



Design an Interfacing Tracking System in Rehabilitation Therapies Between The Elbow Joint of The Human Arm and The Prosthetic Arm

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DOI: <https://doi.org/10.30880/ijie.2020.12.08.006>

Received 9 August 2019; Accepted 28 November 2019; Available online 30 August 2020

Abstract: Myoelectric prostheses have seen an increased application in clinical practice and research, due to their potential for good functionality and versatility. Yet, myoelectric prostheses still suffer from a lack of intuitive control and haptic feedback, which can frustrate users and lead to abandonment. To address this problem, a prosthetic arm was designed to help the amputees, who unfortunately lost their upper limb. Then, the prosthetic arm was equipped with a hybrid haptic feedback stimulation system to compensate for the missing sensation and enable the amputees to easily perform their normal life activities. The tracking system between the elbow joints of the human and the prosthetic arms was required to accomplish the experimental tests with the able-body subjects. Accordingly, this study is a platform for the main project. The major problem is to synchronize the movements of the prosthetic arm's elbow joint with the human arm's elbow joint within a high response, acceptable accuracy, and low error. Therefore, the PID controller was used to control the tracking system and the flexible bending sensor was attached to the volunteer's elbow joint to record its rotational movements. The results verified the functionality of the proposed tracking system to synchronize the joints movements and enable the prosthetic arm to follow the movements of the volunteer's arm within 0.062 sec. Finally, the effectiveness of the proposed elbow joints tracking system to synchronize the motions of the volunteer and the prosthetic arms was concluded.

Keywords: Prosthetic arm, upper limb prostheses, prosthetic elbow joint, motion tracking system, flexible sensor.

1. Introduction

In spite of the fast progress in medical science over recent decades, patients of upper limb amputation have only little change in the daily life [1]. In fact, the amputees thought that most of the upper limb prostheses are still as a hook at the end of the arm [2]. According to the statistical study that has been made on 2477 amputees of upper limb mutilation [3], the basic requirement of the typical upper limb prostheses are: (i) enable the users to perform their daily life activities with less visual attention required, (ii) allow the patients to manipulate different sizes of objects as easy as possible, and (iii) design a prosthetic hand which has the highest similarity to the healthy human hand in overall appearance and functionality. However, the insufficiency to deliver exteroceptive [4] and proprioceptive [5] information makes the upper limb prostheses very difficult to control. Nowadays, many research efforts seek to overcome the challenges of the lack of sensation during using the prostheses and enable the amputees to discover their environment through their own prosthetic hands [6].

Traumatic injury or disease can lead to the loss, or the need of amputation, of a patient's hand or arm. This loss has a major impact on the patient as different tasks of day-to-day life are complicated or made impossible. Therefore, to assist patients suffering such loss, prostheses are available. Prostheses are artificial devices used to replace these missing body parts. However, it can be separated into multiple categories depending on the level of amputation, i.e. below or above elbow amputation, ranging from a single finger to amputation of the whole arm and shoulder. Prostheses can be further

classified into those simply aiming to restore aesthetic properties and those restoring functionalities of the limb as well. In order to restore functionality, prosthetics must have the option to be actuated. For instance, regarding the below elbow amputations, the most crucial function is to allow opening and closing of an artificial hand. This enables the patient to grip, hold, and manipulate objects.

Nowadays, the main goal behind designing the upper limb prostheses is to ensure that the patient could, as possible, interact normally with the social environment. Therefore, the prostheses should look like a human hand. Additionally, the upper limb prostheses should help the patients in their daily life. Consequently, the patients have to interact with their environments through their own prostheses. To ensure this, the prostheses should have motors to drive the prostheses' joints, which can be controlled by the patient and a feedback stimulation system. In addition, the prosthetic hand should be equipped with a haptic feedback stimulation system. Associated with this interactive prosthetic hand, the patients, which have unfortunately lost their hands, become able to feel and recognize their environment through their own haptic upper limb prostheses. This leads to improve their daily life activities and increases the proportion of their acceptance and comfortability to their robotic arms [7].

Thus, the following study is proposed to design an interfacing tracking system in rehabilitation therapies between the elbow joint of the human arm and the prosthetic arm. The current work is a part study of the entire designing haptic upper limb prostheses. The main goal is to make the elbow joint of the designed prosthetic arm working instantly with the elbow joint's movements of the volunteer's healthy arm. A flexible bending sensor was attached on the elbow joint of the healthy human arm to record its instant movements. Then, the output signal of the sensory system is utilized to control the movement of the prosthetic arm's elbow joint. The tracking controlling system was controlled by mean of the PID controller to minimize the error and increase the system time response.

2. Motivation

The withdrawal reflex of the human's upper arm is a normal sudden reaction of the voluntary muscles of the upper limb, in order to avoid the noxious stimulus like the thermal shock when the hand contacts a hot surface. In general, the upper limb withdrawal is accomplished by mean of the shoulder extension, elbow flexion, and wrist extension [8]. When a person touches a hot object and withdraws their hand from it without actively thinking about it, the heat stimulates the temperature and pain receptors in the skin, triggering a sensory impulse that travels to the central nervous system. The sensory neuron then synapses with interneurons that connect to motor neurons [9]. Some of these send motor impulses to the flexors that lead to the muscles in the arm to contract.

In fact, the human's brain recognizes an abnormal temperature rise in the objects in contact with the hand by the mean of the thermal's information provided by the thermoreceptors under the hand's skin. After that, the brain controls the upper limb's neural circuits to direct the arm's muscles and then drive the arm's joints, in order to move the limb in the best manner from the painful environment [10], as describe in Fig.1. The response of the upper limb has not been studied in the same detail as the lower limb; however, it has been shown that the reflex response can modulate with the phase of movement, as occurs with reaching tasks in the upper limb.

To enable the amputees to implement fast withdrawal reflexes against the thermal noxious stimulus has become an effective requiring step in developing the prosthetic arms. Furthermore, to accomplish the main purpose of creating a prosthetic arm comparable to the mechanism of the real arm, the amputee who wears the prosthetic arm must feel the change in temperatures of the environment through his own prosthetic and recognize the painful stimulus. The feedback stimulation system of the proposed haptic prosthetic arm, see Fig. 2, assists the amputees to recognize the thermal shock by utilizing its temperature sensors mounted on the prosthetic fingertip. Then, the tactile information about the abnormal thermal situation is conveyed to the amputee's brain by mean of the haptic wearable device, which is fixed on the amputee's residual limb. Indeed, haptic wearable device consist of two parts named: the hybrid haptic pressure-vibration feedback stimulation system (HHPVFSS) and the hybrid haptic surface texture-thermal feedback stimulation system (HHTTFSS). and Lastly, the brain orders the prosthetic arm's joints to rapidly drag the arm away from the danger zone. For the purpose of developing a good withdrawal reflex of the feedback stimulation system, the actuating motors of the prosthetic's arm joints, and the controller of the prosthetic arm have to be designed to work, as possible, in high response to achieve a fast withdrawal reflex.

3. Design of The Elbow Joint's Tracking System

To test the effectiveness of the haptic system to implement a withdrawal reflex, a withdrawal reflex identification test was considered. The goal of the test is to examine the ability of the haptic wearable device to excite the subject's brain about the noxious stimulus in a quick manner. The main challenge faced by the researchers in this field of study is to find amputees subjects to perform the validation experiments. The only solution for this issue is to completely depend on able-body volunteers. Whilst, the nervous systems of the amputees and healthy amputees are somewhat similar. Hence, 79.55% of 159 relative previous articles depended only on healthy volunteers to perform the validation tests, while only 18.13% of the previous works were performed on the amputees' volunteers[6].

According to what was presented above, the healthy volunteers were engaged in this work. The tracking system between the volunteer's elbow joint and the prosthetic arm's elbow joint was designed, as shown in Fig. 3. The main

reason for this tracking system is to synchronize the movement of the prosthetic arm with the volunteer's arm, in order to convey the instructions from the volunteer's brain to the prosthetic arm, directly.

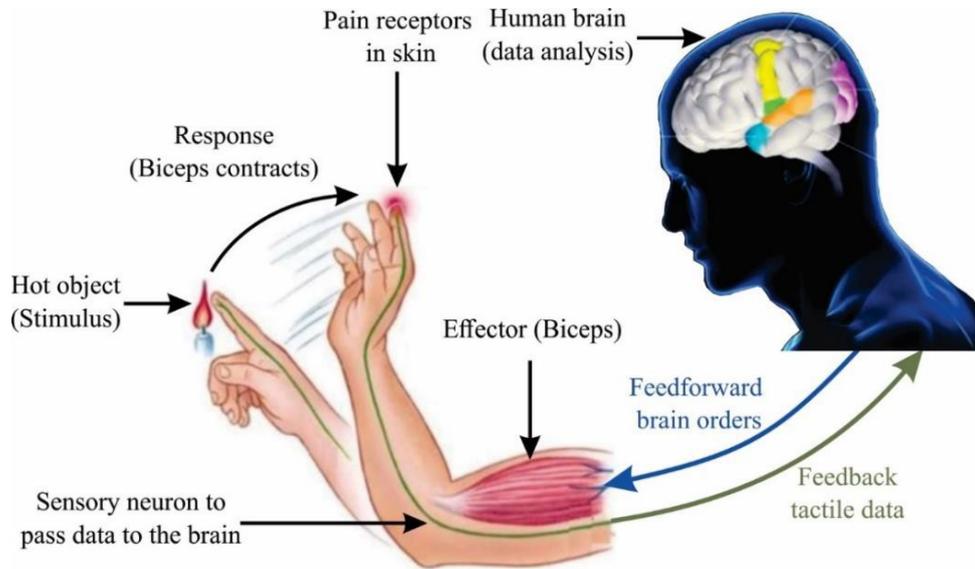


Fig. 1 - The thermal withdrawal reflex of human's upper arm [11]



Fig. 2 - Fabrication of the tactile prosthetic arm: a) front view, and b) rear view

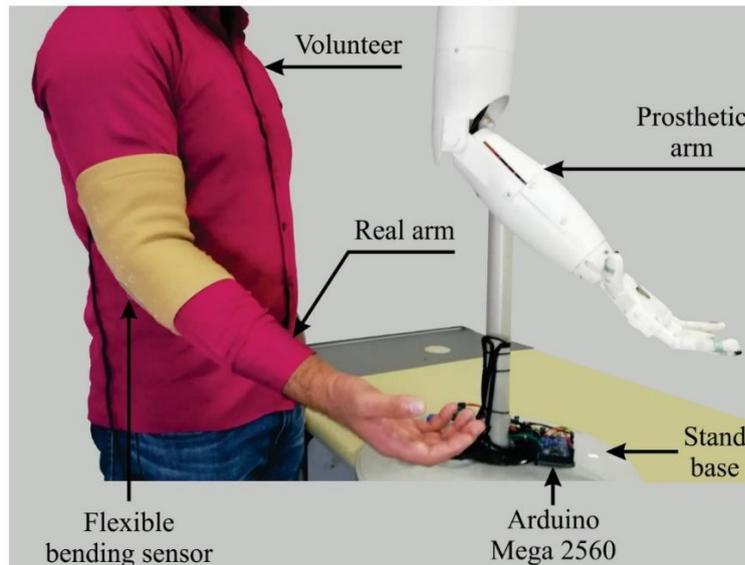


Fig. 3 - The proposed tracking system between the volunteer’s arm and the prosthetic arm

Fig. 4 shows a block diagram of the laboratory experimental setup for elbow joint tracking system. For laboratory tests, a flexible bending sensor of 4.5 inches in length [12] is mounted on the volunteer’s elbow joint by mean of elastic fixing strap. A flexible bending sensor is commonly a passive resistive device typically fabricated by laying a strip of resistive ink on a thin flexible plastic substrate. This sensor, when inlaid flat, is characterized by an intrinsic electrical resistance, which increases with the sensor’s deflection. When the volunteer’s elbow joint has a flexion or extension movements, the flexible bending sensor will record this movement and transferred it to a measurable signal varying between 0 - 5 V. Thus, the flexible bending sensor’s signal is used as the set point desired angular signal (θ_d) for the tracking system controller.

Subsequently, the desired signal (θ_d) will be compared with the actual angular position signal (θ) of the prosthetic elbow joint, which is measured by the potentiometer sensor. The PID controller [13-15] was used to manipulate the produced error signal (e), in order to control the movement of the elbow joint’s servomotor and to make the prosthetic arm follow the movement of the volunteer’s arm as fast as possible.

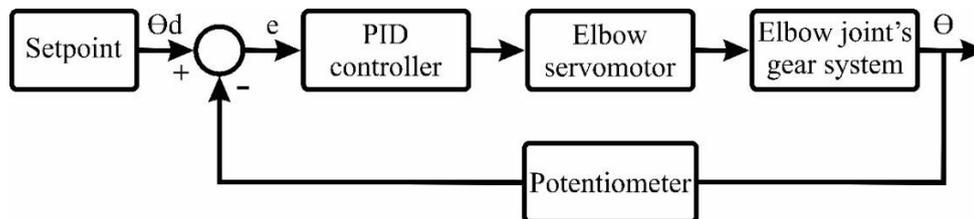


Fig. 4 - Block diagram of the elbow joint tracking system

Before starting the experiments of the tracking system, the flexible bending sensor of the volunteer’s joint and the potentiometer sensor for the prosthetic arm elbow’s joint must be calibrated, in order to ensure that the output of each sensor matches the joints limitations. The movements of the elbow joint angle for the healthy and prosthetic arms were measured by a goniometer in 1°-scale following the measurement method recommended by the Japanese Orthopaedic Association, as shown in Fig. 5. During the measurement, subjects stood and relaxed at the anatomical position. The experimenter places one arm of the goniometer along the long axis of the humerus, and the other arm along the long axis of the radius. Then, the experimenter measures the limitation of angels and calibrates the flexible sensor and the potentiometer sensor according to it.

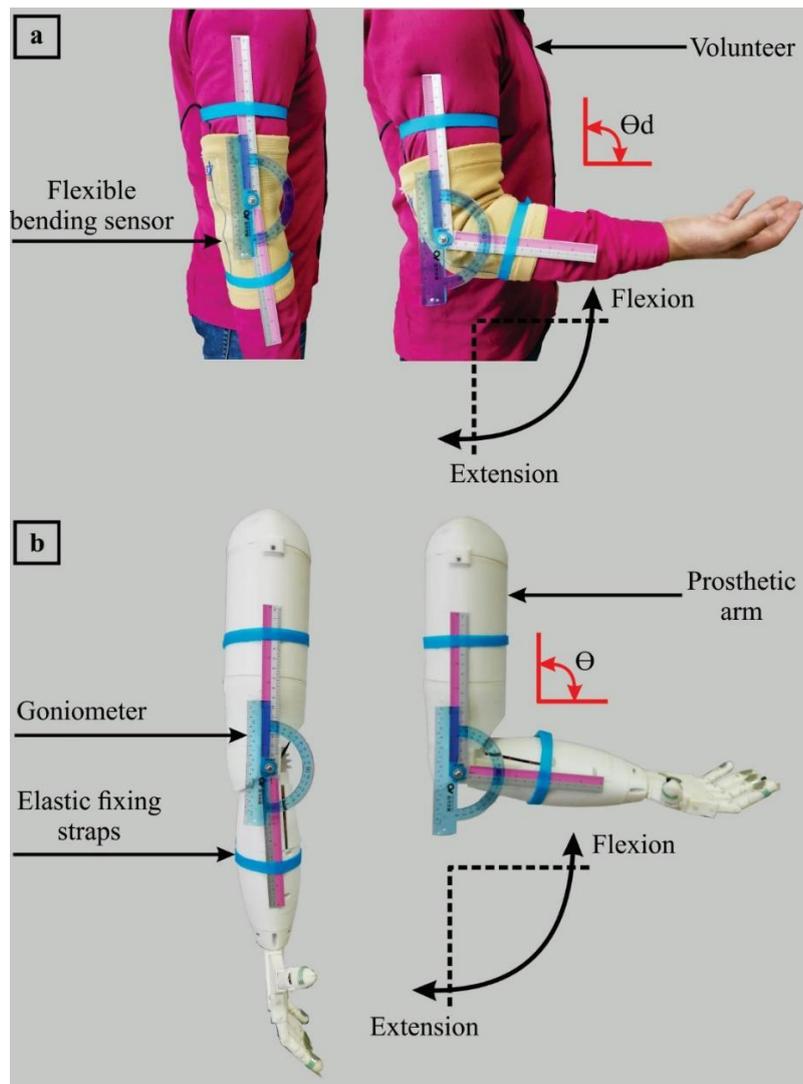


Fig. 5 - The calibration of the elbow joint's angular position: a) the volunteer arm, and b) the prosthetic arm

4. Experimental setup and procedure

In the evaluation experiments, the prosthetic arm and the computer were placed on the table and the healthy subjects were seated against the table in a full rest position, as shown in Fig. 6. The upper limb amputees were simulated by an able-body volunteers (20 males and 20 females, mean age (SD) 25.478 ± 4.45 years). The subjects were right-hand dominant and did not suffer from any cognitive impairment that could affect their performance during the tests. The HHPVFSS and HHTTFSS were installed on the subjects' right upper arm. In addition, the flexible bending sensor of the tracking system was fitted to the subjects' elbow joint to measure its movements. Finally, the subjects' vision and hearing were obstructed using an eye mask and earmuffs to prevent this information from influencing the subject's perception.

5. Result and discussion

The average comparison between the angle responses of the flexible bending sensor due to the volunteers healthy arm's elbow flexion/extension and the potentiometer sensor due to the tracking movement of prosthetic arm's elbow joint are described in Fig. 6.a. Here, the vertical axes represent the position of the elbow joint in degree while the horizontal axes indicate the experiment time in second. It is clearly noted that the volunteer, who wore the flexible bending sensor with his healthy right arm, completely flexed his arm from 0 - 120 degrees and extended it from 120 - 0 degrees at 0 sec and 0.28 sec of the experiment time, respectively. It seems to be a smooth signal due to the high usage of filtering process. Meanwhile, the tracking response of the prosthetic arm's elbow joint followed the volunteer's arm movement within 0.062 sec transit time. On the other hand, at the steady state time, the PID controller worked on keeping the prosthetic joint's position within its desired value. Fig. 6.b shows that the maximum tracking error between the two responses at the steady state time did not exceed 5 degrees. This indicates the acceptable effectiveness of the tracking system and the functionality of its controller.

6. Conclusion

In an overall study, a new lightweight, a low-cost prosthetic arm was designed, fabricated, and evaluated, to be eligible to use by the amputees of upper limb mutilation. While this paper focuses on design, fabricate, and evaluate an interfacing tracking system in rehabilitation therapies between the elbow joint of the human arm and the prosthetic arm. The main purpose of this study is to evaluate the ability of the prosthetic arm to perform a withdrawal reflex as fast as possible similar to the real human arm. The overall conclusion and recommendation from this study were based on the evaluation results and the volunteers' experience. The results proved the ability of the proposed tracking system to synchronize the movement of the volunteer's elbow joint and the prosthetic arm's elbow joint. Accordingly, the human brain can be excited about abnormal noxious stimulus and make the volunteers perform a quick withdrawal reflex within 0.062 sec. The future work will study the first attempt to design and evaluate a thermal haptic feedback stimulation system can assist the operator of the haptic prosthetic arm to implement a withdrawal reflex due to the thermal noxious stimulus.

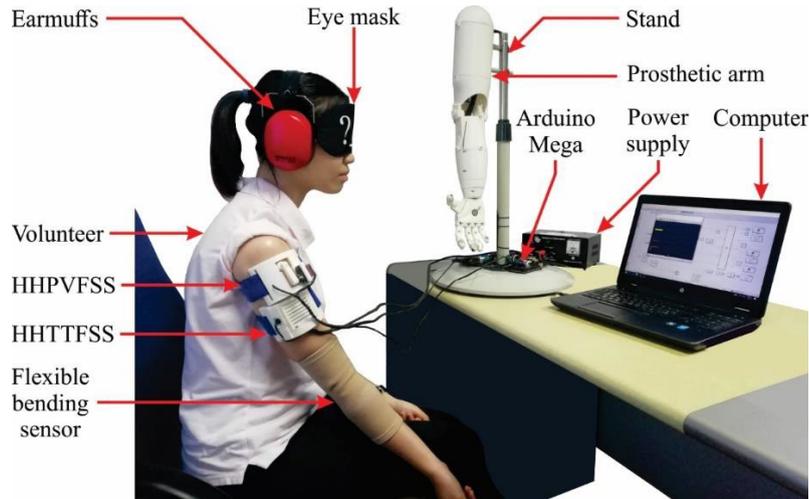


Fig. 6 - Experimental set-up: evaluating the effectivity of the haptic wearable device to convey the tactile information

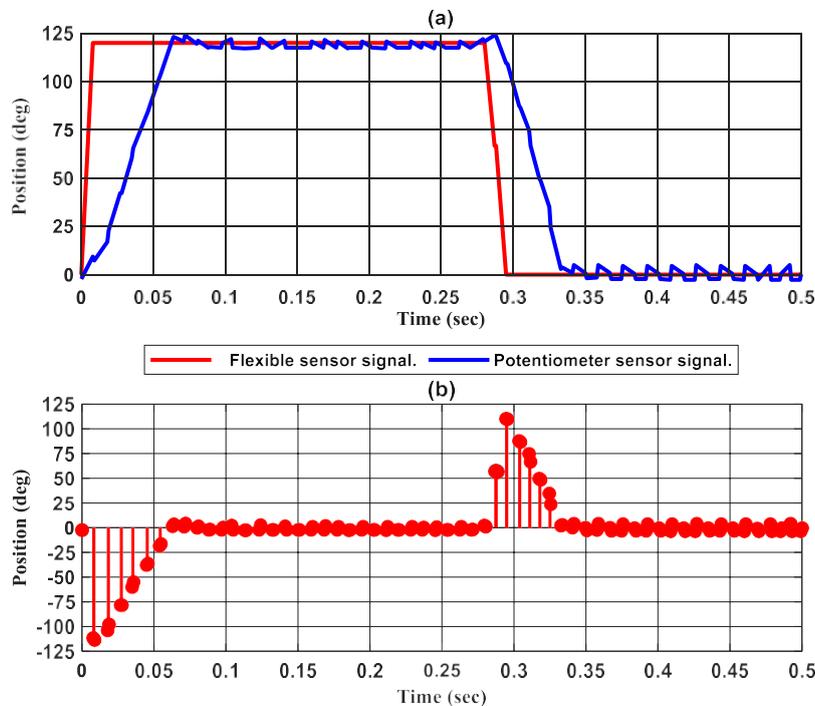


Fig. 7 - The angle responses of the flexible bending sensor and the potentiometer sensor: a) the comparison, and b) the deviation

Acknowledgement

The authors would like to acknowledge University of Tun Hussein Onn Malaysia.

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