EMG based prosthetic leg for above-knee amputee

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Abstract— The work presented in this paper is the first step in development of a prosthetic leg based on EMG signals for above knee amputees. The surface EMG signals picked up from the calf muscles of healthy leg during the muscle activity are interfaced with a microcontroller using EMG acquisition system. These signals are processed, analysed and used to actuate the knee joint of the prosthetic leg.

During the course of the present work, it was possible to control the rotation of a motor of prosthetic knee joint using EMG signals from healthy leg. The complete designed prosthesis will allow users to walk with a better gait.

Keywords—EMG; prosthetic; rehabilitation, biosignals

I. INTRODUCTION

The human history has been accompanied by accidental trauma, war and congenital anomalies. Consequently, amputation and deformity have been dealt with one way or another throughout the ages. Our motivation behind this project is the fact that in India, there are nearly 80 lakh people living with limb loss and around 6 lakh people require prosthetic leg every year. Around 70 percent of these are from rural areas. Being engineers, it is our responsibility to develop the technology that can improve the life of disabled people. Our project aims to provide prostheses for above-knee amputees in which the important part is to acquire EMG signals from the calf muscles of healthy leg and analyze them to provide the control signals to actuate the knee joint of the prosthetic leg using a microcontroller. We intend to design a prosthetic leg which is inexpensive, water resistant and easy to fit.

A. Technical Background

The traditional prosthetic legs which are available are designed mainly for below-knee amputees. Also the knee joints are not automatically actuated in case of prosthetic legs for above-knee amputees. Most of the prosthetics available today are passive, which means people with those devices have to use their intact limb to pull the prosthetics behind them [4]. And the prosthetics that do have motors are either controlled by a remote or require the patient to perform exaggerated movements (like kicking their leg very far back). Such passive prosthetic legs tend to move out of sync with its user's movements. Also the traditional prosthetic legs are quite heavy and expensive enough that the people from rural areas cannot afford them. Researchers have been implementing microcontrollers in prosthetic knees to enhance the basic mechanical design [2][3].

We have attempted to develop a system that integrates the movement of the prosthesis with the movement of the user which is substantially more important.

B. Proposed Solution

In order to create the natural movement of the leg, it is essential to move it in synchronization with the normal healthy leg of the amputee. The idea behind our proposed solution consists of acquiring EMG signals from calf muscles of the healthy leg, analyzing these signals and actuating the prosthetic leg according to the acquired EMG signals. The top level block diagram is shown in Figure 1.

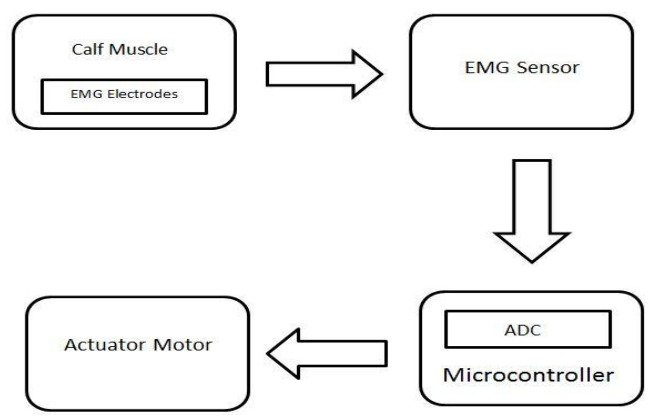

Figure 1: Top level block diagram

We attempted to develop a prosthetic leg system which is more robust, cost effective and easy to use than the traditional ones. Unlike other traditional prosthetics, we wanted the actuation of the knee joint of the prosthetic to automatic and adaptive, hence developed an algorithm based on the EMG signals from calf muscle activities which proved to be very reliable for the purpose.

C. Organization of the Paper

In this paper, first we propose the ideas to enhance tradition prosthetic leg systems. In later section we present the hardware and software implementation and mechanical design of the system. Then we have mentioned observations and test results we obtained and based on that we have state the conclusion.

II. PROPOSED SOLUTION

It is a big challenge making a mechanical limb function a lot, like a human leg. Also to make the movement more natural, the design should be such that the amputee has to put in lesser efforts. We proposed a motor actuated knee to overcome these problems. With a powered knee joint the amputee will be able to walk with deceased hip effort and expending lesser energy than they would while using passive prostheses.

Surface electromyography (EMG) is a technique of measuring the level of muscle activity. When a muscle contracts, electrical activity generates an action potential which propagates along the muscle fiber [1]. These EMG signals are reliable. On analysis, it is seen that the plot of EMG signal values tend to follow a particular pattern for the corresponding the muscle activity while walking. We used the EMG signals acquired from the healthy leg to actuate the motion of the prosthetic leg.

Figure 2: Muscle activity of right leg during normal human walking gait

We studied the normal walking gait of a human being [6]. Normally, while walking, 70 percent weight is shifted alternately from one foot to another. The forward motion of the leg in the swing phase begins when the 70 % of the body weight is shifted on the other. Therefore it is important to detect this point at which the knee joint is to be actuated. For this purpose we took several EMG signal recordings from various muscles. We found that this point is distinctively described by calf muscles EMG signal patterns. So we chose to take the signals from calf muscles. Figure 2 shows the muscle activities of right leg during normal human walking gait.

In our system, the electrodes are placed on calf muscles of healthy leg. The signals from these muscles are analyzed and processed according to our algorithm. Then the knee joint motor of the prosthetic is actuated in accordance with the signals. While designing the system, we had to take care of the constraints like cost of the system, weight of the prosthetic leg and power rating of the actuator motor. We tried to make our circuit as compact as possible, so that it fit on a small PCB. Our whole circuit and power supply can be easily carried in small bag which makes it user friendly.

III IMPLEMENTATION

A. Hardware Implementation

As a part of hardware implementation, we designed a circuit for recording the EMG signal patterns and process them. The circuit also generates the control signal for the actuation of knee joint motor according to the algorithm.

To capture the EMG signals from the muscles we used the Ag/AgCl type EMG surface electrodes. We preferred to use these electrodes because they are disposable and very inexpensive, hence suitable for low cost applications suitable for low cost applications. To measure these signals a Three-Lead Differential Electromyography Sensor is used. This sensor measures the filtered and rectified electrical activity of a muscle; outputting 0-Vs Volts depending on the amount of activity in the selected muscle, where Vs signifies the voltage of the power source. We can also adjust the gain using the on-board potentiometer. This sensor required constant voltage dual power supply. Using Texas Instruments two voltage regulator ICs viz. +5V regulator IC 7805 and -5V regulator IC 7905 along with potential divider arrangement of resistors, we designed a constant voltage dual power supply for the sensor.

The Texas Instruments Stelleris EK-LM4F120XL microcontroller is the brain of our complete prosthetic system. It a good combination of high performance and low cost. Hence we used it as the acquisition and processing unit of the EMG signals. The output from the Electromyography sensor is connected to the analog pin of the microcontroller. We have used the internal 12 bit analog to digital converter of the microcontroller to convert the analog voltage at output of the sensor into corresponding 12 bit digital value. These digital values are then used for the processing according to our algorithm to generate the required control signals for the actuation of knee joint motor. To drive motor from these control signals, we have used Texas Instruments' motor driver IC L293D. This IC can give supply high voltage and current for the actuation of the DC motor, which otherwise is not possible to give with the microcontroller. The microcontroller and the motor driver IC require constant voltage supply for their operation. For purpose we have used Texas Instruments +5 V regulator IC 7805.

B. Software Implementation

Before we implemented the algorithm, we took several recordings of EMG signals from various muscles for debugging purposes and to study the walking gait of a particular person. We have a software program running on the computer which can record the EMG signals. For that we send the digital values of signal from microcontroller to the computer serially, and software program running records and then plots these values in real time.

The EMG signals from calf muscles were studied with the help of recordings taken earlier. It was observed those signals were following some kind of patterns. We found that a peak in the value of the signal is obtained at the point when 70 percent of weight is shifted to foot of that leg. This is the point when the prosthetic knee joint is to be actuated. Based on the patterns recorded, we developed an algorithm. According to our algorithm, our microcontroller reads the value of signal in each loop. This value is checked if it greater than the threshold value set by the algorithm. If this value exceeds the threshold value, a peak is said to be detected and at that point the routine corresponding to the actuation of motor is serviced. The flow chart explaining our algorithm is shown in Figure 3.

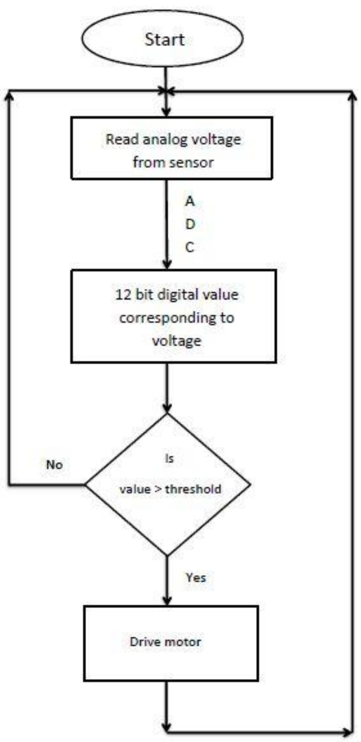

Figure 3: Flow chart explaining the algorithm

C. Mechanical Design

The first main constraint we had to consider was the weight of the system. The system had to be as light as possible, water resistant and should be able to sustain the harsh environmental conditions. Therefore we fabricated the prosthetic leg using high strength, light weight plastic.

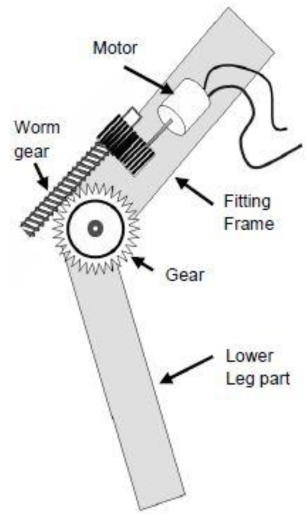

Figure 4: Mechanical design of the prosthetic leg

The system required a transmission system which could provide sufficient speed and torque. We decided to use worm and worm wheel arrangement as it provides a high reduction ratio, which results in an increase in torque and reduction in speed. Another reason to use this arrangement is the inability to reverse the direction of power. Other reasons for using worm gear arrangement are longer life, low noise and low cost vs torque ratio. We used a high torque DC motor to actuate the prosthetic leg. Figure 4 depicts the mechanism of our prosthetic leg.

IV. RESULTS

During initial stages of our work, we took EMG signal recordings from various muscles. We studied their behavior and analyzed the patterns. Figure 4 shows the EMG signal pattern obtained from calf muscle while walking.

The peaks obtained in Figure 5 represent the EMG signal values from the calf muscles of right leg when most of the body weight was transferred on that leg.

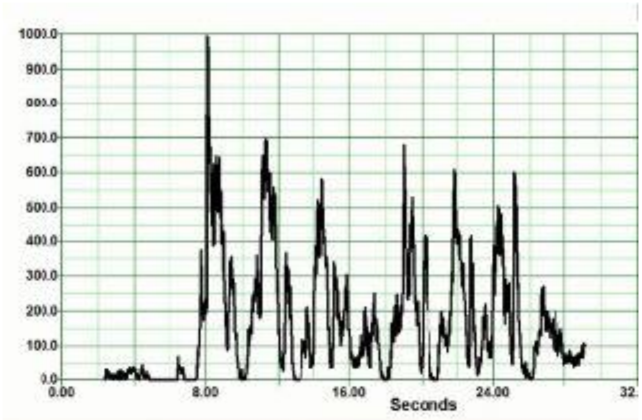

Figure 5: EMG signal recording from calf muscle of right leg while walking

V. CONCLUSIONS

Although developments have already been made in the field of prosthetic leg system, they are not quite fulfilling in terms of the ease of use and convenience for above knee amputees. Also such prostheses are quite expensive and out of reach of most rural people.

Here an attempt is made to design an actuated prosthetic leg which enables the user to gain back his/her natural walking gait with ease of use. Control of knee bending gives one step improvement to a passive leg prosthesis. Design and development of such a system has been accomplished satisfactorily. Our system needs to be tested with an amputee who, at first, has to be trained on using the prosthesis.

The developed prosthesis has been made from the easily available sources. Hence, there is a scope for further improvement using more appropriate parts and components. To optimize the system, the mechanical design may need some modifications and refinement. Further, more degrees of freedom can be introduced to the prosthetic leg so that the mobility of the amputee is enhanced. Also other high strength, light weight and cost effective materials can be substituted for the plastic material that we have used.

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APPENDIX A

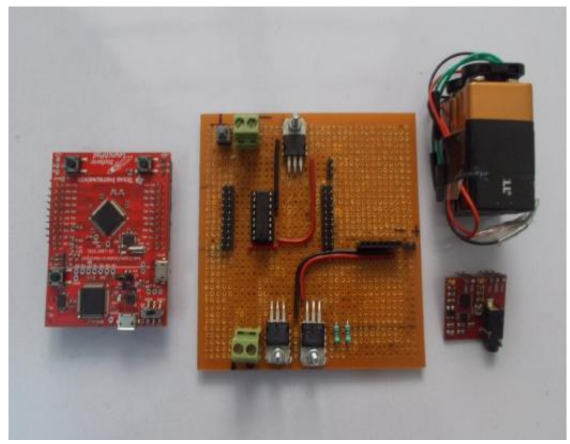

Figure I: PCB implementation of circuit

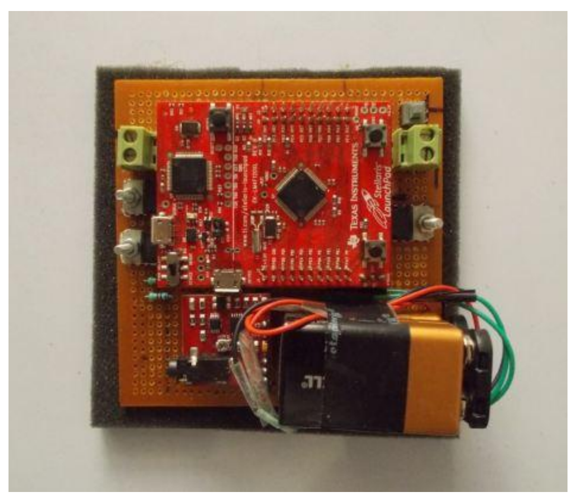

Figure II: Final compact electronic circuit