An Augmented Reality Environment to Provide Visual Feedback to Amputees during sEMG Data Acquisitions

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Abstract. Myoelectric hand prostheses have the potential to improve the quality of life of hand amputees. Still, the rejection rate of functional prostheses in the adult population is high. One of the causes is the long time for fitting the prosthesis and the lack of feedback during training. Moreover, prosthesis control is often unnatural and requires mental effort during the training. Virtual and augmented reality devices can help to improve these difficulties and reduce phantom limb pain. Amputees can start training the residual limb muscles with a weightless virtual hand earlier than possible with a real prosthesis. When activating the muscles related to a specific grasp, the subjects receive a visual feedback from the virtual hand. To the best of our knowledge, this work presents one of the first portable augmented reality environment for transradial amputees that combines two devices available on the market: the Microsoft HoloLens and the Thalmic labs Myo. In the augmented environment, rendered by the HoloLens, the user can control a virtual hand with surface electromyography. By using the virtual hand, the user can move objects in augmented reality and train to activate the right muscles for each movement through visual feedback. The environment presented represents a resource for rehabilitation and for scientists. It helps hand amputees to train using prosthetic hands right after the surgery. Scientists can use the environment to develop real time control experiments, without the logistical disadvantages related to dealing with a real prosthetic hand but with the advantages of a realistic visual feedback.

Keywords: Augmented Reality · Rehabilitation · sEMG Prosthesis

1 Introduction

It is estimated that 1.6 million persons were living without a limb in the United States in 2005 (about 41,000 with an upper limb loss) [25]. This number is expected to more than double by 2050 and to reach a total of 3.6 million people [25]. Amputees have to adapt to the absence of a body part and to deal with numerous problems in order to perform daily activities. On the market, hand prostheses with many functions have recently become available. Such prostheses are usually controlled using surface electromyographic (sEMG) signals and specific control strategies. In scientific research (and in a few recent cases also in commercially available prostheses[4]), pattern recognition algorithms were applied to classify hand movements using sEMG data. On hand amputees, movement classification performance of over 90% can be obtained on very few movements (usually fewer than ten) [19, 7, 8].

Myoelectric hand prosthesis control systems are expected to improve the quality of life of amputees. However, the systems proposed on the market so far are not satisfying for the patients, as they lack intuitive and adaptive real time control. In most cases, the results proposed in scientific research were not translated to clinical practice, mainly due to a lack of robustness and repeatability [4, 12, 18], as well as differences between the performance of amputees related to clinical parameters [2] that are not often taken into account. In a survey led by J. Davidson [10] it was shown that of a total of 65 subjects only 28% were satisfied with their functional abilities when using a hand prosthesis. Biddis and Chau [5] described a rejection rate for electric prostheses of 35% and 23% respectively in paediatric and adult populations. One of the main causes for abandoning sEMG prostheses is the insufficient feedback that users receive during the use of the prosthesis [19]. Furthermore, [21] and [22] concluded that the time that passed between amputation and prostheses fitting has a strong impact on accepting the prosthesis in adults. To address these challenges, Virtual and Augmented Reality (VR/AR) systems can be integrated during the training of hand prostheses use. Virtual reality consists of using an immersive headset (such as the PlayStation VR or Oculus Rift) sometimes combined with controllers. In *virtual reality*, the user is immersed into a fully virtual environment that is completely disconnected from the real world. In such an environment, the user can interact with objects, similarly to what happens in real environments, through the usage of the external controller. In *augmented reality* the real world is enriched with virtual elements, thanks to devices such as smart glasses (e.g. Microsoft HoloLens) or contact lenses (e.g. Emacula contact lenses). While hand prostheses are relatively heavy and can often not be used immediately after surgery, a virtual prosthesis is weightless and can be integrated directly after an amputation with very limited costs. In this way, the subject can train the muscles in the residual limb within the augmented/virtual environment in order to better interact with the future prosthesis. In 1994, Dupont et al. [11] developed a software to train children with upper limb amputation to use myoelectric control. The objective was to open and close the hand until it matched a target. As a result, all the subjects improved their myoelectric control capabilities. Soares et al. [23] developed a virtual myoelectric prosthesis controlled with an Artificial Neural Network (ANN). The outputs of the neural network were used to control the movements of a virtual prosthesis, replicating the movements of the real arm (extension, flexion, pronation and supination). In a related article by Lamounier et al. [15] an augmented reality system was added to the previously cited sys-

[4] for example `http://www.coaptengineering.com/`

tem, showing to the patients a virtual arm in correspondence to the stump on an external screen. Takeuchi et al. [24] developed a virtual reality technology in which amputees could train in a virtual environment. The patients had to grasp a virtual object without breaking it. Thus, the subjects were also able to control the grasping force of the virtual hand. Moreover, the difficulty of the tasks was modified in accordance to the control success rate to better adapt the system to the capabilities of the subjects. Kuttuva et al. [14] developed the composite myokinetic interface-virtual reality (MKI-VR) system composed of a pressure sensor array mounted on an arm sleeve, a trained filter and a virtual hand. Preliminary tests showed that upper-limb amputees were able to grasp and release virtual objects. More recently, augmented reality environments have been developed to give more realistic visual feedback to the subject. Anderson et al. [1] created the Augmented Reality Myoelectric (ARM) Trainer, an augmented reality-based system that provides a natural and engaging interface to train for myoelectric prostheses control. Augmented reality environments have also been used as alternative to the mirror therapy to treat phantom limb pain. Ortiz-Catalan et al. [17] developed an augmented environment in which the virtual limb responds directly to myoelectric activity of the residual limb. During the trial, the sustained level of pain reported by the patient was gradually reduced to completely pain-free periods.

External devices can be used to better interact with augmented and virtual reality systems. The Myo Gesture Control (Thalmic Labs, Canada) is an affordable (approximately 199$) armband containing 8 sEMG sensors, 9 axis Inertial Measurement Units (IMU) and Bluetooth communication. The Myo was successfully tested for pattern recognition-based control systems to classify hand movements on healthy subjects, obtaining a performance comparable to expensive electrodes on the classification of 40 hand movements [20] and high classification accuracy on the classification of 9 movements [16]. One disadvantage of the Myo is however its low sampling frequency (200 Hz) but for the task of detecting the hand movement the influence of this low sampling frequency seems limited. Recently, the Myo was also used to classify hand movements performed by hand amputees, obtaining good results [9].

Following these projects, the goal of the work presented in this paper is to create a new augmented acquisition and training system for hand amputees integrating Microsoft HoloLens (Microsoft, USA) and the Myo armband. To the best of our knowledge, this is one of the first portable implementations of augmented reality to help amputees created using both Microsoft HoloLens and Myo Armband. This environment allows transradial amputees to train in myoelectric control and to receive real-time visual feedback of the performed movements. The flexibility of an augmented reality environment that allows to use virtual 3D holograms in the real environment can also be used to create more interactive and game-based acquisition setups and to simplify the investigation of neurocognitive parameters related to the amputation such as the phantom limb sensation.

2 Methods

2.1 Device Setup

This section presents the equipment used in this work, which includes the following:

- a Dell XPS 13 laptop: the personal computer used to receive the data from the Myo and send it to the HoloLens;
- the Thalmic Labs Myo Gesture Control armband: the wearable device used to recognize the hand movements;
- the Microsoft HoloLens: the augmented reality headset used to display the holographic hand and objects;
- a JETech Bluetooth Mini Keyboard: a bluetooth keyboard allowing the calibration of the Myo armband and the resetting of the virtual scene.

The Myo Gesture Control Armband, developed by *ThalmicLabs*[5] is composed of eight medical grade stainless steel EMG sensors, a nine-axis IMU containing a three-axis gyroscope, a three-axis accelerometer and a three-axis magnetometer. The device is connected to the laptop through Bluetooth. The Myo can recognize 5 predefined hand movements (6 including the rest position): fist, spread finger, wave in, wave out and double tap. The holographic hand is displayed in the Microsoft HoloLens[6]. Microsoft's custom-designed Holographic Processing Unit (HPU) is a TSMC (Taiwan Semiconductor Manufacturing Company)-fabricated 28nm coprocessor with 24 Tensilica DSP (Digital Signal Processing) cores. The HoloLens has an inertial measurement unit (IMU) (that includes an accelerometer, gyroscope, and a magnetometer), it is also able to recognize voice and gesture commands. The software was developed using the Unity 3D platform [7] that is used for building 2D and 3D games and deploying them on various devices (mobile, VR/AR, consoles, etc.).

2.2 Myo software

The Myo software aims at continuously receiving the data stream from the Myo and modifying the appearance of the virtual hand accordingly. The Myo armband is provided with a calibration tool and a real-time hand gesture recognition algorithm. The manufacturer does not provide information regarding the classifier and the used time window length. The Myo algorithms and software directly provide the estimated hand pose. The first step was to create a channel to transfer Myo data to the HoloLens. The Myo offers an SDK (Software Development Kit) that allows to easily extract data from the Myo, such as the pose or the quaternions for the rotation. However, the Myo SDK does not support the Universal Windows Platform (UWP) used by the HoloLens. Thus, it was not possible to

[5] https://www.myo.com/
[6] https://www.microsoft.com/en-us/hololens/
[7] https://unity3d.com/

send the Myo data to the HoloLens without an appropriate connection between the two devices.

Since the application presented in this paper is designed to work in real-time, the User Datagram Protocol (UDP) was chosen to transmit Myo data to the HoloLens. UDP is suitable for real-time experiments in which a limited delay on data transmission is fundamental, even though it does not guarantee packet delivery and packet duplicate protection. The communication between the Myo and the HoloLens is performed with a custom made script written in C++. It runs on the acquisition laptop to which the Myo is connected via Bluetooth. The script manages the UDP communication using the Windows Socket API. It acquires the Myo hand pose and forearm orientation at 100 Hz using the Myo SDK and it sends the data through the UDP socket to the HoloLens. An assessment of the latency of sending each package from the UDP server and receiving it to the UDP client on the HoloLens was estimated analysing the experimental data and it was found to be 200ms.

2.3 HoloLens software

The HoloLens software was developed using Unity3D and Visual Studio 2015 and the scripts were coded in C#. A script implementing an asynchronous UDP communication was adapted from the *hololens-littlebits* github repository [8] and included in the Unity application running on the HoloLens. The Myo sends all the relevant data to the computer and the laptop transmits them to the HoloLens through the UDP connection. The creation of the UDP client is included in the *Main.cs* script that is attached to the *Arm Holder* object in the Unity3D space, which contains the rigged model of a hand. The hand model used in this work is openly available on the bitbucket repository[9]. The *Main.cs* sends the classified grasp to the script *MyoPoseCheck.cs*, while the angles of the rotation are delivered to the *ArmRotation.cs* script. The *Arm Holder* is encapsulated in a primitive capsule GameObject called *Player*. This game object is a Controller type that allows the arm to be moved through the angle obtained from the quaternion provided by the IMU of the Myo and to control the collisions and the object grasping. The Myo armband returns the orientation of the device in quaternion, from which the roll, pitch and yaw angles of the hand are calculated. It is possible to accurately detect the change in orientation of the device, which allows to understand how the user moves his/her forearm. The Bluetooth keyboard is used to calibrate the Myo orientation and to reset the virtual scene at any time by simply pressing the specific keyboard button. The calibration of the orientation returned by the Myo is fundamental to achieve an accurate and reliable orientation control of the virtual hand. The possibility to reset the virtual scene is provided to quickly restart the training trial either after the completion of the task or when some virtual objects are moved too far from the hand. In Figure 1, a simplified version of the framework used in this project is shown.

[8] https://github.com/rondagdag/hololens-littlebits/
[9] https://bitbucket.org/AngryBurritoCoder/

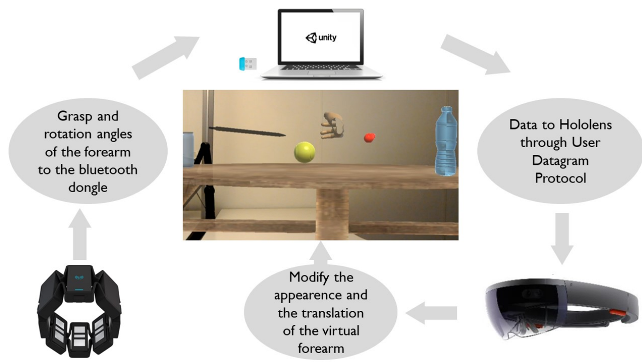

Fig. 1. Overview of the project framework. The Myo sends the classified grasp and the rotation angles to the computer that transmits them to the Microsoft HoloLens through a UDP protocol. The latter displays and modifies the appearance of the virtual hand allowing it to interact with augmented reality objects.

2.4 Virtual hand control

The system was designed to give a visual feedback to subjects with transradial amputation for training and data acquisitions purpose. The Myo and HoloLens work in parallel towards this goal. The subjects are asked to wear the Myo and the HoloLens. A calibration of the Myo is performed on the user. Then, the augmented environment starts on the HoloLens, while on the computer the script providing the communication between the Myo and the HoloLens is running. At this point, the HoloLens sets the subject in an augmented reality environment, which renders a table, a set of objects and a hand. The set of objects includes, from right to left: a bottle, a screwdriver, a tennis ball, a pen and a can. The rotation of the real arm can be calibrated with the rotation of the augmented arm by pressing the ”K” button on the Bluetooth keyboard, allowing the subject to control the virtual hand with the real forearm. Each predefined gesture classified by the Myo was associated to a grasp chosen among the most important grasps for the activities of daily living (ADL) [13, 6]:

– Fist → Power sphere;
– Wave In → Index finger extension;
– Wave Out → Tripod grasp;
– Spread Fingers → Large diameter;
– Rest → Rest.

Figure 2 represents the grasps that can be performed by the virtual hand. The gesture ”Double Tap” was not included in this experiment, since it was shown that this hand gesture is not easily recognized in hand amputees [9], likely because it purely based on sEMG data.

Each grasp was associated with a specific object, as described in the following list:

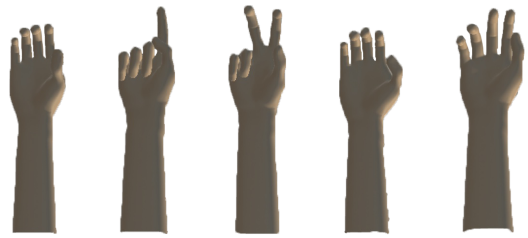

Fig. 2. The set of movements that are performed by the virtual hand. From left to right: power sphere, index finger extension, tripod, large diameter, rest.

- Tennis ball → Power sphere;
- Pen, Screwdriver → Index finger extension;
- Can → Tripod grasp;
- Bottle → Large diameter;

The rotation of the hand is performed acquiring the angles from the quaternion provided by the Inertial Measurement Unit (IMU) of the Myo armband, which allows the user to find a proper position to grasp the desired object. In this augmented reality environment the subjects can visualize the movements they are performing and they can easily train to activate the required muscles to perform each grasp. Whenever the subject feels the need to reset the scene (for instance when an object falls from the table), he/she can press the button ”R”. Figure 3 shows the holograms in the augmented reality environment.

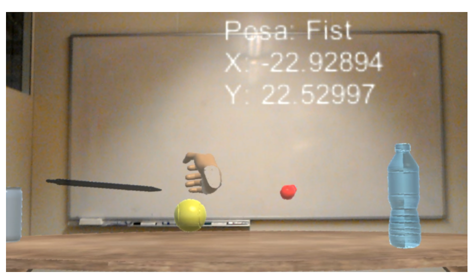

Fig. 3. View of the virtual hand in the augmented set in the real world.

3 Evaluation of the Augmented Reality Environment

The main goal of the framework presented in this paper is to give visual feedback to hand amputees during myoelectric control training. The system was tested on five intact subjects (5 males, average age 30.2±2.94 years old), in order to have a qualitative evaluation of the augmented reality myoelectric control environment and a proof of concept. The details of the 5 subjects are shown in Table 3.

Subject	Gender	Age	Height (cm)	Weight (kg)
1	M	35	184	95
2	M	29	185	90
3	M	31	170	60
4	M	28	187	82
5	M	28	180	70

Table 1. Description of the participants in the Augmented Reality acquisitions. The weight is expressed in kilograms. The length is expressed in centimetres.

It was previously shown that intact subjects can be used as a proxy measure for amputees in hand movement classification tasks [3], despite the fact that overall results are higher for non-amputees compared to what amputees can reach. Each subject was asked to pick up each object with the virtual hand using a specific grasp starting from the right to the left. At the end of each successfully performed grasp, the system was restarted. The sequence was repeated ten times. Among the set of subjects, Subject 1 and Subject 2 had previously tested the system and had more knowledge on how to perform the tasks. Subject 3 and Subject 4 completed one previous acquisition of three repetitions before the current acquisitions. Finally, Subject 5 completed one trial run before starting the acquisitions to get used to the system. Table 2 presents the average time required to grasp the respective object. The subjects were divided into two categories: experienced subjects (subject 1 and 2) and non-experienced subjects (the remaining ones). It is possible to notice that the time required to grasp an object for the experienced group is, in most of the cases, constant. While in the non-experienced group, the time tends to decrease through the usage of the system. The most difficult object to grasp is the can. This may be related to the fact that this object is positioned below the virtual hand and a double rotation of the arm (horizontal and vertical) is required to grasp it correctly. Nevertheless, with experience the time required to pick it up decreases. Figure 4 shows the total time required to finish one repetition of the acquisition. Each line represents a subject. Raw data are used to better show the learning curve of each subject. A statistical test was performed on the results to check their statistical significance. The non-parametric Friedman test that tests for differences between groups, returned a $p\text{-value}<0.001$, which indicates that the number of repetitions influences the time required to grasp an object. The results suggest that the augmented reality environment is operational and that the control of virtual hand improves well through training of the users.

Subject	Object	Repetition	Time Required
Experienced (Subject 1 Subject 2)	Bottle - Large Diameter	1	0:04
		2	0:07
		3	0:04
		4	0:07
		5	0:04
		6	0:03
		7	0:03
		8	0:04
		9	0:04
		10	0:03
	Screwdriver - Index Finger Extension	1	0:04
		2	0:01
		3	0:01
		4	0:01
		5	0:01
		6	0:01
		7	0:01
		8	0:01
		9	0:01
		10	0:01
	Ball - Power Sphere	1	0:12
		2	0:03
		3	0:04
		4	0:03
		5	0:03
		6	0:02
		7	0:03
		8	0:03
		9	0:03
		10	0:03
	Pen - Index Finger Extension	1	0:02
		2	0:02
		3	0:03
		4	0:02
		5	0:01
		6	0:02
		7	0:02
		8	0:02
		9	0:01
		10	0:01
	Can - Tripod Grasp	1	0:11
		2	0:08
		3	0:04
		4	0:05
		5	0:04
		6	0:02
		7	0:03
		8	0:04
		9	0:06
		10	0:04

Subject	Object	Repetition	Time Required
No Experience (Subject 3 Subject 4 Subject 5)	Bottle - Large Diameter	1	0:18
		2	0:05
		3	0:05
		4	0:08
		5	0:04
		6	0:06
		7	0:04
		8	0:02
		9	0:08
		10	0:04
	Screwdriver - Index Finger Extension	1	0:07
		2	0:03
		3	0:04
		4	0:04
		5	0:07
		6	0:02
		7	0:02
		8	0:02
		9	0:02
		10	0:02
	Ball - Power Sphere	1	0:13
		2	0:14
		3	0:07
		4	0:11
		5	0:07
		6	0:07
		7	0:03
		8	0:06
		9	0:05
		10	0:06
	Pen - Index Finger Extension	1	0:05
		2	0:05
		3	0:04
		4	0:03
		5	0:02
		6	0:03
		7	0:02
		8	0:02
		9	0:02
		10	0:02
	Can - Tripod Grasp	1	0:15
		2	0:09
		3	0:17
		4	0:14
		5	0:09
		6	0:05
		7	0:07
		8	0:18
		9	0:07
		10	0:10

Table 2. The table shows the required time to grasp an object in the augmented reality environment. The subjects were divided into experienced and without experience. The second column of the table corresponds to the virtual objects with the respective hand pose. The third one indicates the number of the repetition. A total of ten repetitions were performed on each object. The last column illustrates the required time to grab the object with the respective hand pose activated through the sEMG data of the Myo armband.

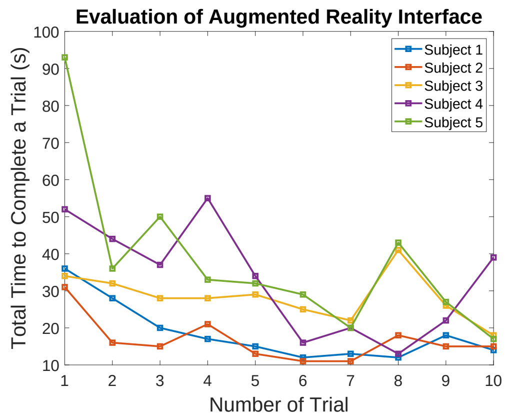

Fig. 4. Results of the Augmented Reality Environment. Each line represents one of the five subjects. The horizontal axis represents the number of the trial performed. On the vertical axis the total time required to complete the corresponding trial is shown.

4 Conclusions

This work presents an augmented reality environment to provide visual feedback of sEMG activity to amputees when training for using an sEMG hand prosthesis. The environment was developed to allow myoelectric training for prostheses control and research, and to allow sEMG data acquisitions of upper limb amputees. We expect visual feedback to improve results in the training phase compared to an analysis where no feedback is given to the amputees. The environment integrates the immersive headset Microsoft HoloLens and the low-cost sEMG sensor Thalmic Labs Myo. The environment allows to receive real-time visual feedback of diverse hand movements controlled via sEMG. The system can help hand amputees to train using myoelectric prosthetic hands after surgery with visual feedback. It is also capable to help scientific researchers to perform experiments on sEMG and prostheses using an augmented reality environment, which can be easier than dealing with real physical hand prostheses that are very expensive, often heavy and less flexible, as they may need to be made to fit a subject. Grasping some of the objects was more difficult than others, due to differences in the classification performance of movements by the Myo and to the characteristics of the object collider included in the Unity platform. Increasing the size of the collider allowed to make grasping easier.

The software is now planned to be tested on hand amputees. Using amputees in prototype phases is often not considered ethical, as each test creates stress for them when trying to perform the movements, so only well tested setups can be used for experiments with amputees. The raw data of the Myo will also be analyzed with the usage of more complex real time classifiers. This has shown to lead to better results after a training phase and it can also help in the real-time control speed.

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