, and it's called swing phase.

When a person walks evenly, the gait cycle is smooth and periodic (Figure-7). The two legs follow each other in phases, i.e., the swing phase and stance phase happen evenly, in one leg after another.
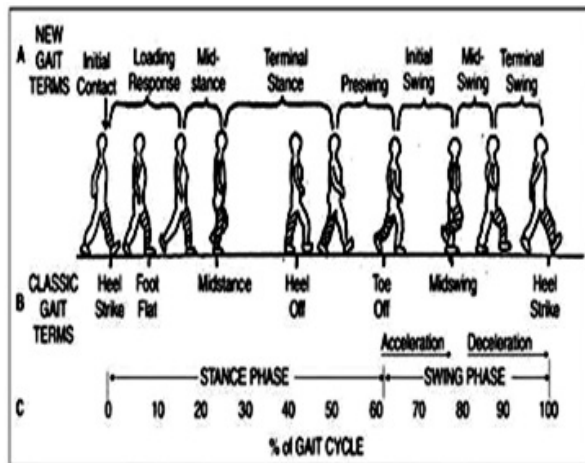
Figure-8. Vastus lateralis in human limb.

Figure-7. The gait cycle.

4. POSITIONING OF EMGS (ELECTROMYOGRAPHY)

The Placement of the electromyography's electrodes is necessary to analyse nerve impulses to the most widely used/effective muscle in the leg amputations.

a) The effective muscles

Human anatomy has classified the muscle fibres that are present under the hip as
  a) VastusIntermedius
  b) VastusLateralis
  c) VastusMedialis
  d) Gstroenemius
  e) Tibialis Anterior
  f) Soleus

We have considered only Vastus Laterails and Tibialis Anterior because these are the most effective and major muscles that are responsible for the motion by the leg. Figure-8 shows the Vastus Lateralis in human limb.
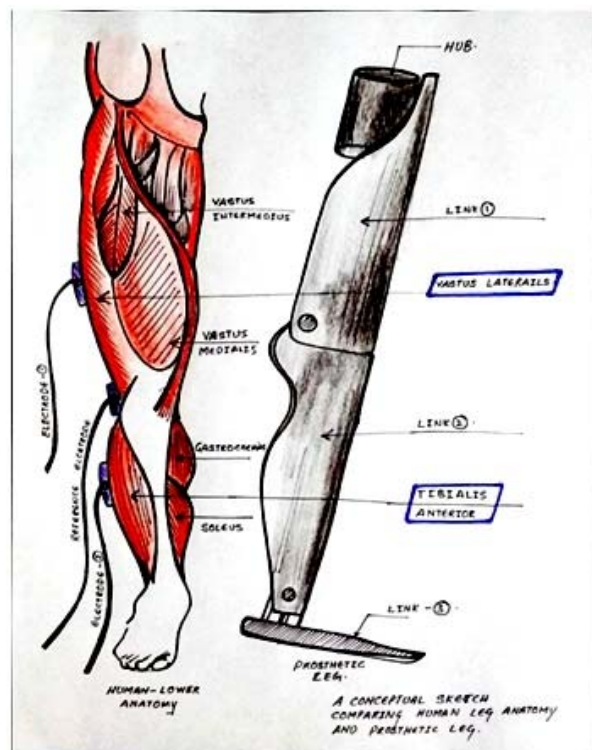
Figure-9. Electrodes placed on the muscles and with a comparison to the prototype.

The above Figure-9 gives the arrangement of EMG electrodes placed on the muscle and a comparison prototype. The electrical impulses are identified from the EMGs and are sent to the motors for actuation. Figure-10 shows the implementation of the EMG analysis during cycling, jogging and standing.
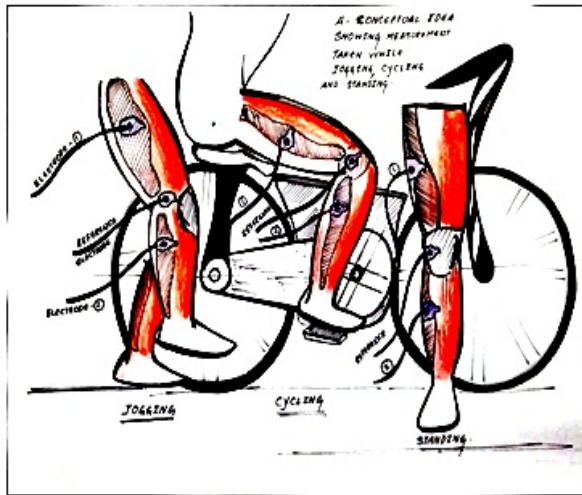
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Figure-10. Implementation of the EMGs analysis during cycling, jogging and standing.

5. IMPLEMENTATION

The experimental implementation here consists of two parts.

- The data acquisition system for procuring the EMG signals from normally functioning leg.
- The control system that processes the online signal inputs from sources and sends actuation signals to the motor.

a) Data acquisition

For the purposes of testing the signals inputs from the source a NI MyRIO- 1900 system was used. NI MyRIO- 1900 (Reconfigurable I/O) system with the high speed hardware allows high speed data acquisition from the A/D converters.

The surface patches on the test subject's body send out signals in the form of pulses, which are passed to the Analog to Digital Converter. The ADC converter then quantifies the analog signal into an integer form. This quantification happens according to the resolution of the ADC used. Here, a point to note is that every muscle may (or may not) emit a pulse signal. The output is considered to be one from the EMG signals if and only if the pulse emitted from the specific muscle is considerably high with respect to the other muscle inputs. The inactive muscle does not mean that the muscle won't take part in the activity of the leg but it suggests that the contraction of other muscle during this activity is greater than the effort on this muscle.

In the actual prototype implementation, Arduino microcontroller is used, which has an inbuilt 10-bit ADC. This 10-Bit ADC converts the input analog voltage signals to a value between 0 – 1023.

The setup for preliminary testing includes a configurable I/O port device NI MyRIO- 1900. This is coupled with an EMG sensor viz. V3 muscle sensor. The sensor sends the muscle contraction signals to the myRIO

setup which then processes the given information and graphs the data with respect to time. The MyRIO setup and V3 muscle couple is shown below.

The EMG transducer used in this experiment produces a voltage value within a range of 0-4 volts. Using appropriate formulae, the analog value thus acquired is converted into voltage and stored in a variable.

The microcontroller uses continuous polling method to check for rising side of the EMG signal. That is then counted as a pulse. The analog voltage value that is acquired from the first channel is stored as a reference value.

Next, a for loop polls the other analog input values in a sequence and records analog voltage values given out by the transducer (electrode.) The eight analog input values thus acquired are then stored away in an array. Figure-11 shows the NI MyRIO setup used in the analysis of the EMG Signal.
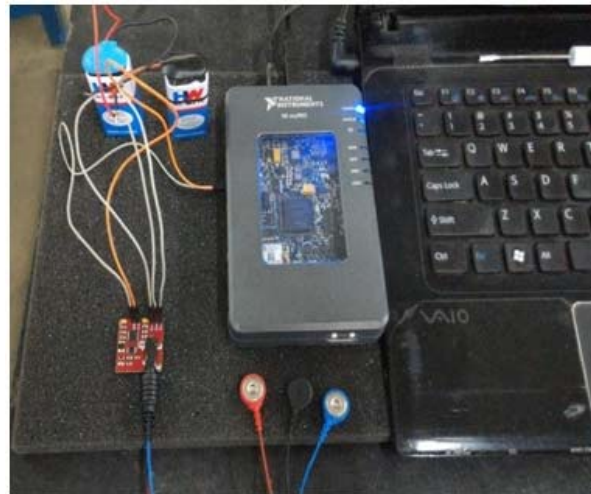

Figure-11. NI MyRIO Setup used in the analysis of the EMG signal.

Before the implementation of the prototype for practical use the trainer records several samples of signal from the subject for different motion gate cycles from the eight channels. A library is built, which consists of row arrays of width equivalent to the number of channels. The number of such rows is equivalent to the number of different types of possible motions stored.

In the initial sample collection stage we have acquired inputs from the Gait or walking cycle of a subject at a constant speed under simulated conditions i.e., when the subject is made to walk at the constant speed on a tread mill, we have acquired the data related to the EMG signals obtained from these respective muscles. This data will be fed into the microprocessor for processing with the reference library. The setup of the subject being tested in walking cycle is as shown below in Figure-12.

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Figure-12. Setup showing the subject being experimented on a tread mill at 2 kmph.

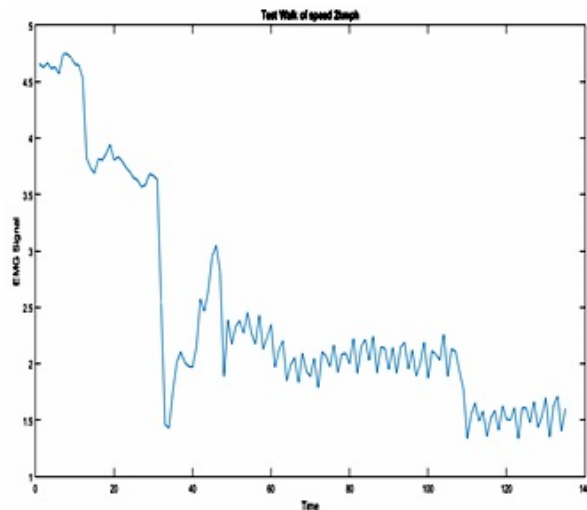The graph sketched from these results is given in figure-13.

Figure-13. Graph of EMG signal vs time.

The library is hard coded in to the Arduino C++ code as a LUT (Look up Table). Now, when the system is being used, data is acquired and stored in an array. The acquired vector of data is then compared to all the available motion vectors in the LUT and the motion vector which best matches the input signal vector is used for actuation.

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