Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

7th International Conference
on Electrical Engineering
ICEENG 2010

Design & Implementation of a Low Cost Intelligent Arm based on GA

By

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Abstract:

Prosthetic limbs can be controlled directly by the brain, yet are not intelligent enough to perform the functions demanded of them. The main design of the electromechanical parts has evolved over a period of time, but the controllers are yet to be suitably advanced to adapt to the different amputees. Over the period of time many researchers have achieved this by various innovative techniques. With the widespread use of artificial intelligence [especially Genetic Algorithm] and its implementation cost reducing over the years, our goal was primarily to 1) design the mathematical model based on Genetic Algorithm for the intelligent arm, and 2) develop a low cost implementation of the model.

Keywords:

Artificial Limbs, Genetic Algorithms, Prosthetics, ANN, Biomedical Signal Detection, Myoelectric Signals, Electro-mechanical Controllers

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1. Introduction:

This investigation looks specifically at the Myoelectric Signals [MS] that are collected from the patients' amputated arm as input signals. However, it has been a challenge to use these MS to control electromechanical systems due to low accuracy and instability in multi-function controls. Comparison between healthy human MS and amputee patient MS have been analyzed to achieve a working model at a lower TCO. For this purpose the concept of Genetic Algorithm [GA] was used to classify the signals by selecting the optimal features from the MS. Earlier works based on Artificial Neural Networks [ANN] has been successful in this area but the problem of getting the patient use the device tends to be unusually long [1-3 months] due to the inherent learning nature of the technique.

GA was invented couple of decades back [1] and have gained popularity as general purpose optimization and search technique. GAs are attractive because instead of the regular "search and choose" methods, they use crossover to exchange pertinent information among the group of existing solutions to come up with "the" solution. Nevertheless, there are open issues such as: choice of control parameters, the crossover and mutation mechanisms, convergence properties etc.

There have been some thoughts in reversing the way the process has been followed – instead of the patient getting used to the device, making the device getting used to the patient. It is basically the optimum search for coming up with the result [in this case activation of certain electro-mechanical setup designed specifically for the prosthetic arm] from the set of MS from the stump. The input signal is fed into the specifically designed Reference Controller [RC], which implements the concept of GA for its application.

The RC receives two signals, viz., the reference input and the feedback signal (the plant output generated by the sensors). The biopotential electrode detects the signal and the processed signal gets amplified by the biopotential amplifier as designed in the circuit. The noise free amplified signal is then transformed into mechanical energy through a biopotential transducer. The output from the plant is fed into the Model RC as feedback and also displayed as output through scope. The use of cables in the entire system enables the amputees to do their work very smoothly.

The very concept was formulated keeping in mind the fact that the number of people losing their extremities for different reasons (accidents, diseases, malignancy) every year is rising at an alarming rate in India. But a majority of the people cannot bear the high expensive prosthetics currently available. Our design of an Intelligent Arm uses low cost off-the-shelf devices easily available in our country. This brings down the manufacturing cost of the entire device considerably and makes it affordable for the common people.

2. Review of Existing Work:

Present day robotic or "intelligent" arms have more functionality than their older counterparts and at a lesser cost. The design and constructions of such robotic arms are being carried out in different research institutions throughout the world. These designs and technology involved are advancing in such a pace that a day will come when the difference between normal hand and artificial hand will cease to exist. Previous robotic hand designs have focused on the mechanical issues of the construction and operation of the prosthesis e.g. the Novel Dexterous Hand which uses motors located at remote positions to operate the joints of the fingers through cables attached much like the tendons of the human hand [2], the All Electric Prosthetic Hand using a series of gears to transmit the motion of motors housed in the forearm to the relevant fingers [3]. The RSL Steeper modular arm system, which uses lightweight prosthesis and allows range of movements like wrist extension and flexion, shoulder rotation, extension and flexion [4]. Other designs transmit the power directly to the joints. Shape Memory Alloy [SMA] wires are also used, to both provide the force and transmit the motion. SMA wires contract when heated and return to their initial shape when cooled [5].

Our research work is based on the concept of developing intelligent arms, upper limbs primarily, whose movements can be controlled by signals from the brain & the control of prosthesis is directly from the body's neural network, which is a more natural control. As opposed to a conventional prosthesis that only provides motion of the extremity, this design aims to lay the foundations for incorporation of added sensory feedback into the nervous system so as to provide the tactile sensations experienced by a human arm. The input signal is fed into the specifically designed Reference Controller which implements the concept of Genetic Algorithms for its application. All studies were carried out on the RSL Steeper modular arm system.

3. Experimental Setup:

3.1 *Circuit Design Specifications*

Due to the complex nature of this project and its constraints, an ideal intelligent arm was designed featuring interaction with the human bodies' nervous system using the RSL Steeper modular arm system. The purpose of the design is to demonstrate the operation concepts involved in the ideal design. The circuit design and components are listed below.

- 2-Lithium ion batteries / NiMH rechargeable batteries
- 2-implantable bio-potential electrodes consisting of
    - Parallel R-C device containing a resistance and a capacitance
    - Impedance measurement device
    - Voltage measurement device
- Position controller micrometer/an ultrasonic micrometer
- RSL Steeper Hand model shaped covering of polypropylene or glass fiber/carbon fiber
- A bio-potential amplifier consisting of
    - A preamplifier
    - A low-pass filter
    - General amplifier
    - A noise canceller
- A bio-potential transducer consisting of
    - Parallel L-C Device
    - Parallel R-C Device
    - A voltage measurement device
- Viscoelastic cable
- Aluminum wires/SMA wires
- A micro-controller for controlling the setup

The intelligent arm works assuming the nerve signals (coming from brain) as input signals. This is actually the external stimulus. The signal is fed into the model reference controller which implements the concept of using Genetic Algorithm for its application. It receives two signals: the reference input and the feedback signal (the plant output) and optimizes on the action that is desired. The output from the model reference controller is now a processed signal.

The plant has three sub-systems:

a. Subsystem 1: Biopotential electrode
b. Subsystem 2: Biopotential amplifier
c. Subsystem 3: Biopotential Transducer

The output from the plant is fed into the model reference controller as feedback and also displayed as output through a scope. The two lithium ion 1.2V batteries are placed between the chest and amputated arm of the patient which acts as the main power source for the total circuit as well as the motor. The position controller micromotors are placed with the elbow for versatile movement. The viscoelastic cables are connected with the micromotor so as to control the movement of the wrist as well as the fingers efficiently and effectively.

The polyurethane or/polypropylene covering is very much durable, tough, lightweight and low cost lamination material.

3.2. Circuit Diagram for the Biopotential amplifier used in our intelligent arm

Figure (1): *Block Schematic of the BioPotential Amplifier*

4. The Model:

The collection of nerve signals and their interpretation/ communication was the main objective in the ideal 'Intelligent arm'. In order to achieve this a few factors were taken under consideration. The main objective was to make the 'Intelligent arm' acceptable to the person concerned. For this reason any risk factors that might arise due to any complications in the system were taken into utmost consideration. The design of the 'Intelligent Arm' involved common-of-the-shelf circuitry for the collection of nerve signals and their interpretation.

4.1. Role of the Central Nervous System

The tissues of the human body are connected by a network of nerve cells that form the nervous system [6]. Earlier investigations have shown that data taken directly from the primary motor cortex can be utilized to predict the motion of the arm at least one tenth of a second before the arm moves based on the pattern that form when the neurons trigger [9]. It has also been found that less than one hundred brain cells are required to give an accurate prediction of the arm's motion [8]. The 'Intelligent Arm' utilizes simple mathematical models and Genetic algorithms to accurately predict the hands pathway in real time. External Stimulus is fed into the core RC which used a set of Genetic Algorithms to provide the final processed signal into the 'Intelligent arm', which was be recorded through EMG studies [9]. Based on the specifically designed RC, the reference sensory feedback information used from the hand comes in the form of contact, pressure, cold, heat and pain. For our implementation, sensory information for weight studies has been chosen.

In real life, this information could be fed directly back into the brain through the thalamus through a small chip. However this poses the inherent danger of cell damage in the neurons which would result in a loss in feedback from other parts of the body. Therefore, a non-invasive sensory feedback is best done through the peripheral nervous system [10]. It was not possible to accurately map the peripheral signals, but with enhancement in various sensor and computing technologies, it now possible to do so.

4.2. Role of the Peripheral Nervous System

In case of amputation of an extremity of the human body, the brain is still capable of sending information through the nervous system to the site of amputation. For the movement of the arm, the signals are sent from the motor cortex down the spinal cord, through a spinal nerve to a network near the shoulder where the directions for each finger are sent along either the Radial nerve, Median nerve or the Ulnar nerve [6]. Each nerve consists of thousands of fibres, each fibre can capable of carrying an individual message. Propagation of the signal from the nervous system to the artificial limb can be achieved using a bionic chip that acts as an interface between organic and mechanical systems [6] and is compatible enough to integrate itself into the human body's system without the immune system treating it as a foreign object and triggering any immune reaction. By this method of data transmission it would also be possible to send information back to the brain to provide tactile sensory feedback sensation. For our design and implementation, only external signals emitted from the stump, was collected through the sensors, processed and the final output given to the prosthesis. There is no feedback to the patient of the action.

5. Constructed Model:

The components of the model system are outlined in the following schematic:

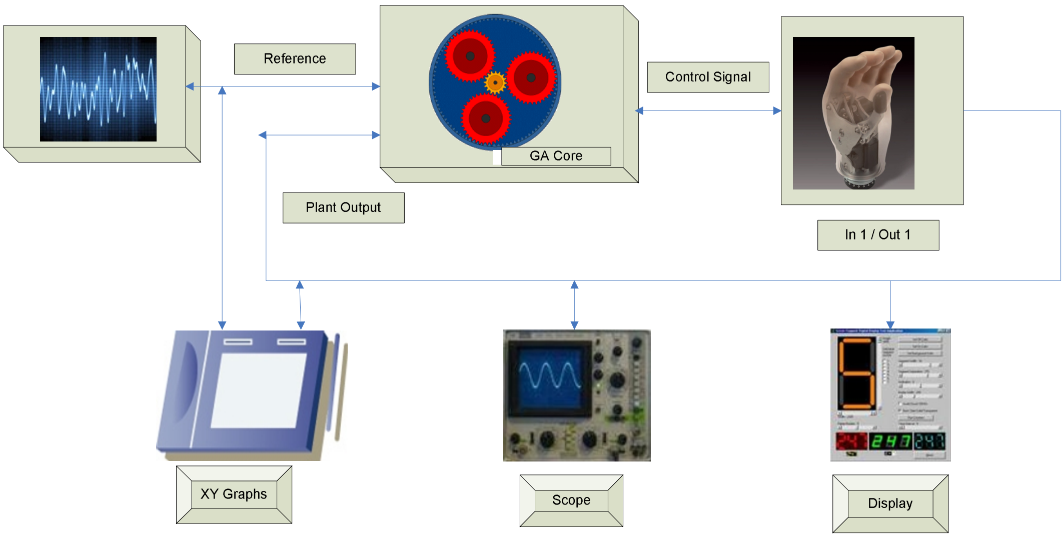

Figure (2): *Schematic of the Prototype Model*

6. Results:

The project has successfully demonstrated the potential of the hands controller design as well as providing insight into improvements to the design. The graphical representations demonstrate that that the 'virtual amputees' fitted with 'Intelligent Arm' (Fig 2) are having an output signal of significantly same amplitude to the output signals received from the 'virtual normal' individuals (Fig.1). Output signals from 'virtual amputee' cases were taken as Control signals (Fig. 3b)

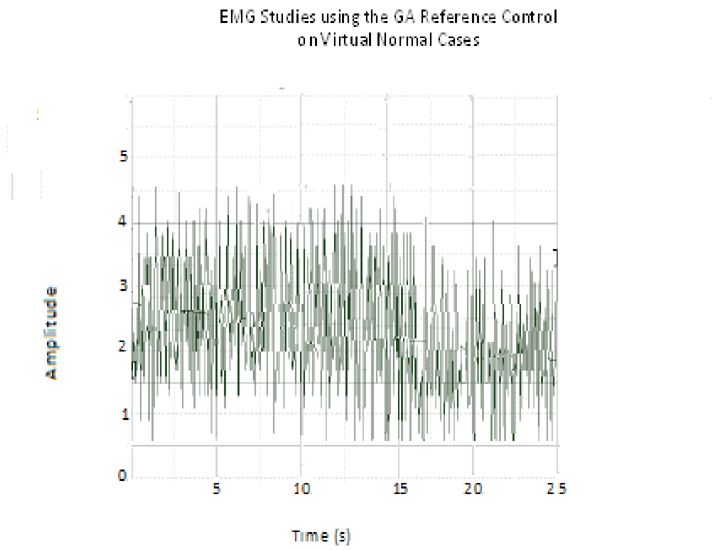

Figure (3a)

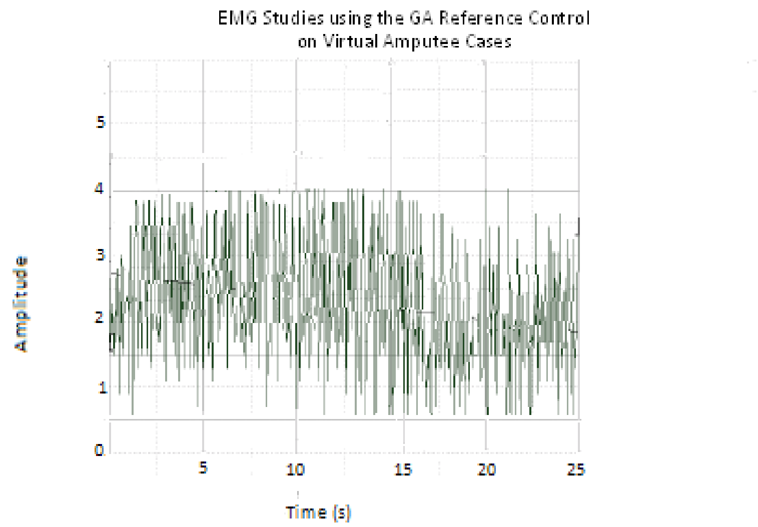

Figure (3b)

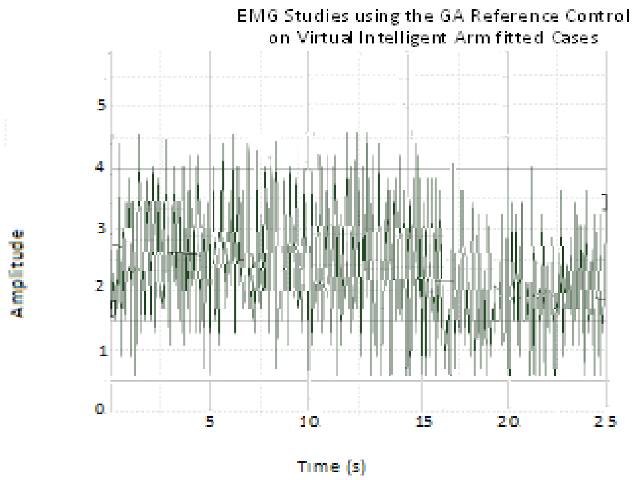

Figure (3c)

Figure (3a), (3b), (3c): *Matlab Simulated EMG studies on Virtual Normal, Virtual Amputee and Virtual Intelligent Arm fitted cases. Data obtained from our GA based Model reference Controller*

Matlab Simulated EMG studies on Virtual Normal, Virtual Amputee and Virtual Intelligent Arm fitted cases. Data obtained from our GA based Model reference Controller

This result is significant enough to indicate that our designed 'Intelligent Arm' can mimic the functions of the normal hand. On the basis of the theoretical model developed and the mechanics functioning smoothly, the initial step in the process of manufacturing a prosthetic arm controller that is attached to the body's neural network working on the MS has been completed, keeping the TCO low. This will allow patient to lead a more or less normal life under constrained economic conditions.

7. Conclusion:

The project has successfully demonstrated the potential of the controller design as well as providing insight into improvements to the design. With computing power per sq cm of silicon increasing greater than the Moore's Law, and the cost going down with more mobile users, design and implementation of the GA controller with added DSP capabilities appear to be more near the reach of the common man in the less developed countries.

8. Future Work:

The design requires the addition and testing of the various degrees of freedom so that the prosthetic is able to mimic its biological counterpart to general purpose daily life usable levels. To achieve the desired performance characteristics within the confined space of the ideal arm design, SMA wires are suggested for actuation. This alternative method of actuation will determine the power requirements for the new design. This is obviously cost intensive at the moment.

Several areas require further research and development so that the prosthetic will be able to function as a part of the human body's neural network more or less like plug and play. Volunteer studies are required to determine the levels of acceptable neuron stimulation without cell or tissue damage and it needs to be investigated further. Also the method of attaching the prosthesis to the human nervous system needs to be studied more inorder to increase the usability of the device for a longer duration. Many research works are going on in this area. The goal is to combine all the benefits of various disciplines viz. more computing power/unit, reusable high life energy modules, prosthesis integration, to come up with more reliable and usable artificial limbs. Finally the method of interpretation and implementation of the acquired data, to generate the desired motion/activity, needs to be established based upon the point and means of data extraction chosen.

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