Hardware Implementation to Develop Prosthetic Hand – A Review

Ruchika Thukral[#], Mr. Gulshan[*], Ms. Pratibha Tyagi[#]
[*] [#]Department of Electrical and Instrumentation Engineering,
Sant Longowal Institute of Engineering and Technology, Sangrur, Punjab, India

***Abstract* - Electromyographic control is a technique that involve with the detection, processing and classification of the electromyography signal that could be applied in human-assisting robots, prosthesis application or rehabilitation devices. Electromyographic signals can be used in biomedical engineering and/or rehabilitation field, as potential sources of control for prosthetics and orthotics. In such applications, digital processing techniques are necessary to follow efficient and effectively the changes in the physiological characteristics produced by a muscular contraction. Analysis of EMG signals with powerful and advanced methodologies is becoming a very important requirement in biomedical engineering. The SEMG signal generated from the remnant muscle is used as the control channel of the system. This paper reviews recent research on hardware implementation of electromyography signals for prosthesis application.**

***Keywords* - Prosthetic hand, sEMG, FPGA, EHW chips, digital and analog processor chips**

I. Introduction

The concept of using EMG for prosthesis control started in the 1940s. Electromyographic control is when the signal is used as the input for the control of powered prostheses. The signal is used to select and modulate a function of a multifunction prosthesis Roberto Merletti (2004).

Electromyography (EMG) is a medical technique for measuring muscle response to nervous stimulation. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells contract. The smallest functional unit to describe the neural control of the muscular contraction process is called a Motor Unit. It is defined as "...the cell body and dendrites of a motor neuron, the multiple branches of its axon, and the muscle fibers that innervates it. The term units outline the behavior that all muscle fibers of a given motor unit act "as one" within the innervations process. The excitability of muscle fibers through neural control represents a major factor in muscle physiology. Electromyography (EMG) is the electrical manifestation in the contracting muscles; it is the most simple and direct way to represent the contracting information of a muscle. The two most important mechanisms influencing the magnitude and density of the observed signal are the Recruitment of MUAPs and their Firing Frequency. These are the main control strategies to adjust the contraction process and modulate the force output of the involved muscle. Thus EMG signal directly reflects the recruitment and firing characteristics of the detected motor units within the measured muscle.

The number of aged or physically handicapped people requiring someone's assistance in everyday life has been increasing in recent years. Furthermore, it is expected that robots will extend their usefulness to home and office environments to support daily activities. Under such situations, if the human operator's intention can be discerned from the electromyographic (EMG) signals, EMG signals may be used as a new interface tool for human-assisting robots and rehabilitation systems. The EMG signals contain a lot of important information such as muscle force, operator's intended motion, and muscle impedance. EMG signals have often been used as control signals for prosthetic hands. Thus we uses EMG signals to realize a feeling of control similar to that of the human hand. For all these purposes, it necessary to preprocessed and processed the raw EMG signals and thus extract and analyzed the features of EMG.

EMG signals can be used for variety of applications like clinical/biomedical applications, EHW chip development, human machine interaction, etc. Clinical applications of EMG as a diagnostics tool can include neuromuscular diseases, low back pain assessment, kinesiology and disorders of motor control. EMG signals can be used to develop EHW chip for prosthetic hand control. Grasp recognition [1] is an advanced application of the prosthetic hand control.

Due to the advanced development of the biomedical science, the application of biomedical instruments becomes essential in daily life. Design of application specific integrated circuit for the biomedical instrument has become quite important recently. Various hardware has been implemented to develop prosthetic hands for disabled people. Hardware chips have also been designed to filter EMG signal to achieve the accurate signal for the prosthetic arm control and other applications like grasp recognition and human computer interactions.

II. HARDWARE DEVELOPMENT FOR PROSTHETIC HAND

The microprocessor system for myoelectric signal identification proposed by Graupe *et al*. [2] is based on an 8080 Intel Corporation microprocessor which is an 8- bit parallel central processing unit. It is fabricated on a single Large Scale Integration (LSI) chip using N-channel silicon gates and is furnished in a 40-pin dual in-line ceramic package, having a 2 μs instruction time. The microprocessor is then interfaced with its input-output ports and with a 4K-bytes semiconductor memory. Furthermore, to increase speed, the microprocessor is interfaced with a hardware multiplier unit based on Fairchild 9344 4x2 bit multiplier modules where multiplication time is 350 ns versus 1 μs in the microprocessor itself.

Analog processor chip can be designed to handle the physiological signals. Since EMG signal has the characteristics of very low voltage amplitude and carries some low-frequency common-mode noise, Yen *et al*. [3] integrated the instrumentation amplifier, gain control stage, and filters into the chip for processing the EMG signal into the adequate amplitude and limited bandwidth. It is divided into three parts: analog signal processing unit, wireless data transmission unit, and digital processing unit. Their research focused on the transmission system design. By the design concept of the system on a chip, the chip has achieved goals of low cost, low power consumption and minimizing layout area. To enhance the lives of people who has lost a hand, prosthetic hands have existed for a long time. Evolvable hardware (EHW) chip has been implemented for myoelectric prosthetic hand application. The EHW chip for an autonomous mobile robot and a myoelectric artificial hand was also developed in April 1998 to serve as an off-the-shelf device for gate-level hardware evaluation. The chip consists of three components: 1) a PLA; 2) the GA hardware with a 2K word chromosome memory and a 2K word training pattern memory; and 3) a 16-bit 33 MHz CPU core (NEC V30; 8086 compatible). Arbitrary logic circuits can be reconfigured dynamically on the PLA component according to the chromosomes obtained by the GA hardware. The CPU core interfaces with the chip's environment and supports fitness calculations when necessary. The size of the GA hardware, excluding memories, is about 16K gates. In terms of gate size, this is almost one-tenth of a 32-bit CPU core (e.g., NEC V830). However, genetic operations carried out by this chip are 62 times faster than on a Sun Ultra2 (200 MHz). The chip implemented by Kajitani *et al*. in 1999 (69) consists of GA (genetic algorithm) hardware, reconfigurable hardware logic, a chromosome memory, a training data memory, and a 16-bit CPU core (NEC V30). Myoelectric prosthetic hands are operated by signals generated in muscular movement. The proposed EHW chip consists of seven functional blocks, GA unit, PLA Unit (2 array), CPU, Register File, Random Number Generator, Chromosome Memory and Training Data Memory. The workflow of the EHW chip can be divided in two phases. The first phase is to make the two children and evaluate phase and the second is the "select two chromosome" phase. The GA adaptively implements the circuit on the PLA in the EHW controller.

In 2001, Torresen described a two-step incremental evaluation of a prosthetic hand controller that requires a floating point CPU or a neural network chip [4]. Using gate level EHW, a much more compact implementation can be provided making it more feasible to be installed inside a prosthetic hand. Such a complex controller could probably only be designed by adapting the controller to each dedicated user. It consists of AND gates succeeded by OR gates. One of the main problems in evolving hardware system is that there seems to be limitation in the chromosome string length. A long string is normally required for representing a complex system. A large number of generations are required by genetic algorithms (GA) as the string increases. The main advantage of the method is that evolution is not performed in one operation on the complete evolvable hardware unit; instead it is performed in a bottom-up way. The digital gate based architecture of the prosthetic hand controller is illustrated in Figure 1. It consists of one subsystem for each of the six prosthetic motions. In each subsystem, the binary inputs *x0 . . . x15* are processed by a number of deferent units, starting by the AND-OR unit. This is a layer of AND gates followed by a layer of OR gates. Each gate has the same number of inputs, and the number can be selected to be two, three or four. The outputs of the OR gates are routed to the Selector. This unit selects which of these outputs those are to be counted by the succeeding counter. That is, for each new input, the Counter is counting the number of selected outputs being "1" from the corresponding AND-OR unit. Finally, the Max Detector outputs which counter corresponding to one specific motion having the largest value. Each output from the Max Detector is connected to the corresponding motor in the prosthesis. If the Counter having the largest value corresponds to the correct hand motion, the input has been correctly classified.

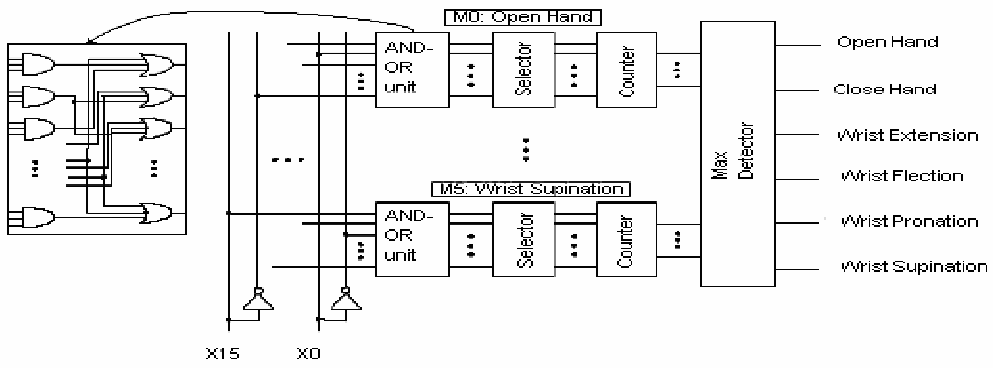

Fig. 1 The digital gate based architecture for the prosthetic hand controller

Two types of artifacts usually exist in the EMG signal from an electrically-stimulated muscle: stimulation artifacts and M-wave. In 2000, Peasgood and his researchers [10] assumed that the M-wave is stationary and therefore used a fixed comb filter. But the

M-wave is clearly a non-stationary signal in a statistical sense, mainly due to the fact that its temporal variation depends on many factors, such as stimulation intensity, fatigue, the contraction level of the muscle, etc. An adaptive prediction error filter (PEF) based on the Gram- Schmidt (GS) algorithm is presented in 2004 by Yeom *et al.* [5] for the suppression of the M-waves. The presented filter is implemented on a field programmable gate array (FPGA). Implementation is done using a 6^{th} order GS PEF using Xilinx XC2S200pq208-6 FPGA chip. The design was synthesized using Xilinx ISE 5.2i and verified using ModelSim XE 5.6a. One major advantage of separating the correlation computation and filtering process in hardware is that the filter system is not involved with a complicated state machine. Figure 8 shows the schematic of the core processing unit implemented on FPGA. M-waves must be removed in order to use voluntary EMG from electrically stimulated muscle. The proposed M-wave cancellation system based on the GS PEF is not only efficient to eliminate periodic signals like M-waves, but also suitable to FPGA implementations than the conventional linear PEF [6].

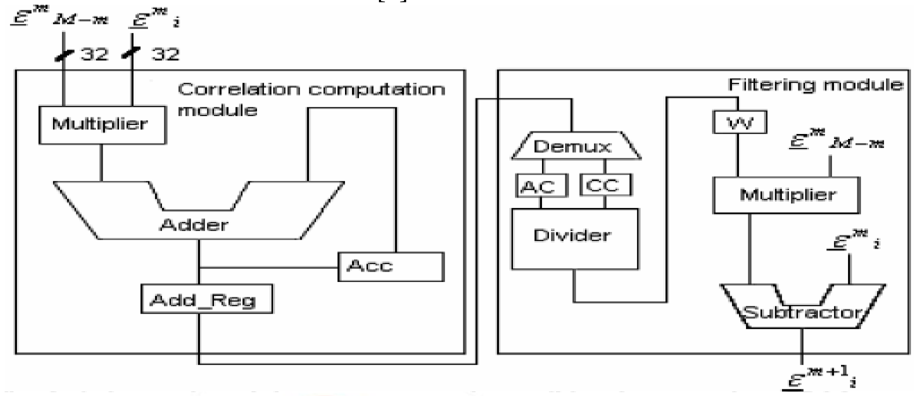

Fig. 2 Schematics of the core processing until implemented on FPGA

EMG can be used to sense isometric muscular activity (type of muscular activity that does not translate into movement). This feature makes it possible to define a class of subtle motionless gestures to control interface without being noticed and without disrupting the surrounding environment. The device for this purpose includes a high input impedance amplifier connected to electrodes, an anti-aliasing filter, a microcontroller to sample and process the EMG signal, and a Bluetooth communication module to transmit the processing results. When activation is detected, the controller sends a signal wirelessly to the main wearable processing unit, such as a mobile phone or PDA. Using EMG, the user can react to the cues in a subtle way, without disrupting their environment and without using their hands on the interface. The EMG controller does not occupy the user's hands, and does not require them to operate it; hence it is "*hands free*" [7].

Interactive computer gaming offers another interesting application of bio-signal based interfaces. The game system would have access to heart rate, galvanic skin response, and eye movement signals, so the game could respond to a player's emotional state or guess his or her level of situation awareness by monitoring eye movements. An interactive game character could respond to a user who stares or one who looks around, depending on the circumstances. This use of eye tracking is easier than using the eyes as a precision pointing device, which is difficult because the eyes constantly explore the environment and do not offer a stable reference for a screen pointer. To provide more fun and strategies, there are usually two styles of attack possible in fighting games. One is the weak attack and the other is the strong attack. Common input devices for fighting action games are the *joypad* and *joystick*. These use a stick to move the character and a button to make a certain type of attack, for example, a punch or kick. To make a strong attack the user has to input a complex key sequence that makes that motion difficult to invoke, thereby achieving a balance between two types of attack. Though those devices are cheap and easy to use, they have disadvantages. These interfaces are not intuitive for human fighting movement control, and the user has much to memorize, such as the meaning of the button and the input sequence for a strong attack motion. A human-computer interface device designed for a fighting action game, *"Muscleman,"* has been developed by D. G. Park and H. C. Kim in Korea. The game characters are usually depicted as making an isometric contraction of their arms as an expression of power concentration to make a strong attack like a fireball [8].

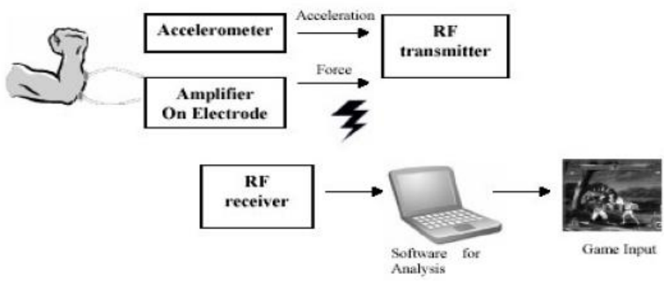

Fig. 3 Schematic block diagram of "Muscleman"

To measure the force of the isometric muscle contraction, a surface EMG was used. Moreover, to obtain more precise information about the user's forearm movement, the gaming system is installed with an accelerometer. By analyzing acceleration data record obtained from the accelerometer, it is possible to know which direction the forearm is moving. Furthermore, the classification of attack movement in cases such as whether the motion was a straight punch motion or an upper cut motion is possible. Wireless transmission is adopted so as not to disturb the user's motion. By adopting wireless transmission, the stage of a game can be extended virtually with no limits in space. Figure 3 shows the system block diagram of *"Muscleman."*

Communication with a computer by certain muscle contractions would make it possible to perform all sorts of computer-controllable actions using EMG. The muscle contractions can be detected in a robust way, almost insensitive to any kind of noise, so an interface device based on muscle tone could also be used to control moving objects, such as mobile robots or an electrical wheel chair which can be great help for persons with disabilities. Of course, this might offer an alternative for able-bodied persons as well for controlling home entertainment appliances. The constant stream of EMG signals associated with any arbitrary muscle of the wheelchair driver is monitored and reduced to a stream of contraction events. The reduced stream affects an internal program state which is translated into appropriate commands understood by the wheelchair electronics. The standard way of steering an electrical wheelchair involves the use of one hand to operate some sort of two dimensional joysticks.

III. CONCLUSIONS

While reviewing the hardware implementations we understand that, although reconfigurable hardware devices, such as FPGA and PLD are spreading rapidly and the usefulness of reconfigurable hardware is being more widely recognized, reconfiguration in FPGA's is not autonomous and requires human intervention. Thus, EHW indicates a new direction in reconfigurable hardware beyond FPGA's.

REFERENCES

[1] Zhang LQ, Shiavi R, Hunt MA, Chen J. Clustering. Analysis and pattern discrimination of EMG linear envelopes. IEEE Trans Biomed Eng 1991; 38(8):777-784.
[2] Christodoulou CI, Pattichis CS. A new technique for the classification and decomposition of EMG signals. Proceedings in IEEE International Conference on Neural Networks 1995; 5:2303-2308.
[3] McComas AJ, Fawcett PR, Campbell MJ, Sica RE.Electrophysiological estimation of the number of motor units within a human muscle. J Neurol Neurosurg Psychiatry 1971; 34(2):121-131.
[4] Stashuk DW, Kassam A, Doherty TJ, Brown WF. Motor Unit Estimates Based on the Automated Analysis of F-Waves. Proceedings of the Annual International Conference on Engineering in Medicine and Biology Society 1992; 14:1452-1453.
[5] Zhengquan X, Shaojun X. Estimation of motor unit firing statistics from surface EMG. Proceedings of the 20th Annual International Conference on Engineering in Medicine and Biology Society 1998; 5:2639-2642.
[6] Ping Z, Rymer WZ. Motor unit action potential number estimation in the surface electromyogram: wavelet matching method and its performance boundary. Proceedings of the 1st International IEEE EMBS Conference on Neural Engineering 2003; pp. 336- 339.
[7] Major LA, Jones KE. Simulations of motor unit number estimation techniques. Journal of Neural Engineering 2005; 2(2):17-34.
[8] Graupe D, Magnussen J, Beex A. A microprocessor system for multifunctional control of upper-limb prostheses via myoelectric signal identification. IEEE Transactions on Automatic Control 1978; 23(4):538-544.
[9] Yen C-J, Chung W-Y, Lin K-P, Tsai C-L, Lee S-H, Chen T-S. Analog integrated circuit design for the wireless bio-signal transmission system. The First IEEE Asia Pacific Conference on ASICs 1999; pp. 345-346
[10] Kajitani I, Murakawa M, Nishikawa D, Yokoi H, Kajihara N, Iwata M, Keymeulen D, Sakanashi H, Higuchi T. An evolvable hardware chip for prosthetic hand controller. Proceedings of the Seventh International Conference on Microelectronics for Neural, Fuzzy and Bio-Inspired Systems 1999; pp. 179-186.
[11] Torresen J. Two-Step Incremental Evolution of a Prosthetic Hand Controller Based on Digital Logic Gates. ICES 2001; pp. 1–13.
[12] Peasgood W, Whitlock T, Bateman A. EMG controlled closed loop electrical stimulation using a digital signal processor. Electronics Letters 2000; 36(22):1832-1833.
[13] Yeom HJ, Park YC, Yoon YR, Shin TM, Yoon HR. An adaptive M-wave canceller for the EMG controlled functional electrical stimulator and its FPGA implementation. Conference Proceedings in 26th Annual International Conference of Engineering in Medicine and Biology Society 2004; 6:4122-4125.
[14] Ferguson S, Dunlop G. Grasp Recognition From Myoelectric Signals. Procedures Australasian Conference Robotics and Automation 2002; pp. 78-83.
[15] Stanford V. Biosignals offer potential for direct interfaces and health monitoring. Pervasive Computing, IEEE 2004; 3(1):99-103.
[16] Park DG, Kim HC. Muscleman: Wireless input device for a fighting action game based on the EMG signal and acceleration of the human forearm. [http://melab.snu.ac.kr/Research/melab/doc/HCI/muscleman_paper.pdf].
[17] Wheeler KR, Jorgensen CC. Gestures as input: neuroelectric joysticks and keyboards. Pervasive Computing, IEEE 2003; 2(2):56-61.
[18] Manabe H, Hiraiwa A, Sugimura T. Unvoiced Speech Recognition using EMG-Mime Speech Recognition. Conference on Human Factors in Computing Systems 2003; pp. 794-795.
[19] de Luca CJ. The use of surface electromyography in biomechanics. J Appl Biomech 1997; 13:135-163.