HUMAN PROSTHETIC INTERACTION: INTEGRATION OF SEVERAL TECHNIQUES

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Abstract—Current open-source upper limb robotic prosthesis projects have limitations regarding the functionality they offer to users. Moreover, prostheses that succeed in this requirement are extremely expensive and involve a challenging interaction, which requires hard practice from the amputee to be able to control the device. To decrease the training time that upper limb amputees usually spend to control the prosthetic hands, and to simplify the interaction, we developed friendly human-machine interfaces based on hybrid Electromyography (EMG) with Inertial Measurement Unit (IMU) and Radio Frequency Identification (RFID). The results suggest that the use of these interfaces in prosthesis is beneficial since they do not demand a lot of effort from the user, meaning they will be able to control the prosthetic hands easily and without an extended period of training.

Keywords—Robotics, Prosthetic Hands, Hybrid Human-Machine Interfaces, Electromyography

1 Introduction

According to (Association, 2017), assistive technology is the term used to any item whose objective is to increase or maintain the functional capabilities of people with disabilities. Typical examples of assistive devices are orthoses, crutches, wheelchairs and prostheses (Organization et al., 2011). In developing countries, 80% of people do not have access to prosthetic care (Slade et al., 2015). Thus they have difficulties performing most activities of daily living. Besides, amputation has an unfortunate effect on social integration and acceptance.

There are solutions available for amputees to try to overcome all those problems. A first one addresses the social acceptance and integration through the use of a purely cosmetic prosthesis, which looks like a regular arm but cannot perform any grasp. The second solution is to use a myoelectric prosthesis that might not be aesthetic, but that perform a great set of grasps from the most basic one, such as opening and closing the fingers together to more complex hand gestures. Although this solution, also called high-end prosthetic hands (Bionetic, 201-), (Dynamics, 201-), and (Bionics, 201-), offers several possible interactions, the high cost, and the increased difficulty in the mean of interacting with the device are disadvantages that cannot be forgotten. A third solution emerged from the community of makers, thanks to new low-price 3D printers technology. Open source prosthesis projects such as (Robohand, 201-) or (Langevin, 201-) emerged to address the problem of functionality, aesthetic, and high cost. Some projects like our previous work (Fajardo et al., 2015) are aiming at offering the same level of functionalities as the high-end prosthesis. At the same time, we aim at reducing the complexity of interaction that constrains a user of an electromyography actuated high-end prosthesis to train hard on a daily base to fully control the motion of the fingers.

Even though, as indicated in (Camacho Navarro et al., 2012), handicapped people need to make less effort and learn faster how to control electromyography-based systems, the training process might take several months depending on the level of amputation. A higher level of amputation means that the functional loss of the limb will be higher and that the training process will be harder since the muscles are interwoven in a much smaller place after the surgery. It adds difficulty for the user to control the prosthesis through the activation of these muscles (da Silva, 2014). Because of this, it is not trivial to control a prosthetic hand at first. Additionally, the prosthesis must be comfortable...
to wear and interact, which otherwise, users simply stop wearing them within their first year of use (Foundation, 2017). Other challenges faced to control a prosthetic hand are electrode shift that happens each time the user dons a prosthesis, variation in the position of the limb, and transient changes in EMG (Erik Scheme and Kevin Englehart, 2011).

(Bicchi, 2000) Points out that human operability is necessary for a mechanical hand. That is, systems like a prosthetic hand have to have a friendly and easy interface with the human operator. Taking this into account, we developed innovative and friendly hybrid human-machine interfaces as a first step to building a competitive prosthetic hand: similar functionalities of high-end ones but at an affordable price for people in emerging countries.

This paper is organized as follows: section 1 described a brief review of the importance of this study. Section 2 presents the developed hybrid interfaces for prosthetic hands. In section 3 the analysis of the modules are described. Section 4 concludes this work. Finally, in section 5, the future works are described.

2 System Overview

As shown in Figure 1, the robotic platform is divided into independent modules. Each module is a different hybrid human-machine interface solution that combines Electromyography (EMG) and other techniques - Inertial Measurement Unit (IMU) or Radio Frequency Identification (RFID) - to activate a particular predefined grasp sequence of the prosthetic hand simulated in V-REP (Rohmer et al., 2013). The central controller is a Raspberry Pi 3 with Jessie Lite operating system. It controls how the communication among the robot simulator and the modules happens (TCP/IP for Motion Module and Remote API for RFID Module), as well as manages all the processes involving the acquisition of information from the sensors and the logic of the system. Each module created has its features explained in sections 2.2 and 2.3.

2.1 Simulation

The simulation (Figures 2 and 3) contains 14 predefined grasps kinematically equivalent to a real prosthetic hand with high-end prosthesis capabilities, allowing future users to train without having an actual prosthesis. There are dynamic and static grips available in the simulation. The dynamic grasp (active index grip, and mouse grip) are the ones having triggers in their behavior, which means that besides their initial motion to reach a hand movement, they have a second subset of motion to accomplish tasks. For example, the mouse grip has its original sequence to hold a mouse (Figure 2), and after the user sends a second triggering signal, a sub action is occurring to click the mouse button (Figure 3). The static predefined grasping sequences available in the simulation are precision open grip, precision close grip, key grip, column grip, abduction grip, finger point, hook grip, open palm grip, pinch grip, power grip, relaxed hand, and tripod grip. (Kapandji, 2000) highlights these as being important grasp for everyday life’s activities.

2.2 Motion module

In this module, a hybrid interface solution based on EMG and IMU defines the motion of the fingers in the prosthetic hand. This module takes into consideration the direction and the contractions measured by the sensors. Figure 4 shows the architecture of this module. The Myo armband gathers the EMG sensors used to acquire the contractions of the muscles and the IMU device used to obtain the orientation of the arm. A Raspberry Pi 3 controls the signal processing, contraction detection, analysis of direction, controller processes, and the connection with the armband through Bluetooth.

Firstly, the EMG sensors acquire the raw electromyographic signals and send them to the Raspberry Pi through Bluetooth so that EMG signals are detected as a list of N numbers, each one associated with the number of EMG electrodes presented in the armband. Then, in the Contraction detection box, this list of values is processed to
sort out strong contractions of the muscles. This step is important because we discard contractions that users made unwittingly from the ones they intend to be a command.

Parallel to this, a similar process happens to the IMU information. The IMU sensor in the arm-band sends to the Raspberry Pi the orientation of the arm as a quaternion. The direction of the arm is acquired whenever a user contracts the muscle. In the Analysis of direction box, the quaternion is turned into Euler angles, and the direction (right, up or down) the user performed the contraction is defined. Finally, the Controller receives the pair contraction-direction, validates this command and associates them to a grasp to send to the simulator through a TCP/IP socket. Table 1 shows some examples of commands the user can do and the grip associated with it.

<table>
<thead>
<tr>
<th>Contraction (EMG)</th>
<th>Direction (IMU)</th>
<th>Grasp choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Up + Right</td>
<td>Active index grip</td>
</tr>
<tr>
<td>1</td>
<td>Up</td>
<td>Finger point</td>
</tr>
<tr>
<td>n ≥ 1</td>
<td>Wave-out</td>
<td>Cancel</td>
</tr>
<tr>
<td>1</td>
<td>Down</td>
<td>Hook Grip</td>
</tr>
<tr>
<td>1</td>
<td>Up + Down</td>
<td>Tripod grip</td>
</tr>
</tbody>
</table>

2.3 RFID module

In this module, the motion of the fingers in the prosthetic hand is defined by the RFID tag readings the system performs and by contractions the user does to confirm or to cancel commands. Thus, it is necessary, as shown in Figure 1, that the system has a RFID reader, which must be placed in the prosthesis to perform the required readings for the system to work.

This module works as follows: the prosthesis is initially in the relaxed hand position (Idle State). When the user approaches an object that has a RFID tag on it, the tag is read, and the system goes to the state $S_1$, where it waits for three commands: read another tag, confirmation or cancel. The wave-in contraction (Figure 5) tells the system to go to the state $S_2$, where the grasp is performed, and the state machine waits for other commands. Otherwise, the user can perform a wave-out contraction (Figure 6), which tells the system that the user wants to cancel the current grasp and go back to state Idle. The third command is to read another tag. The user might approach another object, the RFID tag on this object is read, and the system remains on state $S_1$ (waiting for other commands). The Finite State Machine on Figure 7 is implemented in the central controller to manage this behavior of the module.

One can see that once the state machine is in state $S_2$, the user can perform the cancel command, can approach an object to read the tag on it or can carry out the trigger command. The trigger is only available in the dynamic grasps of the set. The trigger command is also a wave-in contraction; the difference is when entering state $S_3$, the trigger is sent to the prosthesis, the grasp is performed on V-REP, and the state automatically changes to state $S_2$, so the user can either continue sending triggers to the prosthesis or do something else.

The architecture of this module is similar to the Motion module. Besides being classified as an active contraction, the system will also distinguish which type of contraction the user performed: wave-in for confirmation and trigger or wave-out for canceling a command. Another part showed in Figure 8 that differs from Motion module is the RFID part. The first step of the process is to read the RFID tag, which is made with a microcontroller since an Android device might replace the Raspberry Pi 3 in a further step. A LED is turned on as feedback when the microcon-
Figure 8: RFID module architecture

Table 2: Volunteers’ information

<table>
<thead>
<tr>
<th>Module tested</th>
<th>ID</th>
<th>Gender</th>
<th>Amputee</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID</td>
<td>1</td>
<td>M</td>
<td>N</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>M</td>
<td>N</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>F</td>
<td>N</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>M</td>
<td>N</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>F</td>
<td>N</td>
<td>34</td>
</tr>
<tr>
<td>Motion</td>
<td>6</td>
<td>M</td>
<td>N</td>
<td>34</td>
</tr>
</tbody>
</table>

The controller reads the tag, so the user knows what is happening with the system. The tags on the objects are associated with a type of grasp in what we call a dictionary. After that, this information is available and is validated since it is possible for the system to read a tag which does not represent a type of grasp. Subsequently, the controller receives the grip and send it to V-REP.

2.4 Modules testing description

Both modules were tested in our laboratory. All participants (information regarding the participants are shown in Table 2) provided written consent to take part in the experiment, which was approved by the Ethical Committee of the University of Campinas (Brazil) under the CAAE number 58592916.9.1001.5404.

The RFID module was assessed using NASA Task Load Index. This methodology is used to gather workload ratings to evaluate the system effectiveness and performance. This method takes into consideration six scales: Mental, Physical, and Temporal Demand, Effort, Performance, and Frustration. During the first part of the test, the subjects are asked to evaluate each of these scales, rating them from 0 to 100. In the second part, they will create individual weighting of these measures according to the importance of the scale of the tasks they performed. More information about this method is available on (NASA-TLX, 2011).

Due to the lack of availability of people with amputation to the transradial level, the tests were performed on five non-amputated people to evaluate whether or not the interfaces developed are valid and to have early feedback on the improvements the system needs. During the test, the subjects were asked to carry out a task. The task consisted of using the system for 10 minutes and sending commands to check if the system was working as planned. For instance, if the user sends the command to grasp a mouse, the simulator is supposed to show a prosthetic hand gripping a mouse. If a user sends a command to the prosthetic hand to perform a power grip and the simulation shows another type of grasp but power grip, the system is considered flawed/faulty.

The tests made with the Motion Module were different from the ones previously described. The reason is that the Motion Module works differently from the RFID module. As stated in section 2.2, for the user to have full control of this module, he/she needs to learn the motion language developed, and its grammar takes into consideration the movements the user must perform to select an action. Therefore, we asked a participant to use the interface and try to send commands to the virtual prosthetic hand. These commands were Active Index Grip, Finger Point, Tripod Grip and the Cancellation. The functionality of the system was explained, and he was invited to perform the commands previously described to become familiar with the system. Once the familiarization process finished, the user was asked to try out four types of grasp, so we could record how difficult it was to use the system and the percentage of correct commands he could send in less than one hour of training distributed in two days.

3 Results

3.1 Analysis of Motion module

Table 3 shows the hand movements the user sent to the simulator (Grasp) and the accuracy when sending each command (Correct attempts). The sequence of commands he sent to the system to achieve the grips are described in Table 1. In less than an hour of training, the user was able to learn with 94.5% of accuracy the cancellation command, while finger point had 85% of success. Therefore, we consider wave-out contraction being the most easier control of the set. The next command with the higher rate of correct attempts was Active Index Grip with 56.65% of success, followed by Tripod Grip with 50%.

The reason why the participant could not accomplish all the grasps with 100% of accuracy is...
that he needs, as stated before, to learn the sequence of commands and the timing of the system. For example, a contraction for confirmation command must be performed after 2 seconds that the state machine reached a correct contraction-direction combination. Therefore, if the user contracts his muscle to send a confirmation command before the 2 seconds between his last contraction, the system will understand the user is still trying to reach a valid combination. The system timing was perceived to be the most difficult concept for the user to understand.

### 3.2 Analysis of RFID module

Figure 9 shows the results for NASA Task Load Index. According to this result, all the subjects agreed that Mental Demand is not the primary source of workload for tasks involving the RFID module. That means the participants did not have to remember any patterns to perform the work and the tasks were straightforward and easy enough to be carried out by them since they all marked this scale with less than 5 points on a scale ranging from 0 to 100.

The tests also show that the subjects felt little or no pressure during the task – the largest workload score was 9. Most participants of the tests did not think Frustration was significant for the task, and this scale had a low score as 3 out of 5 rating were 0 and the other two less than 5. Regarding Performance, all subjects were satisfied with how successful they were in accomplishing the goals of the task, although it seems in the chart they failed. This fact is explained because Performance was the third greatest contributor to workload, so the raw rating is multiplied by the weight each subject chose during the source of workload comparison cards. Figure 10 shows the raw rating for Performance scale and, therefore, how satisfied were the subjects with their performance.

Unlike Mental Demand, where the scores were less than 5, Physical Demand required more from the subjects since they have to contract their muscles to confirm or cancel a command. Nevertheless, the score is still below or equal to 15, which reveals that even subjects who had more difficult confirmation/cancellation process, had not used a lot of energy or strength to finish the task. The tests showed that physical demand and effort are the scales that represent the more significant contributors to the workload for the task the subjects performed. It means that no matter how much of the other scales are scored, the most important ones are those two. Considering Figure 9 shows ratings below or equal to 15 for these two measures, we believe the use of this interface is valid to be implemented in a low-cost prosthetic hand since this interface proved itself to be friendly and easy to use.

![Figure 9: RFID Module: NASA Task Load Index result.](image1)

![Figure 10: RFID Module result: performance raw rating for each participant of the test.](image2)

### 4 Conclusion

Although high-end prosthetic hands offer advantages for amputees such as a great set of grasps and smooth movements, their cost makes them inaccessible for most of the people who could benefit from them. Besides, these prostheses require the user intense training to learn how to control the prosthesis, and this training is not guaranteed to be successful, leading the users to get frustrated. Hybrid EMG human-machine interfaces help users to decrease the preparation time since they will not need to activate only a particular group of muscles, as happens in most high-end prosthetic hands. With less effort to send a command, they learn faster how to interact with the system, which led them to a better experience.

In this paper, two solutions for the problem of challenging interactions in prosthetic hands were addressed. The first approach combines EMG and motion (using an IMU) to build the interface between the user and the machine. Using a combination of contraction and directions, the users can send commands to the prosthesis and manipulate objects in the simulation environment. In the second approach, EMG is combined with RFID to control the prosthetic hand, and the user needs only to get closer to the object and confirm if that is the object she or he wants to grasp.

The RFID solution has been proven to be relatively easy to use, and calibration phase crucial to obtain good experience while using the system. Visual or audio feedback also play a significant role in the user experience. When first tested, we
could never be sure a command had been sent or, if, in the RFID module, the tag in the object had been read. After adding feedback information, the users felt more confident about the system.

The Motion Module showed itself to be harder to use than the RFID solution, but it was already expected since it requires more effort from the user regarding controlling strategy of the prosthesis since a language has to be learned. In this module, feedback for the user and calibration also happened to be essential for the user experience.

It becomes apparent that the two methods developed cannot be compared relating the complexity of use since their fundamental principle is different, although they can complement each other. While RFID Module is more straightforward to use than Motion Module, it requires tagging all possible objects the future users of the prostheses will need to grasp or place all the possible tags on the users (e.g. put the tags in the pocket). Although in a controlled environment such as a laboratory or their house this is not a problem, the users would have difficulties using this interface in public places. The Motion Module would not have this issue since it depends only on the ability of the user to remember the commands.

In spite of the fact that the modules described in this paper could not be tested with amputees, the solutions are valid to be implemented in prosthetic hands for people who have the transradial level of amputation. Three reasons support this affirmation. First, the Motion Module uses directions measured by an IMU device in the Myo armband, and the fact people have a transradial level of amputation does not affect the way this device works. Second, for the RFID Module, reading tags using this technology was already presented in the literature as a viable solution. Our approach differs in the ways of interaction (using contractions to confirm or cancel a command). Lastly, both modules were designed to distinguish at most two different types of contraction, which is possible to acquire in amputees since they still can flexion and extend their muscles.

To summarize, it is important to increase the accessibility to prosthetic care in developing countries and to improve human operability, a key factor in success (Bicchi, 2000), we developed easy and friendly HMI. Although the tests were performed with non-amputee people, due to the lack of amputees available to test the systems, we can ensure that those solutions are valid to be placed in prosthetic hands.

5 Future works

A larger group of people has to evaluate the Motion Module to prove the users can learn the language developed in it, and that it requires less training than high-end prosthetic hands to control the device.

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