An f-MRI study of an EMG Prosthetic Hand Biofeedback System

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Abstract: The need of biofeedback in Man-Machine interfaces is of vital importance for the development of subconscious control with external devices. In order to include external devices into the user's body schema, we need to provide more information channels to the human body. In this case study we focus on a EMG controlled prosthetic system. We use electrical stimulation to translate pressure information into biofeedback for the human body. We used functional magnetic resonance imaging in order to measure the effectiveness of this system.

Keywords FES, Biofeedback, Cortical Reorganization, fMRI

Introduction

The development of myoelectric prosthetic hands has advanced incredibly since their introduction in 1960 [1]. Some studies present the preference of the myoelectric prostheses over body powered and cosmetic ones, due to its functionality. Still there is the need for tactile feedback in these systems. Some research has been done on electrically powered prosthetic devices [2, 3] and the increase in their efficiency when using some forms of tactile feedback [4, 5], but there is a little research done on the application of biofeedback to provide information to the human body [6, 7].

In the man-machine interfaces we find some research [8] on haptic interfaces in order to provide tactile feedback. Their direct application to prosthetics is limited due to the fact that all these researches focus on the sensorial substitution using the finger tips. Regrettably, those cannot be applied to prosthetic devices where the user presents partial or complete loss of the arm, which are our interest in this study. Therefore, we need to find a different way to provide sensorial information to the human body. It is been demonstrated that the brain works with correlative information, therefore when provided with simultaneous stimuli, the brain can associate the stimuli into a unique event [9, 10]. Using this knowledge, we can generate new sensations, provided that the stimulus is simultaneous, so the person using a prosthetic hand can have sensorial feedback besides the visual.

Our proposal is to use electrical stimulation to interact with the human body providing tactile information. In his study, we use an EMG controlled electrically powered prosthetic hand with 13 DOF (Figure 1).

The system uses a neural network as classification unit to identify the intended movement from the user based on [11].

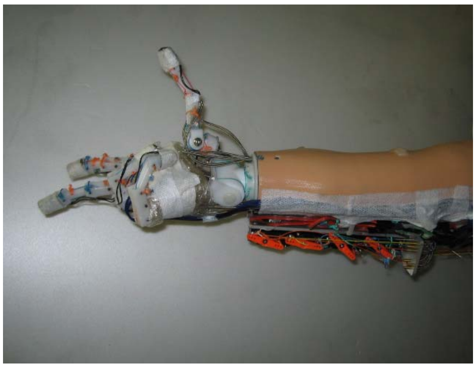


Figure 1Myoelectric Prosthetic Hand

As in the studies done on control of Functional Electrical Stimulation (FES) using Electromyography (EMG) signals [12], the electrical noise generated by the electrical stimulation affects the EMG signal processing, sometimes, overwriting the signal generated by the muscles. This becomes a challenge for the current system. In this study we intent to provide feedback to the hand user to interact with the environment in order to develop extended proprioceptive control of the robot hand. In this paper we present the results from our system information transition to the human body without affecting the EMG acquisition process by the electrical stimulation. In order to evaluate our system we used a functional magnetic resonance imaging system to measure the activation on the brain due to the electrical stimulation.

Background

In medicine, biofeedback is used as treatment of several illnesses by providing information of the internal status of the body to the patient. For purposes of this paper, we treat the term “biofeedback” not only as the information acquired from the human body for control, but also, we include the information provided to the human body. There has been some work going on the application of different types of feedback besides visual to increase the efficiency in the interaction with mechatronics systems [7]. In most of the cases, the objective is to provide some form of tactile feedback, either to the human body or directly to the controller to improve its performance.

To provide artificial feedback to the body, we could either, connect directly to the nervous system (invasive solution) or use sensory substitution (visual, auditory, tactile). The first solution might provide more reliable information to the brain, but there is high risk of rejection from the body, as well as, the development of infectious diseases. The use of visual or auditory feedback is not reliable enough when extended proprioception is intended [13]. Tactile and proprioceptive feedback substitution for artificial limbs can use direct neural stimulation, transcutaneous stimulation, or mechanical vibrators.

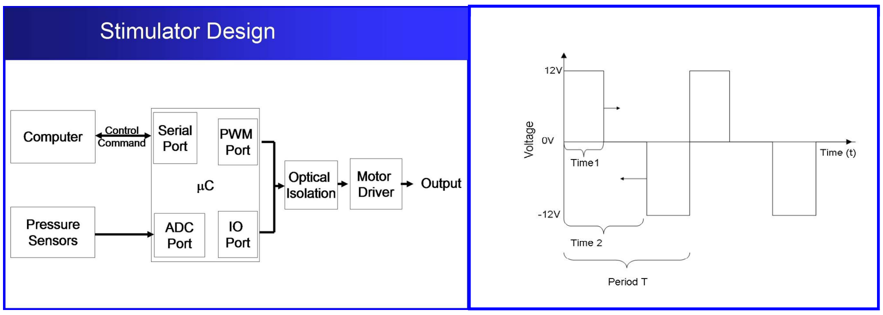
There has been some research concerning the use of electrical stimulation in order to provide proprioceptive feedback in lower limb prosthesis mentioned in [14]. From the results of these studies, it’s been show the benefits of providing biofeedback. We decided to provide tactile feedback to the prosthesis’ user by means of electrical stimulation.

The use of myoelectric prostheses helps to reduce phantom pain and cortical reorganization in the brain [15]. There are some studies that try to measure the effects of the use of myoelectric hands [16] as well as to measure the activation in the brain of imaginary hand movements [17] using magnetic resonance. In this study we use functional magnetic resonance imaging to measure the activation on the brain due to the hand movements along with the tactile feedback provided by the electrical stimulation.

Methods

This study focuses in the development of biofeedback, in this particular case, the transmission of tactile information from a prosthetic hand into the human body. In this paper, we describe the effects of the electrical stimulation when providing tactile feedback to the human body. In order to measure such effects we used a functional magnetic resonance imaging device.

The system can be divided in two parts, EMG classification part and sensory part. The EMG classification system is based on the work done in [11,21]. The sensory part is composed by the electrical stimulator connected to the body. The stimulator device used during the course of this study was constructed using a Hitachi’s tiny H8 microprocessor. Figure 2a shows the stimulation device design used for this study.



a) b)

Figure 2 a) Stimulator Design. b) Stimulator Output signal

The device has two output channels; the signal at channel 0 is generated by using the PWM port of the microcontroller. The output signal at channel 1 is generated by software, using general I/O ports of the microcontroller. The device is controlled by receiving the control commands from the computer using serial communication at 19,200 Bauds. The voltage output is set at 9 Volts. This device uses the biphasic stimulation method [18,19] (Figure 2b), because it requires of less energy to provide with the same effects of other stimulations, keeping the flowing current at a low level (10mA). The device translates the signal obtained from the pressure sensors into a pulse based electrical stimulation signal, providing with tactile feedback to the system user's body. The stimulation level control is done by changing simultaneously the duty rate of both phases, positive and negative, while keeping the pulse frequency constant. For purposes of this study, we used only the channel 1 of the stimulator.

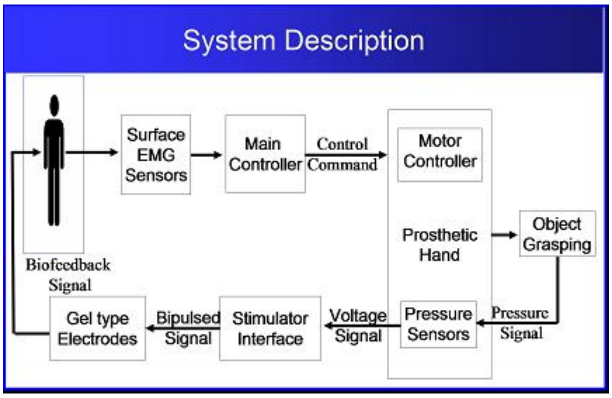


Figure 3. The diagram shows the distribution of the different components of the system.

A. Experimental Setting

In order to measure the effects of the electrical stimulation when using the EMG prosthetic hand, we performed the following experiments with system as shown in Figure 3.

To identify and measure the brain activation due to the electrical stimulation, we applied two different levels of stimulation low and high. In order to determinate the stimulation levels, due to individual changes, we increased gradually the stimulation until the stimulation was perceptive enough (22%) to set the lower level. For the higher level of stimulation, we continue increasing gradually the stimulation until the feeling was stronger than the previous stimulation, but without any unpleasant reaction (44%). We used one channel for the surface electrical stimulation. Figure 4 a) shows the place used during the course of the experiment for the stimulation electrodes. The distance between electrodes was set to 1 cm to avoid muscle contractions.

For this experiment, we used a test subject (amputee) and a control subject (healthy person). The test subject presents a 5 years old right arm amputation in the forearm. Figure 4 c) shows the amputee arm. For the pattern classification process, the surface EMG sensors were located as shown in Figure 4 c) and b). For this experiment, we trained the classifier with the following motions: fingers flexion/extension, wrist flexion/extension, thumb flexion.

Cerebral activity was measured with fMRI using blood oxygen level-dependent contrast [22]. After automatic shimming, a time course series of 59 volumes was obtained using single-shot gradient-refocused echo-planar imaging (TR = 4000 msec, TE = 60 msec, flip angle = 90 degree, inter-scan interval 8 sec, in-plane resolution 3.44 x 3.44 mm, FOV = 22 cm, contiguous 4-mm slices to cover the entire brain) with a 1.5T MAGNETOM Vision plus MR scanner (Siemens, Erlangen, Germany) using the standard head coil. Head motion was minimized by placing tight but comfortable foam padding around the subject's head. The first five volumes of each fMRI scan were discarded because of non-steady magnetization, with the remaining 54 volumes used for the analysis.

The fMRI protocol was a block design with one epoch of the task conditions and the rest condition. Each epoch lasted 24 seconds equivalent to 3 whole-brain fMRI volume acquisitions. Data were analyzed with Statistical Parametric Mapping software 2 [23]. Scans were realigned and were transformed to the standard stereotactic space of Talairach using an EPI template [24]. Data were then smoothed in a spatial domain (full width at half-maxim = 8 x 8 x 8 mm) to improve the signal to noise ratio. After specifying the appropriate design matrix, delayed box-car function as a reference waveform, the condition, slow hemodynamic fluctuation unrelated to the task, and subject effects were estimated according to a general linear model taking temporal smoothness into account. Global normalization was performed with proportional scaling. To test hypotheses about regionally specific condition effects, the estimates were compared by means of linear contrasts of each rest and task period. The resulting set of voxel values for each contrast constituted a statistical parametric map of the t statistic SPM {t}. For analysis of the each session, voxels and clusters of significant voxels were given a threshold of $P < 0.005$, not corrected for multiple comparisons.

In order to measure the effects of the stimulation while using the prosthetic hand we set the following setup. First we trained the EMG classification system for each subject. In this experiment we used the fingers flexion/extension task to grab a sphere. In order to provide with visual feedback, we used a video camera to show the subjects the prosthetic hand movements while inside the fMRI device. The subjects see the image through a set of mirrors that allow transmit the image from the video camera (Figure 4e).

The subjects were requested to grab the sphere as soon as they saw it approach the prosthetic hand. When grabbing the sphere the pressure sensors placed on the hand were activated sending the stimulation signal at 44% of the maximum output to ensure that the test subjects perceived the stimulation while inside during the scan acquisition process.

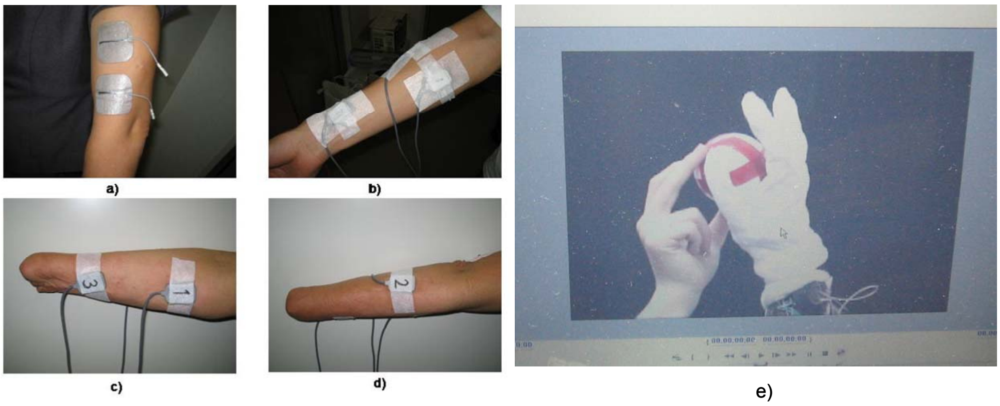


Figure 4 Shows an example for the surface stimulation method electrodes placement. a) gel type surface stimulation electrodes (PALS), b) surface EMG sensors (control subject), c) and d) surface EMG sensors (amputee) e)The image of the prosthetic hand was projected inside the fMRI device through a mirror array to show the movements of the prosthetic hand

Results

From previous experiments we found that when using surface electrical stimulation, the subjects were able to identify the changes in the stimulation strength with a delay of 300 ms. The dynamical changes were discriminated properly, whether the stable phase level showed an error between 13% and 17%. The subjects were able to say when the stimulation changed, but needed some training in order to differentiate the different levels of stimulation (Figure 5).

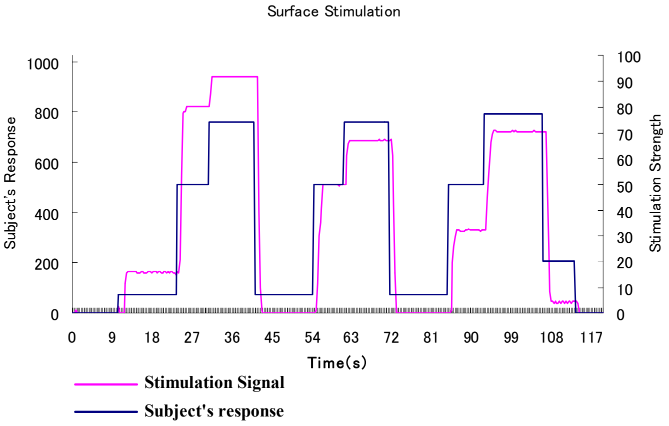


Figure 5 Response to the surface electrical stimulation

When analyzing the effects on the EMG signal with the frequency spectrum, we found a small effect in the 50-60 Hz, with a more influential part at the higher frequencies. The EMG signal information is found between the 1-500Hz, by applying a low pass filter at 50 Hz we nullify the effects of the stimulator over the EMG pattern classifier (figure 6).

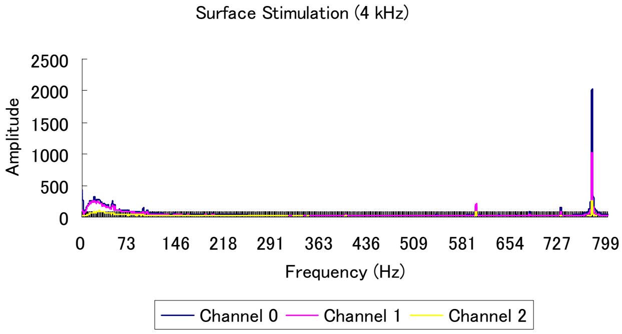


Figure 6 Spectrum analysis of the electrical noise produced by the stimulator over the surface EMG sensors

For the fMRI data analysis we used a value of $p=0.005$ (spm2), resulting in a threshold value of 2.59. With these settings, we found that when applying surface electrical stimulation only, the brains of the test subjects presented activation on the frontal lobe, denoting the processing of a new sensation, but the activation on the somatosensory and parietal area was not localized on a specific point.

When the subjects were asked to grab the sphere using the prosthetic hand, the results show a decrease in the activation on the frontal lobe, as well a decrease in the activation on the posterior parietal lobe, instead, we found a clear activation in the primary motor cortex due to the hand activation. We also found that the activation on the visual cortex does not appear in this test. Besides the activation on the right hand area, we found activation on the somatosensory area related with the right hand.

The amputee subject present activation on the frontal lobe, equally to the healthy subject, for the application of electrical stimulation at 44% of the maximum on the left arm (healthy arm). The activation on the visual cortex is higher that the activation found on the healthy subject. The electrical stimulation again is not localized in a specific area.

In the grasping case, the activation in the amputee brain increased along the primary motor cortex related to the right hand, due to the use of the right hand muscles for the prosthetic hand control. When asked, this person affirmed that there is still the image of the hand, which is what is used in order to control the prosthetic hand.

In the primary somatosensory cortex, we see an increase in the activation, principally in the area related to the hand, but also, we see the activation on the area related on the left arm, where the stimulation is actually performed.

After the fMRI scanning, the subjects were questioned on the sensation perceived during the grasping task. The results verified that the subjects presented an illusion of being touching the sphere. The illusion of feeling as if the right hand were touching the object is found in both cases (healthy and amputee subjects). The control subject presents a more specific activation than the amputee one. This may be related to the lack of use in the daily life of the right hand, besides the cortical reorganization present in amputees due to the lack of sensorial input from the missing limb.

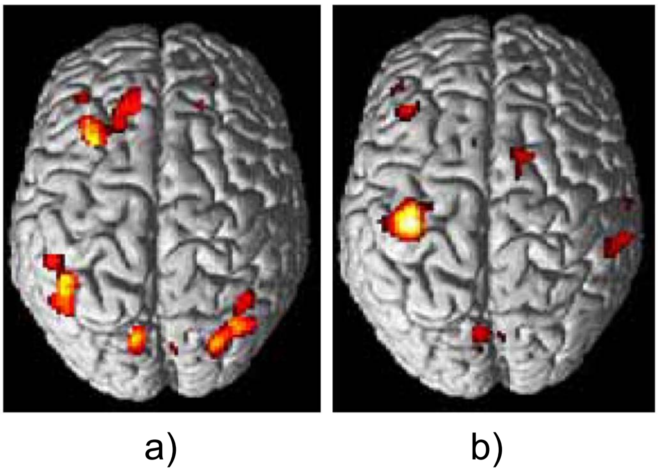


Figure 7 Comparison between the stimulation results. a)electrical stimulation at 44% , b) grabbing an object while receiving stimulation at 44%.

In Figure 8 we can see in the case of the healthy subject the clear differentiation the stimulation when provided along with the grasping action using the prosthetic hand.

Discussion

In the course of these experiments we confirmed the importance of the simultaneous stimuli needed for the brain to correlate, in order to be identified as a single event, opening new channels in the man-machine interaction. The fMRI is a useful tool to measure in an objective way the changes due to the interaction with the system proposed. Still there are several challenges to deal with, such as electrical noise while inside the fMRI chamber for it to become a more practical use. From the previous studies in neuroscience, there was the knowledge on the brain workings, that can be use now in order to generate more efficient man-machine interfaces. In this study we confirm the need for more sensorial channels for prosthetic applications. Along with continuous use and training, the correlation between visual and sensorial stimuli can be strengthened, allowing the development of a more close relationship. In the future work, we expect to continue measuring the development in the sensorial cortex due to continuous use of the prosthetic hand with sensorial feedback.

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