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ELECTROMYOGRAPHIC SYNCHRONIZATION IN THE FABRICATION OF DYNAMIC 3D PRINTED HAND PROSTHESIS- AN ORIGINAL STUDY

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ABSTRACT

Aim: To fabricate a dynamic hand prosthesis using simple sensomotors and programming it using electromyographic synchronization to achieve functional movements at minimal cost.

Materials and methods: The primary design of the prosthesis was done digitally and it was simulated using 3-D printing and milled with light weight polyurethane material. For incorporating the dynamic movements into the prosthesis, motors and electromotors (flex sensomotors) which worked based on the hex code programming were used. These additives allowed free movements and functional movements in the prosthesis. Using electromyography (EMG) healthier neuromuscular coordination was synchronized from a volunteer to the prosthesis. Electromyography worked based on the recording of muscle amplitude in microamperes with two sensors. One sensor transmitted the actual amplitude levels of healthier muscular movements while the other sensor intensified or deranged the value based on the muscle threshold of the individual. The amplitude values were recorded in C code programming format, which is human interfacing language. This was then compiled into the assembly programming for the ease of evaluation.

Results: Based on the design, functional and dynamic movements were obtained in the hand prosthesis, using the synchronized EMG signals, which improved the efficiency of rehabilitation.

Conclusion: Functionally active hand prosthesis at minimal cost will pave way for rehabilitating patients and improving their quality of life.

KEYWORDS : Dynamic prosthesis, sensomotors, electromyography, hex code programming.

INTRODUCTION

Prosthetic rehabilitation of the defective parts in the oral and maxillofacial region have developed extensively in the recent past and have brought about significant improvement in the quality of life of the patients. Newer concepts in the field of prosthetics have extended beyond the boundaries of maxillofacial region to rehabilitate even the other parts of the body. Hand prosthesis is one such arena, where various studies and attempts are being made to make the prosthesis not only esthetic but also to make it functional and dynamic. Although the esthetic demands are being met by the use of silicones, making the prosthesis functional is still a challenge. This design puts forth the concept of hinge joints in fingers alike the natural anatomy of the fingers and hence the prosthesis is made dynamic. The basic prosthetic principles are combined with electronics which will improve the efficiency of the prosthesis, making it functional. Electromyographic impulses from the individual (volunteer) is synchronized to the prosthetic hand and functional movements are brought about by microcontrollers and sensomotors. Therefore, this article brings out an idea to combine electronics and mechanics that will pave way in the evolution of new age functional hand prosthesis.

MATERIALS AND METHODS

Basic structural design of the hand was obtained by CAD CAM designing of the ADA (Open Bionics®) prototype. The design was converted into STL format to proceed with 3D designing and the entire structure was milled from polyurethane bone blocks as it had the properties of enhanced flexibility that could allow for adequate motions and is biocompatible. The prosthetic hand design comprises of individual finger componentsand hollow segments to place the motors [Figure 1,2,3,4,5,6,7].

Figure 1 3D Design of hand base

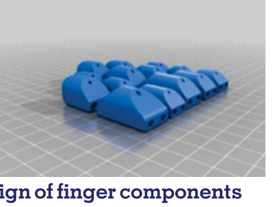

Figure 2 3D Design of finger components

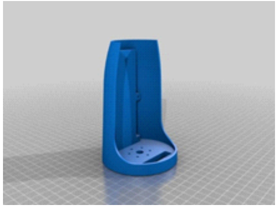

Figure 3 3D Design of forearm components

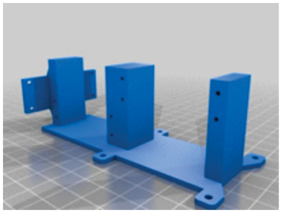

Figure 4 3D Design of motor segments

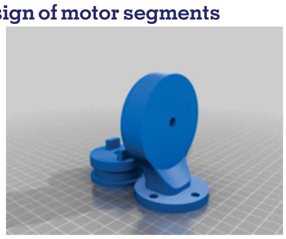

Figure 5 3D Design of elbow components

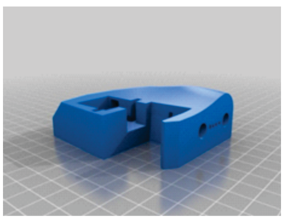

Figure 6 3D Design of palm components

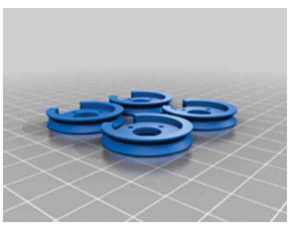

Figure 7 3D Design of thread wheels

The finger segments were attached with the rest of the components using nylon fibers that allowed free hinge movements, which in turn were connected to the sensomotors.

Three major sensomotors, one controlling the thumb motions, one controlling the index and middle finger movements and the other controlling the ring and little finger movements were setup. The dimensions of the sensomotor controlling the thumb were of size 22.8 x 12.2 x 28.5mm withvoltage of 4.8V to 6V DC weighting 13.4 grams working at speed of 0.1 sec/60degrees (at 4.8V), 0.08 sec/60 degrees (at 6.0V). The two other sensomotors controlling the rest four fingers weigh about 1.31 oz (37.0 g) with dimensions of length:1.57 in (39.9 mm), width:0.79 in (20.1 mm) and height:1.42 in (36.1 mm).These sensomotors work at speed of 4.8V for 0.23 sec/60° and 6.0V for 0.19 sec/60° with torque of 4.8V for 44.00 oz-in (3.17 kg-cm) and 6.0V for 57.00 oz-in (4.10 kg-cm) [Figure 8,9].

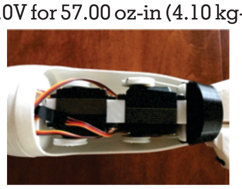

Figure 8 Fore arm components

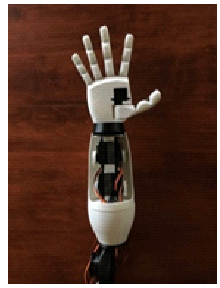

Figure 9 Printed prosthesis

The entire components were then assembled and connected to the motherboard (Arduino Uno Microcontroller Atmega328®). The motherboardconsisted of amplifiers that would send the positive and negative signals during muscular contraction resulting in functional movements of the prosthesis. Three electrodes were attached to the distal end of the arm near the biceps brachii muscleof the operator, which would sense the flow of impulses within the muscles and transmit it to the motherboard to amplify and cause movements of the prosthesis [Figure 10,11].

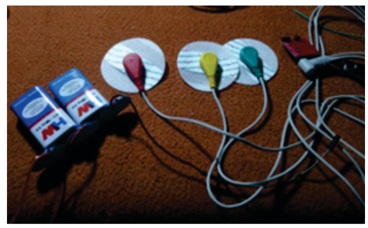

Figure 10 Electrodes

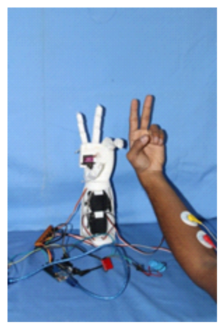

Figure 11 Assembled components

During relaxation of the muscles there was continuous flow of neural impulses through the muscle fibers.Electromyographic synchronization works by amplifying the pooled impulses during muscular contraction that would in turn cause closure of the prosthesis. Initially, an arbitrary muscle threshold value was fixed based on theindividual (volunteer) strength and metabolic index in Arduino software. These threshold values behaved as fixed units above which there will be relaxation of the prosthesis on muscle contraction and vice versa. Repeated muscle contraction and relaxation resulted in opening and closing of the prosthesis also enhancing the ability to hold the objects [Figure 12].

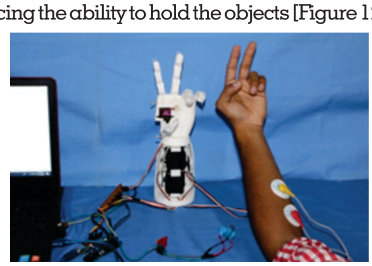

Figure 12 EMG Synchronization

RESULTS

The fabricated hand prosthesis was connected to the vounteer using an EMG (Electromyography) cord and based on the muscle contraction it was found that the prosthesis was dynamic enough to produce flexion and extension of the phalanges. The functional hand was able to hold objects like mobile phone, cups, steel rods that weight upto 1000 grams.

DISCUSSION

Technology is one area, which keeps traversing through time, leading to various developments which have made human life easier.Amputees, generally do not get acquired with the latest and technologically advanced prosthetic upper limb, as they are extremely expensive. In a developing country like India where road traffic accidents, public violence are unavoidable, amputation in such a scenario becomes essential. However, majority of the patients are not provided with functional upper limb prosthesis as the costs are on the higher side.Various authors have put forward different concepts in providing movements to the hand prosthesis. Imamura et al[1]hand's design which was developed using Gaea Drive in its joint driving mechanism. This hand can envelope and grasp an object mechanically, it can be used widely in factories where parts of different shapes and sizes must be handled.

O'Toole and McGrath[2] designed the mechanical hand which had ease of assembly and ease of replacement of SMA wires which offers more comfortable, lighter weight and quieter solution. This work can be implemented for actuation of the thumb to complete a five fingered bio-mimetic artificial hand. Kasim et al.[3] introduced a new hybrid mechanism which integrates a miniature motor driven actuation, SMA actuated mechanism and a passive mechanical linkage. It has highly improved the actuation and tactile sensing methods. The force generated by the actuator has been tested and is satisfactory for prosthetic applications.Zhang et al.[4] made a prosthetic hand controlled by a multiprocessor controller based on FPGA/DSP and its control system is composed of a finger control system and palm control system. Experiments showed that users were able to successfully operate the device in the hierarchical control strategies and that the grasp success increased with more interactive control.

Takeda H et al[5] developed a prosthetic arm with pneumatic prosthetic hand and tendon-driven wrist using a wire drive and two small motors comprised of small pneumatic actuators, they found that the prosthetic hand was safe and flexible.Since the arm had a tendon-driven wrist to expand its motion space it was able to perform many operations. Kuiken TA el al[6] used targeted muscle reinnervation for improved myoelectric prosthesis control in a bilateral shoulder disarticulation amputee where four independently controlled nerve-muscle units were the musculocutaneous nerve was anastomosed to the upper pectoralis major; the median nerve was transferred to the middle pectoralis major region; the radial nerve was anastomosed to the lower pectoralis major region; and the ulnar nerve was transferred to the pectoralis minor muscle. After five months of healing myoelectric prosthesis was attached which produced better movements.

Weir R et al[7] developed a new multifunctional prosthetic arm and hand systems in which they have used 3 articulations and 2 motors with implantable myoelctric sensors attached to peripheral nerves. Carrozza MC et al[8] did a finger with two degree of freedom for a biomechatronic artificial hand with simple grippers having one or two degrees of freedom with modular design and control embedder to enhance the grasping abilities.

Folgheraiter MI, Gini G[9] developed a human-like reflex control for an artificial hand based on dynamic artificial neurons to simulate the neurons acting in the human reflex control. The controller had a hierarchical structure. At the lowest level the receptors converted the analogical signal into a neural impulsive signal appropriate to govern the reflex control neurons. After which, the artificial motoneurons set the actuators inner pressure to control the finger joint position and moment producing dynamic movements .The developed hand was very flexible and efficient for all kind of joints present in the humanoid hand. Edin BB et al[10] developed a bio-inspired sensorization of a biomechatronic robot hand for the grasp-and-lift task using a contact sensor and a sensitive low-noise three-axial force sensor.

This design of hand prothesis is made by using simple sensomotors connected to a motherboard using nylon fibres and coupled by electromyographic synchronization. The EMG impulses obtained from the volunteer was connected to the motherboard which decoded the impulses and caused movements of the fingers by means of the nylon fibres. This prototype, has shown that it could perform grasping, rotating and lifting various objects that can be seen from the environment, when connecting to an individual and obtaining the myographic signals. This will not only mask the defect of the patient but also improve their psychological satisfaction by helping the user perform day-to-day activities to a certain extent. Prosthetic replacement by using this hand prototype will significantly improve the quality of life of the patients.

CONCLUSION

Based on the results we concluded that the hand prototype which we designed using 3D printing and synchronized to the individual's hand using electromyographic synchronization, was able to achieve functional movements like grasping and lifting objects with independent flexion and extension of fingers. Our results suggest that it is possible to make a dynamic functional hand prosthesis using electromyographic synchronization at an affordable cost which will enable the patients to make use of it, when compared to the commercially available robotic hand prosthesis which is very expensive.

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