Sensation Generation using Electrical Stimulation for a Prosthetic System

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Abstract – We propose the use of electrical stimulation to generate a new sensorial input to the human body to improve the man-machine interfacing, increasing the communication channels between a robot and the human body. This study focus on the sensation generation for a electromyographic (EMG) prosthetic hand, where the need of "biofeedback" is of vital importance to achieve subconscious control. We use electrical stimulation as a substitute for tactile feedback. The study shows the importance in the relationship between the intentionality from the user and the feedback provided to the body. This relationship allows the brain to correlate the information in one single event. We used an fMRI device to measure the activation of the brain related to the motor and somatosensory areas to confirm the sensation generation on the brain

Index Terms – Biofeedback, electrical stimulation, man-machine interfaces ,fMRI..

I. INTRODUCTION

The generation of new sensory channels for the communication between the man and the machine is important to develop better interfaces and control systems, closer to the human body. One particular case in the interaction between man-machine is the prosthetic device. The application of intelligent machines has improved the efficiency of prosthetic devices, with adaptive mechanisms and algorithms that interact and learn from the human body. One particular case is the electromyography (EMG) controlled devices, more specifically, the development of myoelectric prosthetic hands, which has advanced incredibly since their introduction in 1960. Still, one mayor drawback of the EMG controlled devices is the minimal or nonexistent biofeedback, that is, information on the status of the prosthetic device, hand or leg, to the body. Our body is a multimodal system that uses several channels to obtain the current status of our bodies, if one channel fails; there are still others that help to provide the missing data. The user of a prosthetic hand needs to overcome the lack of tactile and proprioceptive data with visual feedback, which causes to fatigue faster because of the increment of conscious effort to control the hand. These mechanisms need the implementation of a feedback source that enables the user to develop extended physiological proprioception.

Previous studies point out the advantage of using electrical stimulation, but fail to measure its effects on the brain.The brain works with correlative information, therefore when provided with simultaneous stimuli, the brain can associate the stimuli into a unique event. Using this knowledge, we can force the brain to produce new sensations, provided that the stimulus is simultaneous, so the person using a prosthetic hand can have sensorial feedback besides the visual. In order to do it we use electrical stimulation to interact with the human body providing tactile information.

In this study, we use an EMG controlled electrically powered prosthetic hand with 13 degrees of freedom (DOF) (Fig. 1) with a feed-forward neural network as classification tool (Katoh 2005) to identify the intended movement from the user . In this paper we show the relationship between the stimulation with the intention from the user, using an functional magnetic resonance imaging (FMRI) device. The prosthetic system developed in our laboratory is based on the concept of mutual adaptation between the machine and the human body. In order to acquire the motion intended by the human body, we extract the EMG signals from the body, which are processed in the computer, which sends the control commands to the robot hand. When the robot hand touch an object, the pressure measure by the pressure sensors on the hand is translated into the biofeedback for the body (Figure 2).

FIG. 1 EMG controlled prosthetic hand

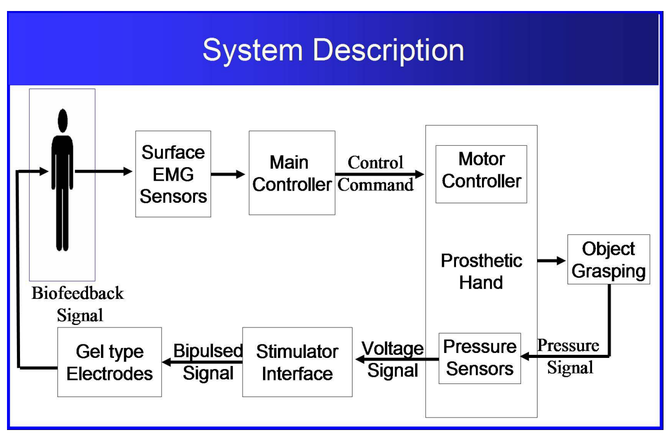

FIG. 2 Prosthetic System diagram.

II. MATERIALS AND METHODOLOGY

The prosthetic system in our laboratory uses an adaptive discrimination method to classify the human intention using the EMG signal from three sensors placed on the forearm of the user. There are several methods to provide the prosthesis to the human body that can be divided in invasive and non invasive. We focus our research in the non-invasive method. This method does not interact directly with the natural pathways, but is easier to develop, does not require complex surgical interventions, and the rejection from the body is minimal. In this study we use transcutaneous electrical stimulation, which also can be applied during the scanning inside the functional magnetic resonation imaging chamber.

The use of visual or auditory feedback only is not reliable enough to provide with sensory feedback for proper subconscious control of the artificial limb. In order to solve this drawback, we need to provide with tactile information, that is, a way for the body to interact directly with the environment. In previous studies, the electrical stimulation has been used to provide an on-off signal as sensory feedback, with promising results, but lack of more objective system evaluation. The participants to these experiments shows an improvement in their use of the prosthetic device, and even voice the opinion of "feeling" the robot hand more as part of their bodies. Although these studies present promising results, we still need to understand more the relationship between the man and the machine for better future applications.

One of the drawbacks of using electrical stimulation is the "noise" generated by it. This noise can affect the discrimination of the EMG signals. We need to implement a system that, while providing the necessary feedback, does not affect the discrimination of the user's intention.

We transmit the tactile information from the prosthetic hand to the body using a transcutaneous electrical stimulator developed in our laboratory that works as a transducer between the forces applied over the pressure sensors installed on the finger tips and the palm of the robot hand and the biphasic square signal applied to the body.

The transcutaneous stimulator device used in this study was built using a Renesas tiny H8 3664 microprocessor. We produce the stimulation signal using the PWM port 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 9Volts. This device uses the biphasic stimulation method, because it requires of less energy to provide with the same effects of other stimulations, keeping the flowing current at a low level (10mA). We regulate the intensity of the stimulation by changing simultaneously the duty rate of both positive and negative phases, while keeping the pulse frequency constant.

A. Experimental Setting

Using the prosthetic system described above, we perform a series of experiments to measure the activation on the region SI of the brain to see the effects of the electrical stimulation when its works as biofeedback for the myoelectric prosthetic hand. In order to measure the effects we first evaluated the response of the body to the stimulation alone as an unrelated event. Following, we measure the brain activation to the electrical stimulation when is applied as a result of the robot hand touching and object, working along with the intention from the body and the visual feedback.

As stated above, we regulate the stimulation by changing the duty rate of the signal, thus, any reference to the intensity in the stimulation will be stated according to the percentage of the duty ratio. The neural transcutaneous electrodes were placed on the upper left arm. This is done in order to avoid the insertion of electrical noise due to the electrical stimulation. The distance between electrodes was set to 1 cm. Our control group consisted of two healthy men in their 20's, who do not present any visible physical alteration. We placed the sensors similarly to the amputee.

Our test subject for this experiment is a right arm amputee woman in her 50's. The amputation was performed 5 years previously to this study. The amputation was performed over the wrist level, leaving most part of the forearm intact. The surface EMG sensors were placed over the right forearm, bellow the elbow joint as shown for the pattern classification process. For this experiment, we trained the classifier with the following motions: fingers flexion/extension, wrist flexion/extension, thumb flexion.

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 (Fig. 3). This is necessary because the fMRI does not allow the inclusion of the robot hand inside the room, due to the strong magnetic force produced by it.

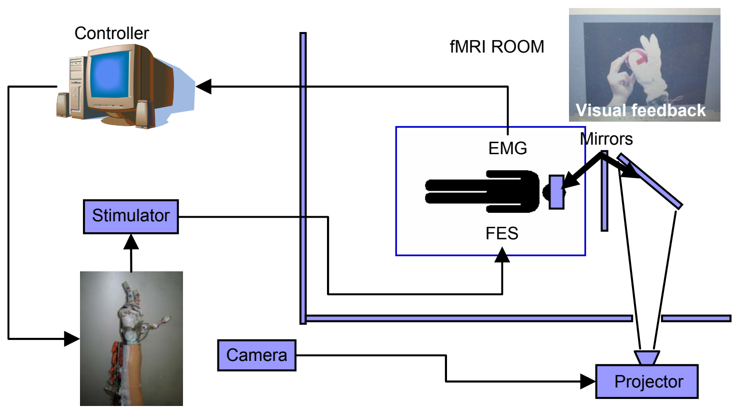

FIG. 3 Experimental setup. The subject lies inside the fMRI device with the EMG sensors on the right hand amd the neurostimulation electrodes on the left arm. The visual feedback is provided by an array of mirrors that shows the image of the prosthetic hand inside the fMRI device,

Cerebral activity was measured with fMRI using blood oxygen level-dependent contrast. 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 analysed with Statistical Parametric Mapping software 2. The functional magnetic resonance test was set to 8 seconds, with a scan time of 3 seconds, and a rest time of 5 seconds between scan. 54 scans were acquired for each test. The scans were realigned and transformed to the standard stereotactic space of Talairach using an EPI template. 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.

B. Experimental Procedure

For the experiment related to the hand movement with biofeedback, first, we configured the EMG motion classifier for the subject, that is, we trained the neural network to match the EMG signals for each participant and its corresponding motion in the robot hand. In particular, for this experiment we used the fingers flexion/extension motion to grab a sphere using the robot hand.

The subject was requested to grab the sphere as soon as she see it approached the prosthetic hand in the image produce by the camera inside the fMRI room. When grabbing the sphere the pressure sensors placed on the hand were activated, and its pressure signal translated into the transcutaneous electrical stimulation signal of 44% to ensure that the test subjects perceived the stimulation while inside during the scan acquisition process.

III. RESULTS

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 (Fig. 8). The EMG signal information is found between the 1-500Hz, by applying a low pass filter we clear the effects of the stimulator over the classifier.

For the fMRI data analysis we used a value of p=0.005 (spm2), resulting in a threshold value of 2.59. The amputee subject presented activation of the frontal lobe, for the application of electrical stimulation at 44% on the left arm (healthy arm). The fMRI analysis shows that the electrical stimulation is not detected on the somatosensory area S1 (Fig. 4), but is spread on the parietal lobe, in charge of the somatosensory information processing. The test shows that the test subject presents some cortical reorganization.

For the amputee, when grasping the cylinder using the robot hand, the activation in the amputee brain increased along the primary motor cortex (M1) related to the right hand. When asked, this person affirmed that there is still the image of the right hand, which is what she used in order to control the prosthetic hand. Figure 5 shows an increase in the activation in the primary somatosensory area (S1), 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 illusion of feeling as if the right hand were touching the object is found in most of the cases.

IV. DISCUSSION

Corroborating the finding in neuroscience, the brain does react to the application of electrical stimulation (activation of the frontal lobe), but the activation on the somatosensory region of the left arm is not high enough to appear in the fMRI image. Therefore, the electrical stimulation alone does not produce an activation of the primary somatosensory area (S1), the area in charge of the processing of sensation in the specific parts of our bodies.

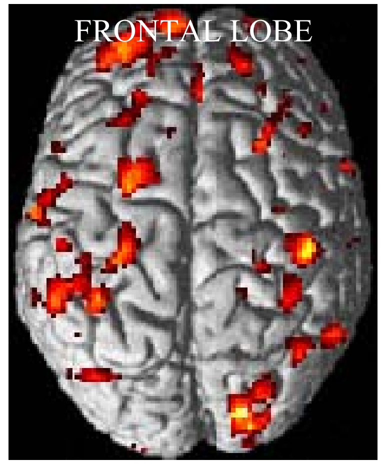

FIG. 4 Shows the fMRI resulting after applying the transcutaneous electrical stimulation on the left arm for the amputee. It is important to notice the activation on the frontal lobe, which identifies the stimulation as new information for the body.

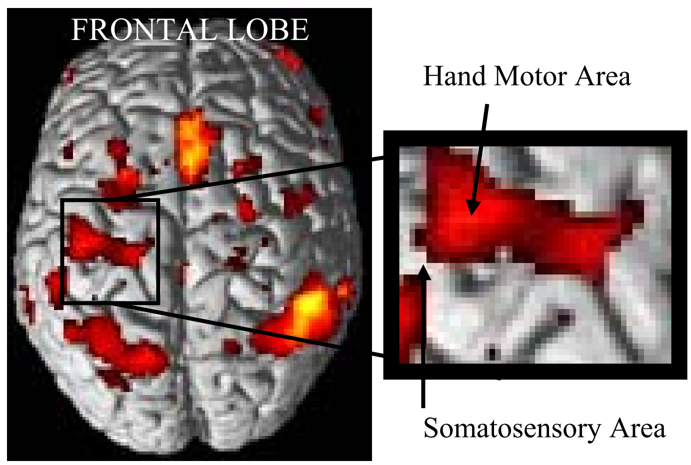

FIG. 5 shows the image resulting after the fMRI scanning for the amputee grabbing a cylinder using the robot hand with electrical stimulation functioning as tactile feedback. The image on the right is the zoom out of the motor and somatosensory area related to the hand and arm. The upper part shows the activation of the motor area in charge of the right hand movement, the lower part shows the reaction from the somatosensory area related to the hand. It is important to notice that the subject does not have the right arm to touch any object.

When the stimulation is applied in concordance with the action of grabbing an object, we have three channels working altogether, the intention from the subject, the visual feedback, and the stimulus provided by the electrical stimulation. This action is done several times during the scanning process (8 min), which allows the brain to correlate this information as a simultaneous and repetitive event. The fMRI resulting shows how the brain changes the perception of the electrical stimulation applied on the left arm. Now, the primary somatosensory area (S1) related to the hand presents an activation high enough to be detected in the fMRI image. The brain still recognizes that the stimulation is done on the left arm. Although, when we compared the results to those of the stimulation alone, we found the activation related to the motion of the hand on the motor cortex, but also, we found the activation of the sensory area related to the right hand. This makes us think that the brain is correlating the multi-sensorial input as a single event, localizing it in to the right hand (in this case, the prosthetic hand). It is important to notice that the subjects do not interact directly with the object in question, but through the robot hand. They receive only visual feedback through the video display and the stimulation on the left arm.

The application of electrical stimulation does seem to affect the adaptation of the amputee to the use of the prosthetic hand. The application of electrical stimulation as tactile feedback, does allows the body to identify the interaction of the hand with the environment, allowing for a new channel of information to work in benefit of the adaptation to the new "Limb".

These results show the possibility to use the brain plasticity into the generation of new communication channels with the robotic system. The fMRI proved a useful tool to measure objectively the changes in the cortical activation due to the use of the prosthetic system, and allowing a more detailed feedback on the workings of the amputee brain. This allow for a more detailed medical evaluation for the rehabilitation process of an amputee.

The EMG prosthetic hand allows reverting to some extent the process of cortical reorganization that occurs when the brain stops receiving the information from the missing limb. This process is even speed up when the use of the EMG prosthetic hand includes feedback to the body. Our experiments with an amputee shows that the main effect of the electrical stimulation is that the person can adapt easier to the prosthetic hand, and actually develop the "illusion " that the robot hand is part of her own body, due to the activation on the sensory motor cortex in the brain.

IV. Conclusion

In the course of these experiments we confirmed the importance of the simultaneous stimuli needed for the brain to correlate events, in order to identify them 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 more practical use. From 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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