



Yadira Garnica Bonome

**Proposing two new handling interaction techniques for 3D
virtual objects using the Myo armband.**

Dissertação de Mestrado

Dissertation presented to the Programa de Pós-Graduação em Informática of the Departamento de Informática, PUC-Rio, as partial fulfillment of the requirements for the degree of Mestre em Informática.

Advisor: Prof. Alberto Barbosa Raposo

Rio de Janeiro
May 2017



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To my parents, for their love.

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Abstract

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Flexibility and freedom are always desired in virtual reality environments. Traditional inputs, like mouse or keyboard, hamper the interactions between the user and the virtual environment. To improve the interaction in qualitative terms in a virtual environment, the interaction must be as natural as possible, and because of that, hand gestures have become a popular means to the human-computer interaction. The development of immersion devices like head-mounted displays brought the need for a new way of interaction and a challenge to developers. Hand gestures recognition using electromyography signals (EMG) has increased the attention because the rise of cheaper wearable devices that can record accurate EMG data. One of the outstanding devices in this area is Myo armband, equipped with eight EMG sensors and a nine-axis inertial measurement unit (IMU). The objective of this work is to evaluate the usability of the Myo armband as a device for selection and manipulation of 3D objects in virtual reality environments, aiming to improve the user experience, taking advantage of the possibility to measure the force applied to a gesture and to use Myo vibrations as a feedback system. This study aims to answer the following question: Has Myo armband high grade of usability for selection/manipulation of 3D objects in Virtual Reality Environments? And to achieve that purpose, four sub-questions were proposed to guide this research: I) Which resources of Myo can be used in Virtual Reality Environments (VRE)? II) What are the limitations of the Myo armband? III) Can selection and manipulation tasks be performed using Myo armband? IV) How can Myo armband enrich the selection and manipulation tasks? To answer to the first

two sub-questions, we conducted a literature review that covers Myo technology, its advantages and limitations, and related works. Also, it includes basic concepts about Interactions in VRE. To answer to the last two sub-questions, we proposed two selection/manipulation techniques using Myo, which were tested with users and the results were compared, evaluating their usability.

Keywords

Myo armband; 3D manipulation and selection; 3D interaction; Virtual reality; Gesture-based control; Human-computer interaction; Wearable devices.

Resumo

Bonome, Yadira Garnica; Raposo, Alberto Barbosa. **Proposta de duas novas técnicas de manipulação para objetos virtuais 3D usando o bracelete Myo.** Rio de Janeiro, 2017. 73p. Dissertação de Mestrado – Departamento de Informática, Pontifícia Universidade Católica do Rio de Janeiro.

Flexibilidade e liberdade são sempre desejados em ambientes de realidade virtual. Dispositivos de entrada tradicionais, como mouse ou teclado, dificultam as interações entre o usuário e o ambiente virtual. Para melhorar a interação em termos qualitativos em um ambiente virtual, a interação deve ser tão natural quanto possível, por isso, gestos com a mão se tornaram um meio popular para a interação humano-computador. O desenvolvimento de dispositivos de imersão como os capacetes trouxeram a necessidade de uma nova forma de interação e um desafio para os desenvolvedores. O reconhecimento de gestos da mão usando sinais eletromiográficos (EMG) tem chamado a atenção devido ao surgimento de dispositivos mais baratos que conseguem gravar dados EMG precisos. Um dos dispositivos mais destacados nessa área é o bracelete Myo, equipado com oito sensores EMG e uma unidade de medição inercial (IMU). O objetivo deste trabalho é avaliar a usabilidade do bracelete Myo como um dispositivo de seleção e manipulação de objetos 3D em ambientes de realidade virtual, visando melhorar a experiência do usuário, aproveitando a possibilidade de medir a força aplicada a um gesto assim como de usar as vibrações do Myo como sistema de feedback. Este estudo pretende responder à seguinte pergunta: O bracelete Myo tem alto grau de usabilidade para a seleção/manipulação de objetos 3D em Ambientes de Realidade Virtual? Para atingir esse objetivo, foram propostas quatro subquestões para orientar essa pesquisa: I) Quais recursos do Myo podem ser usadas em Ambientes de Realidade Virtual (VRE)? II) Quais são as limitações do bracelete Myo? III) É possível realizar tarefas de seleção e manipulação usando o bracelete Myo? IV)

Como o uso do bracelete Myo pode enriquecer as tarefas de seleção e manipulação? Para responder às duas primeiras subquestões foi realizada uma revisão da literatura que compreende a tecnologia do Myo, vantagens e limitações, e os trabalhos relacionados. Além disso, inclui conceitos básicos sobre Interações em VRE. Para responder às duas últimas subquestões foram propostas duas técnicas de seleção/manipulação usando o Myo e foram testadas com os usuários e os resultados foram comparados, avaliando sua usabilidade.

Palavras-chave

Bracelete Myo; Manipulação e seleção 3D; Interação 3D; Realidade virtual; Controle baseado em gestos; Interação homem-computador; Dispositivos Wearable.

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1 Introduction

Flexibility and freedom are always desired in virtual reality environments. For that reason, in recent years, traditional input devices such as keyboard and mouse are losing popularity. Compared to a traditional graphical user interface (GUI), a natural user interface (NUI) enables human-machine interaction via the people's common behaviors such as gesture, voice, facial expression, eye movement, and so on. The concept of NUI was developed by Steve Mann in 1990s (Mann, 2001). In the last two decades, developers made a variety of attempts to improve user experience by applying NUIs. NUIs, as discussed in (Petrovski, 2014), nowadays are increasingly becoming an important part of the contemporary human-machine interaction. In this way, human-computer interactions are not separate entities but create a reciprocal relationship between wearer's senses and his second brain, the computer (Ugulino, et al., 2012).

Those traditional inputs, like mouse or keyboard, hamper the interactions between the user and the virtual environment. The development of immersion devices like headsets as Oculus Rift¹, Samsung Gear VR², Project Morpheus³ and the HTC Vive⁴ brought the need for a new way of interaction and a challenge to developers. This situation affects many users. Those who have interacted with an application developed for headsets, and the way of the interaction or navigation was with the keyboard or mouse, in most cases, lose the reference of where are the inputs in the real world. One of the most natural ways of interaction, that one learns since was born, is with the hands. Hands are very powerful instruments of communication and those instruments are naturally attached to our bodies. We don't need any references of their position in the world, we know it with our eyes closed.

¹Oculus Rift official site: <https://www.oculus.com>

²Samsung Gear VR official site <http://www.samsung.com/global/galaxy/wearables/gear-vr/>

³ Project Morpheus official site <https://www.playstation.com/en-us/explore/project-morpheus/>

⁴ HTC Vive official site <http://www.htcvr.com/>

To improve the interaction in qualitative terms in a virtual environment, the interaction must be as innate as possible. Gestures, especially expressed by hands, have become a popular means of human-computer interface nowadays. Human gestures can be defined as a meaningful body movement which involves physical movements of different parts of the body like fingers and hands with the aim to express purposeful information or communicating with the environment (Rautaray, Kumar, & Agrawal, 2012).

The interaction through hand gesture recognition is called gesture control, and it is not only used in virtual reality environments, we can find it in applications such control of robots (Wolf, Assad, Vernacchia, Fromm, & Jethani, 2013) (Sathiyarayanan, Mulling, & Nazir, Controlling a Robot Using a Wearable Device (MYO)., 2015), drones (Nuwer, 2013), electronics (Premaratne & Nguyen, 2007), and simple applications like games, slides presentation, music, video or camera. Sign language recognition and gesture control are two major applications for hand gesture recognition technologies (Zhang, et al., 2011). Particularly in virtual reality environments, the gesture recognition and gesture control may resolve some problems like losing the reference of the input controls in the real world.

Hand gestures recognition has two approaches until now (Mann, 2001), the first is using cameras and image processing, and it is called visual gesture recognition. The other is using devices that record the electromyography signals (EMG) of the arm and, with the additional information of an accelerometer and a gyroscope, translate them into gestures (Zhang, et al., 2011).

Despite the advantages of gestural interactions, they involve several drawbacks. One major drawback is their negative physical impact. To reduce them, it is important to go through a process of measuring risk factors to determine the interactions' level of acceptability and comfort to make them more ergonomic and less tiring (Sobhi, Leroy, & Bouaniche, 2016).

In the past years, hand gestures recognition using EMG has increased the attention because the rise of wearable devices that can record accurate EMG data. One of those

devices is Myo armband⁵, developed by the company Thalmic Labs. It was released for developers use only in 2013 and in the summer of 2014 as a commercial product. Myo is equipped with eight EMG sensors and a nine-axis inertial measurement unit (IMU) that consist in a three-axis gyroscope, three-axis accelerometer, and a three-axis magnetometer. Myo also offers 3 types of vibrations that can be used to give feedback to the user.

Hand gesture control empowers the developers with tools to offer to the user a better experience when it came about selection and manipulation of the objects in virtual environments. Also, with the new wearable devices based in EMG recognition and translation into gestures, we are provided with a new variable: the intensity of the electrical activity produced by muscles involved in a gesture, from now on in this work, we will refer to it as the “force” applied to the gesture.

1.1 Research Question

Has MYO armband high grade of usability for manipulation of 3D objects in Virtual Reality Environments?

To limit the scope of this research question, only interaction consisting of selection and manipulation will be included in the study, navigation will not be considered.

To answer the main question, it was divided in sub-questions:

- *What resources of MYO can be used in Virtual Reality Environments (VRE)?*
- *What are the limitations of the MYO armband?*
- *Can selection and manipulation tasks be performed using Myo armband?*
- *How can Myo armband enrich the selection and manipulation tasks?*

This work includes a bibliography review that covers Myo technology, advantages and limitations, related works, and basic concepts and about Interaction in VRE. Also, we propose two selection and manipulation techniques using Myo. We tested them with users and compared them, evaluating their usability.

⁵ Myo armband official site: <https://www.myo.com>

1.2 Goal of this work

The objective of this work is to evaluate the usability of the Myo armband as a device for selection and manipulation of 3D objects in virtual reality environments, aiming to improve the user experience, taking advantage of the possibility of calculating the force applied to a gesture, and the possibility of use the Myo vibrations as a feedback system.

1.3 Dissertation Structure

This dissertation is structured as follows. Chapter 2 presents the basic concepts and summarizes related works. Chapter 3 presents the methodology of this work, including the tasks and techniques proposed, the definitions of the test environment and performing the user's evaluations. Chapter 4 shows the results of the tests and present the comparison between the techniques. Chapter 5 brings the conclusions of this work and possible future work.

2 Background

The Myo armband is a relatively new wearable device. Its platform provides some strong functionality that involves techniques of electromyographic signals processing, gesture recognition, and vibration feedback system. Also, it is equipped with an accelerometer, a gyroscope, and a magnetometer which enables the detection of arm movement. Many interesting works had been developed in last years: from mobile apps to rehabilitation systems, and virtual reality games.

This chapter presents the basic concepts and knowledge used to design the experimentation and evaluation stage of this work, and summarizes a bibliography review, that covers Myo technology and related work. The bibliography review aims to answer the two sub-questions:

- What resources of MYO can be used in Virtual Reality Environments (VRE)?
- What are the limitations of the MYO armband?

We also wanted to know how to design interaction techniques for VRE and to correctly evaluate their usability, consequently, the review was divided into four big topics: usability, interaction techniques in virtual reality, haptic feedback and Myo armband. Therefore, the review search terms include: Myo armband, Wearable devices, Hand gesture-based control, gesture-based 3D interaction, 3D manipulation and selection, Usability, Haptic feedback, Manipulation and selection techniques. The sources of the bibliography review were, mainly, IEEE, Google Scholar and Springer Link. Inclusion and exclusion criteria: Abstract and/or Introduction, Domain 3D virtual environments or Works with Myo. The result was a total of 37 papers.

2.1 Usability

Usability can at first impression appear to be a one-dimensional measure, either a system is usable or it is not. But usability is a complex composite measure (Nielsen J. , 1994) (Rubin & Chisnell, 2008). Two systems can be equally usable, but for very different reasons. For that reason, it is necessary to establish a definition of the factors that makes something usable, to be able to determine the usability of a product. The definition of usability used in this study (Rubin & Chisnell, 2008) can be decomposed into the five components: Usefulness, Efficiency, Effectiveness, Learnability and Satisfaction, each described in the following subsections.

2.1.1. Usefulness

Rubin (Rubin & Chisnell, 2008) describes usefulness as at which degree the user can complete the task that the product is intended to solve. Regardless of how easy a product is to learn or how satisfying it is to use, if it cannot solve its intended task it is useless for the user. So, for user test perspective, it is an important reminder to make sure that the users can achieve their specific goal with the product.

2.1.2. Efficiency of Use

Efficiency is how quickly a user can finish a task, commonly determined by measuring the time it took for a user to complete a given task (Rubin & Chisnell, 2008). Nielsen (Nielsen J. , 1994) takes a slightly different approach, detailing the “Efficiency of use” as the performance of a user which can be considered an expert of the system. Nielsen (Nielsen J. , 1994), which names learnability as the main component (rather than usefulness as (Rubin & Chisnell, 2008) suggests), therefore makes an important point in that measuring the efficiency of a user, one must consider the level of mastery the user has achieved. This displays the complexity of measuring usability, in that the individual factors are not independent of each other. For user tests, it is therefore important to consider the level of expertise the user has when measuring and comparing efficiency.

2.1.3. Effectiveness

Rubin (Rubin & Chisnell, 2008) describes effectiveness as: “the extent to which the product behaves in the way that users expect it to and the ease with which users can use it to do what they intend”. They further write that quantitative error rate is the most common way to measure a product's effectiveness. As an example, if a user pushes a button on a user interface in the belief that it will save their current work, but instead it deletes it, the system has clearly behaved unexpectedly from the user’s point of view, deluding the user to perform an error

2.1.4. Learnability

In the usability definition by (Rubin & Chisnell, 2008), learnability is closely tied with effectiveness. The learnability of a system determines how hard or easy it is to understand the system, i.e. if a new user of the system must put a lot of effort into learning the functionality of the system. They further write that learnability can refer to the ability of a user to remember how to use a system with infrequent use, that matches the (Nielsen J. , 1994) definition of usability referred to as “memorability”, i.e. the memorability of a system with sparse usage patterns.

2.1.5. Satisfaction

Finally, satisfaction is the users’ subjective opinions of the system, if they like it or dislike it, commonly recorded either orally through interviews or in written format through surveys (Rubin & Chisnell, 2008). (Nielsen J. , 1994) points out that satisfaction is especially important for systems which is related to leisure rather than labor, since a satisfying experience does not necessarily entail an efficient or easy to learn system. He also notes that there are more objective alternatives to measure the satisfaction of a user, such as measuring the blood pressure, heart rate, Electroencephalography (measuring electrical brain activity), but that such means of measurement can intimidate already nervous test subjects further. Instead, he suggests that the satisfaction of the system can be determined by averaging the answers of many subjective users.

2.2 Interaction Techniques in Virtual Reality Systems

The virtual reality technologies started with two-dimensional (2D) input systems. Such 2D input systems included physical input devices like mouse and joysticks, and some studies attempted to integrate simple 3D input methods using light rays or strings into a “simulated” 3D input system. Therefore, at first, the limitation of technology prohibited users’ abilities in virtual environments to simple manipulations, like select, rotate, and move (Jung, et al., 2014).

Some of the examples of such 2D or simulated 3D systems are ray-casting (Roth, 1982), the Bat (Ware, 1990), and SPIDAR (Hirata & Sato, 1992). However, advances in technologies related to virtual reality, have made the application of much more complex virtual interface and interactions. Instead of the physical devices acting as pointers or “self” in a virtual environment, hand gestures and motions became the standard input methods, thus making the interaction techniques much more immersive to the users. For example, the Go-Go (Poupyrev, Billinghurst, Weghorst, & Ichikawa, 1996), ISAAC: Immersive Simulation Animation and Construction (Mine, 1995), and HOMER: Hand-centered Object Manipulation Extending Ray-casting (Bowman & Hodges, 1997), are virtual interaction techniques with highly advanced 3D inputs.

2.2.1. Interaction Technique Classification

Classification is necessary to be able to organize and compare interaction techniques in virtual environments (Dam, Braz, & Raposo, 2013). One of the more complete works about classification of interaction techniques was presented in (Bowman & Hodges, 1999). According to them, the taxonomy of an interaction technique is divided into two parts: navigation and selection/manipulation, which are the basic tasks. These tasks are divided into subtasks, which are the product of an analysis by the authors on the possibilities of actions for each task. From this, each subtask has a list of methods that a technique can offer to perform this subtask. It is important to note that the authors recognize that it is not possible to list each component, but

pursued to maintain abstract terms to cover as many interacting techniques as possible.

The categorization of techniques tends to explain fundamental differences between the techniques, allowing a more specific comparison (Dam, Braz, & Raposo, 2013). Since this work is focused on selection/manipulation techniques, the concept and taxonomy for this kind of interaction are going to be analyzed more deeply.

2.2.2. Selection and Manipulation

Selection is the task of letting users mark an object as the target for further action. Selection is known to be a universal interaction task, serving as a building stone to form more complex interaction tasks. Due to its atomic form, selection is a well-studied area, especially since selection usually is a prerequisite to manipulation (Argelaguet & Andujar, 2013).

In (Mine, 1995) selection techniques are separated in *direct interaction* of the user (hand tracing, gesture recognition, among others), *physical controls* (joysticks, Example) and *virtual controls*. Specifically, for selection techniques, the study lists interaction techniques: local (interaction with objects that are within the reach of the user), distance (objects that are not within the reach of the user), directed by the look, and voice command.

In some works, in the literature, Selection and Manipulation are often classified inside the same interaction (Poupyrev, Weghorst, Billinghurst, & Ichikawa, 1997). Manipulation allows the user to move the selected object around, rotating it to see it from different angles.

As regarding selection, most interaction techniques that enable manipulation can be split into those based on either a grabbing metaphor or a pointing metaphor. There are two most common types of manipulation techniques. Egocentric, where the viewpoint of the user is from a first-person perspective, with the user interacting from inside the virtual world (Poupyrev & Ichikawa, 1999). The opposite category as the

less common is defined as exocentric techniques, where the user takes on a “God perspective”, changing the world from the outside.

To define what a manipulation task is, (Poupyrev, Weghorst, Billingham, & Ichikawa, 1997) makes use of the strategy to identify a set of basic tasks which together can form any complex manipulation actions. They used the following set as a basis for manipulation tasks:

- Selection
- Positioning
- Orientation
- Text input
- Numerical input

According to (Bowman & Hodges, 1999) the taxonomy of selection/manipulation tasks can be divided in three subtasks: selection, manipulation and release (Figure 1). These subtasks are further divided, for example manipulation is divided into: Object attachment, object position, object orientation and Feedback.

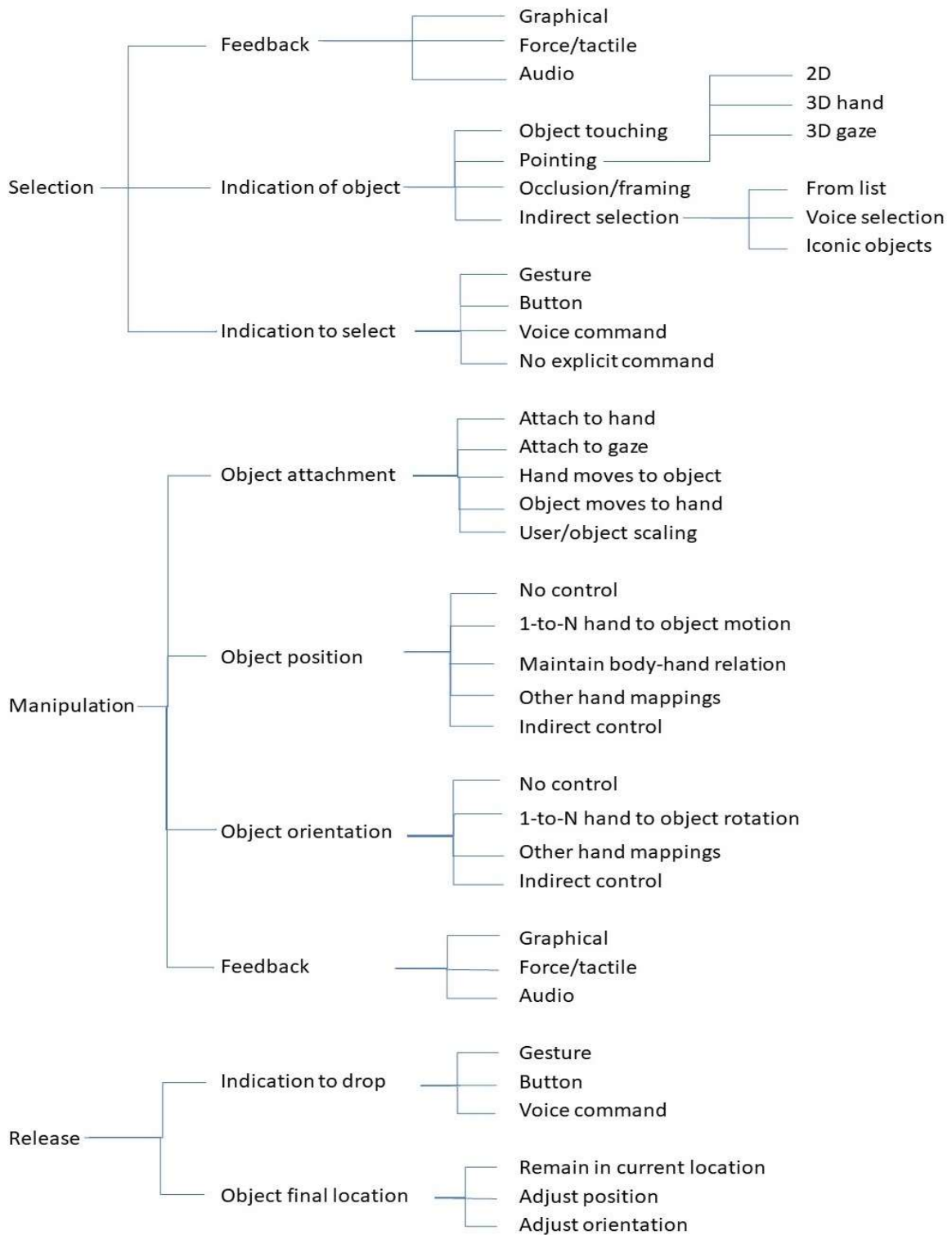


Figure 1 Selection/Manipulation Taxonomy (Bowman & Hodges, 1999)

2.3 Haptic feedback system

High-frequency vibrations are a fundamental part of many manipulation tasks. But many current human interfaces for virtual environments do not provide vibrotactile feedback. The benefits of vibration feedback systems include the simple addition to existing haptic displays often without additional hardware. Vibration feedback augments force-feedback, making simulations of high-frequency contact, texture, and issues like puncture, more realistic (Frisoli, et al., 2005). It can also compensate the limits of the interface actuators when force-feedback is restricted. In (Stone, 2001) the history of haptic feedback systems is summarized until then, and the author highlights that vibration feedback applications include critical-procedure training of astronauts for space missions, surgical training, commercial computer interface devices for Computer Aided Design (CAD), training of big machinery operators and entertainment.

A haptic interface sends a kinesthetic sense of presence to the user interacting with a computer-generated environment. Most human-computer interaction has taken place through one-directional channels of information, sending visual and audio information from the computer to the user. Keyboard, mouse and joystick inputs convey human information to the system, and human neuromuscular and decision responses close this information loop.

In haptic interaction, the difference is that physical energy flows bi-directionally, from and to the user. The haptic display creates a feedback loop which includes not only the human neuromuscular and decision responses but also the biomechanical impedance characteristics of the user's contact with the device.

2.4 Wearable Devices

Wearable devices are electronic devices that can be worn on the body. They utilize various sensors to collect related data, including physiological information (such as heart rate, body temperature, blood pressure, blood oxygen, and steps taken), environmental data (such as temperature, humidity, CO₂, and light), and motion perception (in which inertial sensing elements gauge complex human actions and behaviors). Wearable devices can have a greater range of application when connected to a mobile phone through a communication interface such as Bluetooth or when wirelessly connected to a cloud platform through Wi-Fi for big data processing. Areas of application for wearable devices include leisure and entertainment, health care and health management, information transmission, and environmental monitoring (Chien, Hu, Tsai, Wu, & Chen, 2016). The most successful wearable products on the market are smart wristbands and smart watches, many of which have built-in accelerometers and gyroscopic sensors that calculate and analyze the collected sensing data and then provide wearers with statistical information on various aspects of life, such as running, walking, lying, and standing. They can even be used to detect the quality of sleep and provide an entirely different “quantitative” experience for users: long-term health management based on statistics from more realistic data and long-term records.

2.5 Myo armband

Myo armband is a wearable device (Figure 2) equipped with several sensors that can recognize hand gestures and the movement of the arms, placed just below the elbow. Myo recognizes each gesture using eight EMG sensors to capture the electrical impulses generated by arm’s muscles. Therefore, it is necessary for each user to make a calibration step before using the gadget. This is necessary because each user has a different type of skin, muscle size, etc. From these data, and based on machine learning process, the Myo can recognize the gestures performed.

Other components of Myo include a lithium rechargeable battery, an ARM processor, Bluetooth 4.0 LE, a micro USB port for charging, and wireless compatibility with PCs, Macs, iOS, and Android. In addition to the EMG sensors, the Myo also has a IMU, which enables the detection of arm movement. The IMU contains a three-axis gyroscope, three-axis accelerometer, and a three-axis magnetometer.



Figure 2 Myo armband from Thalmic Labs

Another feature of Myo armband is the open application program interfaces (APIs) and free software development kit (SDK), allowing more developers to be involved in build solutions for various uses such as home automation, drones, computer games and virtual reality. Thalmic Labs has released more than 10 versions of SDK since the initial version Alpha 1 was released in 2013. The last release version of SDK (0.9.0) was in June 2015. In Beta release 2, gesture data collection was added. Thus, developers are enabled to collect and analyze gesture data to help improve the accuracy of gesture recognition.

According to Myo SDK Manual⁶, the Myo armband provides two kinds of data to an application, spatial and gestural data. Spatial data informs the application about the orientation and movement of the user's arm. The Myo SDK provides two kinds of spatial data:

- An orientation represents which way the Myo armband is pointed. In the SDK, this orientation is provided as a quaternion that can be converted to other representations, like a rotation matrix or Euler angles.

⁶Thalmic developer's blog: https://developer.thalmic.com/docs/api_reference/platform/index.html

- An acceleration vector represents the acceleration the Myo armband is undergoing at any given time. The SDK provides this as a three-dimensional vector.

Gestural data tells the application what the user is doing with their hands. The Myo SDK provides gestural data in the form of one of several preset poses, which represent a configuration of the user's hand. For example, one pose represents the hand making a fist, while another represents the hand being at rest with an open palm.

Auxiliary events typically occur infrequently and correspond to situations such as the MYO armband becoming disconnected or connected. While the SDK will generally maintain a connection with the MYO armband once it is established, it will inform the application when the MYO armband is disconnected. This might happen, for example, when the MYO armband is moved out of range of the device it has been connected to. All types of events identify the MYO armband from which they occurred and provide a time detail at which the event occurred.

The Myo armband provides information about which arm it is being worn on and which way it is oriented - with the positive x-axis facing either the wrist or elbow. This is determined by a Sync Gesture performed upon putting it on. The Myo armband similarly detects when it has been removed from the arm. An application can provide feedback to the wearer of the Myo armband by issuing a vibration command. This causes the Myo armband to vibrate in a way that is both audible and sensed through touch. The vibration system consists in three types of vibrations: long, medium and short (Figure 3).



Figure 3 Myo vibration system

While the Myo SDK provides powerful and complete facilities for writing applications that make use of the Myo armband's capabilities, some tasks can be more easily accomplished through scripting. Myo Connect meets this need by running

connectors that can handle Myo events and use them to control applications. Myo Scripts are connectors written in Lua⁷.

In December 2014, Thalmic released a new functionality in the SDK, making the EMG raw data available to developers. Now developers can implement their gestures recognition system using Thalmic's hardware and the data collected by the sensors, or they can use the gestures that Myo SDK recognize and implement a system for recognition of new gestures. Also, it opened the possibility to make analyses of the signal that represents each one of the pre-set gestures, like measure the intensity of the electrical signal.

2.5.1. Electromyography signal recognition

Electromyography signal recognition plays an important role in NUIs. EMG is a technique for monitoring the electrical activity produced by muscles (Polsley, 2014). There is a variety of wearable EMG devices such as Myo armband, Jawbone⁸ and some types of smartwatches. When muscle cells are electrically or neurologically activated, these devices monitor the electric potential generated by muscle cells to analyze the biomechanics of human movement.

Extracted patterns of EMG activity, specific for each hand movement, allow to increase the amount of information and to realize a more natural, and hence satisfactory, reproduction of the gestures. Fundamentally, a pattern recognition-based system consists of three main steps (Riillo, et al., 2014):

- EMG signal acquisition by means of an array of sensors;
- Feature extraction, consisting in the calculation of relevant characteristics from the signals, e.g. mean, energy, waveform length, etc.;
- Feature translation, or classification, to assign the extracted features to the class (gesture) they most probably belong to. Once the gesture attempted by the user of the system is recognized, it can be mapped towards the controlled device.

⁷ Lua official site: <http://www.lua.org/>

⁸ Jawbone official site: <https://jawbone.com/>

Work directly with the EMG raw signals has two main difficulties:

- The battery's life: Processing the raw data onboard using classifiers that are optimized for power efficiency results in significantly better battery's life than streaming that amount of data through Bluetooth.
- User Experience: Working with EMG signals is hard. Building an application that works for one person or five is straightforward, but building something that will work for everyone is entirely another question. The signals that are produced when different people make similar gestures can be wildly different. Different amounts of hair, fatty tissue and sweat can impact the signals, and this is compounded by the fact that the Myo armband can be worn on either arm and in any orientation.

But having the possibility of using raw data means new uses for the Myo armband from prosthetics, muscle fatigue and hydration monitoring, sleep state monitoring, to identity authentication based on unique muscle signals.

Until now, most of the works related to the gesture recognition based on the EMG, focus their efforts in the recognition of the gesture and do not take advantage of the intensity of the electrical activity like a variable to measure the force applied to the gesture.

2.5.2. Limitations of the MYO armband

There are a few drawbacks in the current generation of Myo armband. First, the poses that can be recognized by the band are limited. In the developer blog, they announced that Myo armband can recognize 5 pre-set gestures (Figure 4) including fist, double tap, finger spread, wave left, and wave right. By setting up the connection through Bluetooth 4.0, users can map each gesture into an input event to interact with the paired device. But, the developers of the armband tend to simplify the human-machine interaction. Therefore, using only 5 gestures to interact with the environment is a user-friendly design which largely reduces the operation complexity. However, on the other hand, this design makes some restrictions on application development. Secondly, the accuracy of gesture recognition is not completely satisfactory,

especially in a complex interaction. When a user aims to implement a complicated task with a combination of several gestures, the armband is not sensitive enough to detect the quick change of user's gestures.



Figure 4 Gestures recognized by Myo armband

2.5.3. Low Costs

Since 2013, Thalmic Labs sold about 1,000 of the Myo Alpha Units to third party developers as a strategy to do more prolific the development of applications for Myo. In the summer of 2014, it released the production version of the Myo, which has accumulated more than 50,000 pre-orders. Once the pre-orders were fulfilled, it begins selling the Myo on Amazon. The standard price⁹ of Myo armband is USD \$199. Other replacement parts are also sold in a range of USD \$10 to USD \$40.

The main inputs for the Myo armband are custom-built, hospital-grade sensors. For less than USD \$200, the Myo armband can already do things that currently requires a USD \$10,000 desktop EMG machine with amplifiers. The medical uses for the device - prosthetics, monitoring, and improved accessibility - are many.

Its low cost is not only related to its physical components, also the computational costs and the requirements for it works are lower than other gesture recognition technologies.

2.5.4. Recent works with Myo

Since its release in 2014, Myo had an impact in the Human Computer Interaction, and currently there are a lot of applications developed for it and, considering the short time since it is in the market, there are important researches about it.

⁹Myo store: <https://store.myo.com/>

On November 27 of 2014, Thalmic posted in their blog¹⁰ a new innovating application of Myo in the medical area. Letting surgeons control information in real time without touching anything was a very early idea for using the Myo armband. They formed a relationship early on with a medical imaging firm from Spain called TedCas. TedCas used a Myo armband, various cameras, and voice recognition software to give surgeons total control over the information they need during an operation: it's a multi-sensor solution for operating rooms all connected to a device called the "TedCube".

Although most of the works about Myo are not related with virtual reality, since its very beginning the creators think about it like a strong tool in that field. In March 2014, they announced, in the Myo developer blog, that their software team had created a Unity¹¹ API that allows any developer to quickly and easily use the Myo armbands as controllers for their games, allowing them to drag and drop the package into their project for easy integration. They affirm, "We're bringing virtual reality to live today with two Myo armbands and an Oculus Rift" and show a video of a simple demonstration of how it could be, very inspirational by the way.

In April 2014, Pascal Auberson published, as a guest of the Myo developer blog, a demo (Figure 5) using an iPhone, a Myo and an Oculus Rift (Figure 6). Pascal Auberson is the founder of Lumacode¹², a consultancy specializing in creative development for the web, mobile, and installations. Before that, he was co-founder and technical director of Specialmoves, an award-winning digital production studio. Currently, he's investigating better ways to navigate and interact in VR.

His demo consists in moving all the navigation controls to an iPhone, leaving a free hand for interaction using a Myo. The touch screen of the iPhone works for 2D movement and this includes running as the further you drag, the faster you go. The gyroscope roll works for body rotations (Figure 7). Myo was used to throwing grenades around the Oculus Tuscany demo scene¹³. The fist gesture makes a grenade appear roughly where your hand is. Then doing a throw gesture releases the grenade

¹⁰Thalmic blog: <http://blog.thalmic.com/>

¹¹Unity official site: <http://unity3d.com/>

¹²Lumacode official site: <http://lumacode.com/>

¹³Oculus Tuscany demo scene: <https://share.oculus.com/app/oculus-tuscany-demo>

in the direction your hand is moving in. This was one of the first works made with Myo even before it be release into the marked.



Figure 5 Demo of Auberson



Figure 6 Kit from Auberson Demo

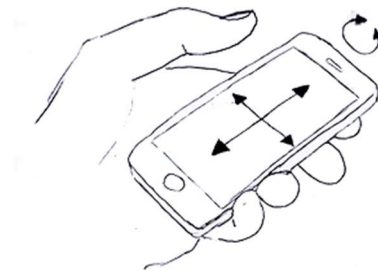


Figure 7 2D movement and rotation

In 2015 (Sathiyarayanan, Mulling, & Nazir, Controlling a Robot Using a Wearable Device (MYO)., 2015) designed and developed an unmanned ground vehicle controlled by hand gestures using MYO armband. (Nymoen, Haugen, & Jensenius, 2015) evaluated and explored the Myo armband for musical interaction and developed a prototype instrument: MuMYO. (Kerber, Lessel, & Krüger, 2015) presented a preliminary evaluation of an approach utilizing eyes-free, same-side hand

interactions with arm-placed devices like Myo and smartwatches, based on EMG. Also, in (Sathiyarayanan & Mulling, Map Navigation Using Hand Gesture Recognition: A Case Study Using MYO Connector on Apple Maps., 2015) a case of study using Myo in maps applications was published.

McCullough et al. (2015) proposed a navigation technique to explore virtual environments, detecting the swing of the arms using the Myo, and translating them into a walk in the virtual environment. Haque et al. (2015) describe a mid-air pointing and clicking interaction technique using Myo, the technique uses enhanced pointer feedback to convey state, a custom pointer acceleration function, and correction and filtering techniques to minimize side-effects when combining EMG and IMU input. Phelan et al. (2015) created a virtual prototype for amputee patients to train how to use a Myoelectric prosthetic arm, using the Oculus Rift, Microsoft's Kinect and Myo.

In April 2015, Thalmic published a post about its game Icarus Rising (Figure 8) (Figure 9) released in the Myo Market for free. This is an immersive game, and for playing it, you need a Myo armband (or two) and an Oculus Rift DK2. By spreading your fingers (or waving out), you thrust away from wherever your arms are pointing.



Figure 8 Icarus Rising Trailer



Figure 9 Icarus Rising Trailer

In the same post, they promote another game called Crate Whacker (Figure 10) also available in the Myo Market for free. This time the game consist in an endless stream of boxes to mash with a mace, or burst with bombs. The Myo armband again tracks the arm orientation to let the user wield the mace or throw grenades. The users still need a Myo armband, but for this experience the Oculus Rift DK2 is optional though definitely recommended. The commands are: make a fist for taking out the mace and swing it around, spread the fingers to enter grenade mode, and then grab an imaginary grenade on the opposite side of your body and hurl it out onto the field.



Figure 10 Create Whacker

Icarus Rising and Crate Whacker were both built in Unity with the Myo Unity package included in the Myo SDK.

All reviewed works used Myo's predefined gesture set and they did not use the resource of the vibration system to improve the user experience. Is important to note that all of them, focus their efforts in the recognition of the gesture and do not take advantage of the intensity of the electrical activity like a variable to measure the force

applied to the gesture. Additionally, we did not find any study about usability of Myo for selection/manipulation of 3D objects in VRE.

This work proposes selection/manipulation techniques using the Myo's SDK to capture and analyze the special and gestural data of the users. And additionally, using the intensity of the electrical activity obtained from the EMG raw data, we try to simulate the force that the user is applying to the virtual object. Also, we create a feedback system that include visual and haptic feedback, using the vibration system of Myo.

3 Methodology

The objective of this work is to evaluate the use of the Myo armband as a device for selection and manipulation of 3D objects in virtual reality environments, aiming to improve the user experience, taking advantage of the possibility of calculating the force applied to a gesture, and the possibility of use the Myo vibrations as a feedback system.

This method proposes two techniques (called Soft-Grab and Hard-Grab techniques) that were designed to test and explore the capabilities of the Myo armband as interaction tool for input and feedback in a virtual reality environment, having as the goal to answer the questions:

- Can selection and manipulation tasks be performed using Myo armband in virtual reality environments?
- How can Myo armband enrich the selection and manipulation tasks in virtual reality environments?

To evaluate the usability of two interaction techniques, the method can be split into three phases:

1. The implementation of the interaction techniques based on earlier research,
2. The preparation of user tests to evaluate the usability of each technique and their execution,
3. The analysis of the gathered data.

In the subsections 3.1 and 3.2 are exposed the two first phases and in the Chapter 4 we analyze the data and show the results.

3.1 Proposed interaction techniques

Manipulation in virtual environments is frequently complicated and inexact because users have difficulty in keeping the hand motionless in a position without any external help of devices or haptic feedback. Object position and orientation manipulation are among the most fundamental and important interactions between humans and environments in virtual reality applications (Nguyen & Duval, 2013). Many approaches have been developed to maximize the performance and the usability of 3D manipulation. However, each manipulation metaphor has its limitations. Most of the existing procedures that attempt to solve the problem of grabbing and manipulating remote objects, fit into two categories, which are called arm-extension techniques and ray-casting techniques (Bowman & Hodges, 1997).

In an arm-extension technique, the user's virtual arm is made to grow to the desired length so the hand can manipulate the object. Arm-extension methods make object manipulation simple because the user moves and rotates the object with natural hand and arm motions. Grabbing is more difficult because the virtual hand must be positioned within the object, which may be small or distant.

Ray-casting techniques make use of a virtual light ray to grab an object, with the ray's direction specified by the user's hand. The use of the light ray makes the grabbing task easy because the user is only required to point to the desired object. Manipulation is not hand-centered, however, and is, therefore, more difficult.

There are also some techniques which approach the problem in a more indirect manner. Rather than attempting to extend or enhance the natural method, they use various aids to allow manipulation of remote objects. One such technique is the World in Miniature (WIM). Here, users hold a small representation of the environment in their hand and manipulate objects by manipulating the iconic versions of those objects in the miniature environment. WIM can be a powerful and useful metaphor. Another technique scales the user or the entire environment so that any object, no matter its size or distance from the user, may be grabbed and manipulated with the real-world metaphor.

The techniques in the present work are based on ray casting model. For the scope of these tests, the boxes can be moved only in the plane (x, y) and not in the z-axis, like in a three-shell game. The virtual environment used in the tests was written in C# using Unity3D 5.6, Microsoft Visual Studio 2015 and the Myo SDK 0.9.0 to connect the Myo.

3.1.1. Soft-Grab Technique

The scenario is a big surface with three boxes with different colors: blue, red, and green, and a pointer (Figure 11). Pointing was implemented using the Myo IMU and the `Raycast` method in `Physics` class from Unity's framework. At the beginning of all the tests, the user must setup the arm orientation, and he/she can do it by pointing the arm to the front and make a finger spread gesture, and every time that the user want to setup the initial position of the pointer can use that command.

When the ray collides with a box, there is a visual feedback by highlighting the box with yellow color and the Myo's short vibration is activated. Once the object was pointed, the user can select an object in the scene by making a fist with the hand. The Myo's medium vibration is activated when the fist gesture is recognized to let the user know that the box is selected and it can be moved.

After selecting it, the box is attached to hand's movements in the (x,y) plane, until the user maintains the fist gesture, and the user can position it by pointing the new place for the box. To release the box the user need to relax the hand and release the fist gesture. When the box is released it is returned to its original color and a large vibration is activated in Myo. The taxonomy of this technique is presented in Figures 12, 13 and 14.

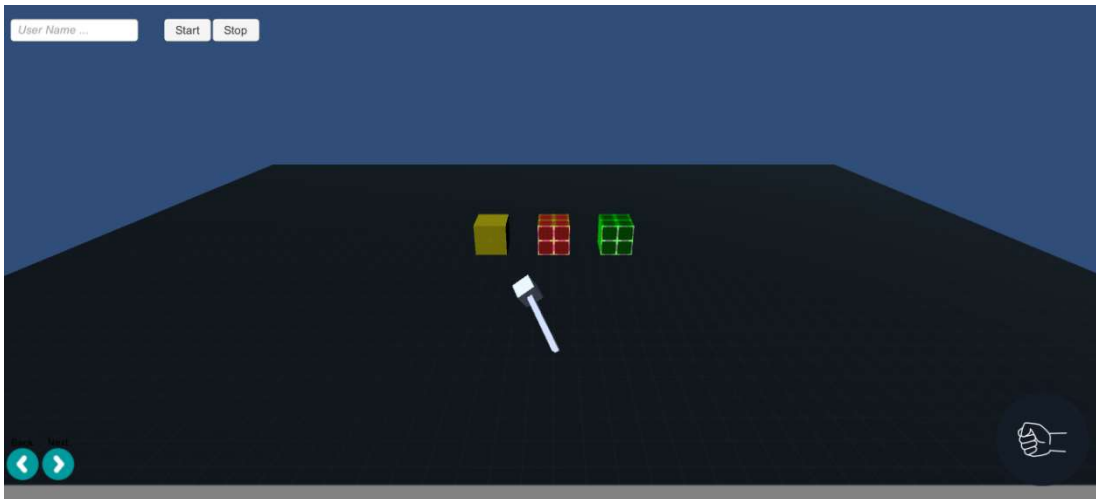


Figure 11 Test Scenario for Soft-Grab technique

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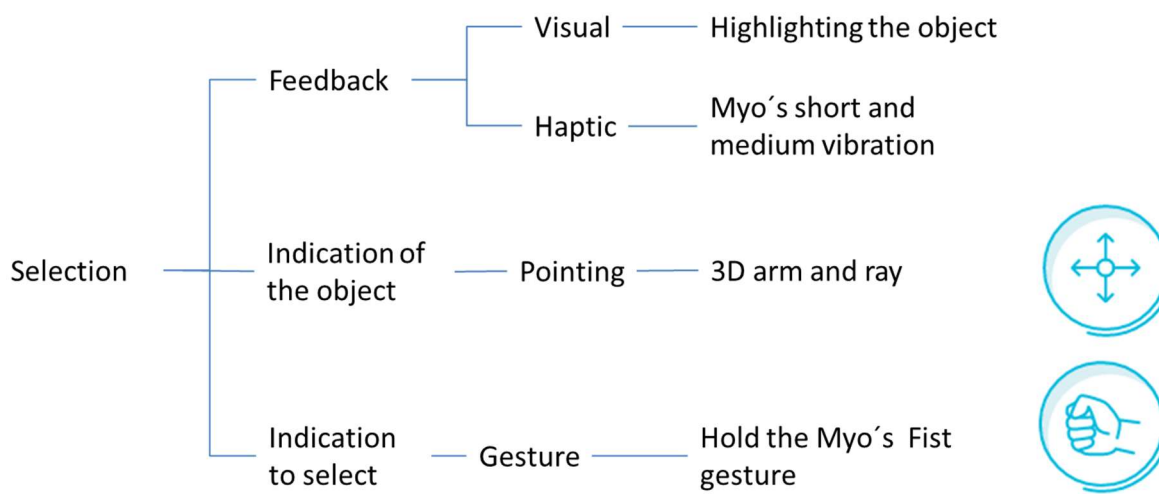


Figure 12 Taxonomy of selection

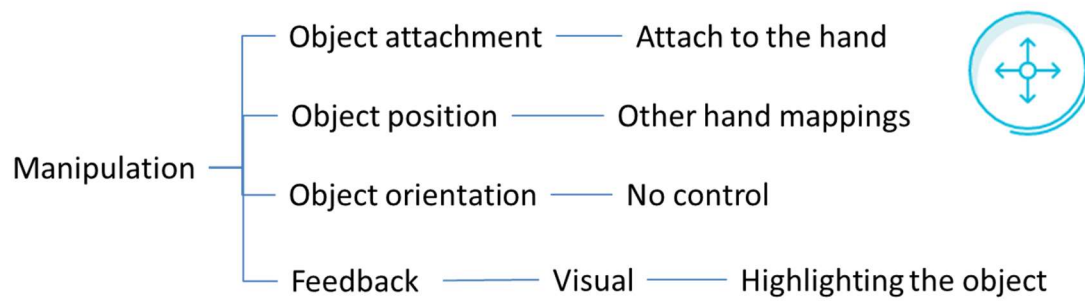


Figure 13 Taxonomy of manipulation

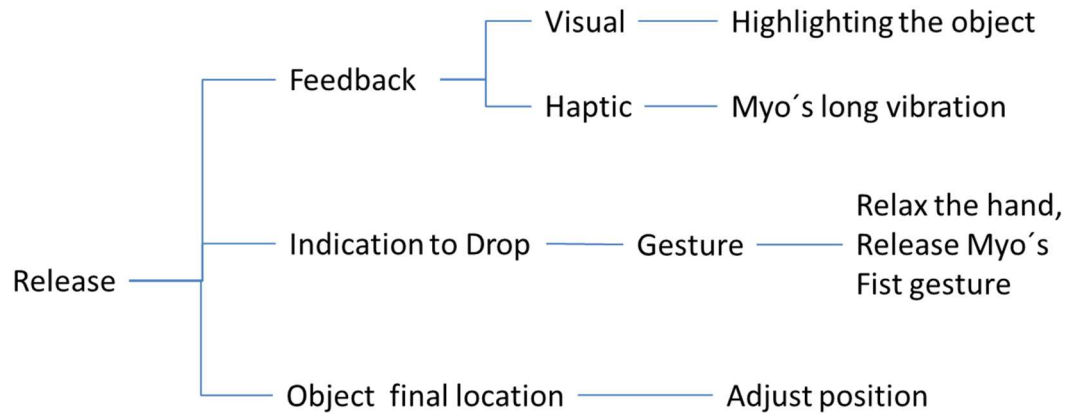


Figure 14 Taxonomy of the deselecting

3.1.2. Hard-Grab Technique

In this technique, the user is presented to the same scenario, but with a new element: each box in the scenario has an associated virtual weight (Figure 15). With this technique, pointing maintains the same. To select a box, the user must make a fist gesture with a hard grabbing of the hand, and the strength he/she must apply to the gesture is proportional to the virtual weight of the box. Additionally, the scenario has a bar that shows the intensity of the gesture made by the user. When the user reaches the necessary strength to lift the box, a Myo short vibration is activated. To maintain the object selected the user must to maintain the fist gesture with a strength within a small range around the activation point. Manipulation maintains the same as in the first technique. When the strength applied to the fist gesture goes under the range the Myo's long vibration is activated, the object is released, and is returned to its original color.

To calculate the strength applied to the gesture we used the mean of the eight EMG raw channels of the Myo (Figure 16) and then the mean of those values in a window of ten samples, right after the detection of the gesture. We did a pilot test, with ten users, to measure the average range of the users' fist gesture's electrical intensity. We

observed that the force applied by the users was proportional to the electrical intensity of the muscles when they were doing the gesture. Based on that observation and on previous works about gesture recognition and EMG data (Chen, et al., 2007) (Polsley, 2014), we decide to use that intensity as quantity measure of the applied force. With the obtained data were extracted the maximum of all the minimums values and the minimum of all maximums values to determinate a possible range of force valid for all users. In the real world, the Weight is equal to Mass multiplied by the Gravitational Acceleration, and equals to the Gravitational Force.

$$W = mg = F_g$$

To suspend an object you must exert a force very slightly greater than F_g , in the opposite direction to the F_g , since in these scenarios we don't have Friction Force. Therefore, the users' average range of forces was mapped to a scale of virtual weights, thus, in the Hard-Grab Technique, the users would move the object by applying a quantity of force in the scale.

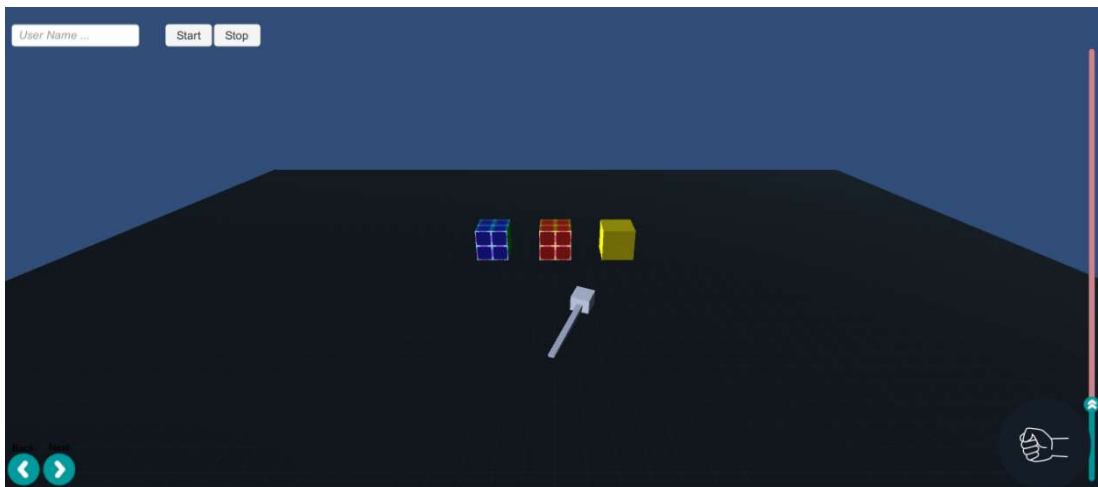


Figure 15 Test scenario for hard-grab technique

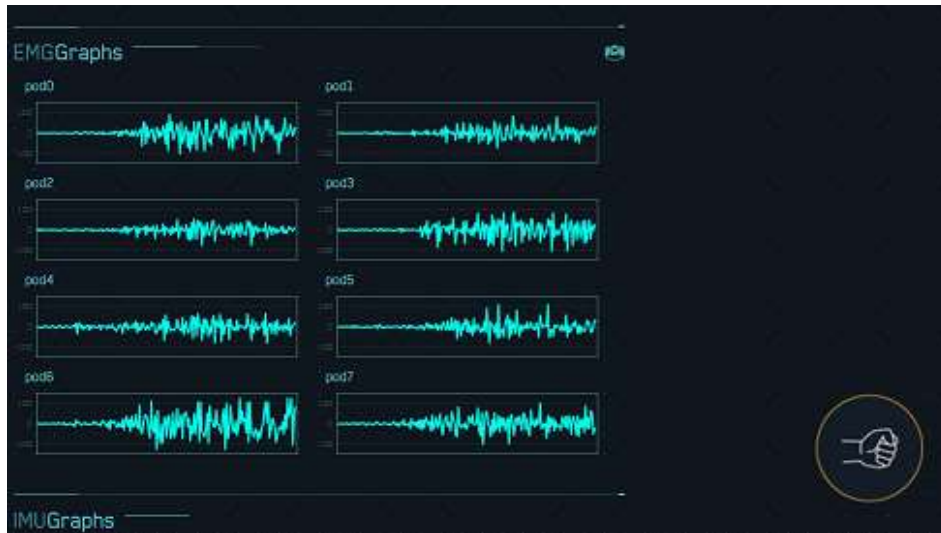


Figure 16 EMG raw data channels corresponding to the fist gesture

3.2 Preparation for User Tests

The user tests conducted in this work followed the guidelines presented by Rubin & Chisnell (2008), including how user studies should be prepared, executed and analyzed. In preparation for user tests, the following tasks had to be completed.

- Establish a Test plan
 - Including:
 - Determine end users
 - An introduction script
 - A consent form
 - A background questionnaire
 - User test research questions
 - Tasks
 - Data to be gathered
 - How data should be analyzed
- Initial Pilot tests

3.2.1. Test Plan

A test plan is a document which gives a general sketch of the conducted tests, containing answers to questions such as why, what, and where considering the testing process. Rubin & Chisnell (2008) details a process of constructing that document and present examples of the different sections. This section describes the main parts of the test plan created for this study.

3.2.1.1. User Test Research Questions

The research questions section is the most important part of any test plan (Rubin & Chisnell, 2008) because it tells the purpose of the user tests, i.e. which problems or questions they are trying to resolve. For this study the main research question is (as stated in section 1.2) the following:

Has MYO armband high grade of usability for manipulation of 3D objects in Virtual Reality Environments?

To answer the main question, it was divided in sub-questions:

- *What resources of MYO can be used in Virtual Reality Environments (VRE)?*
- *What are the limitations of the MYO armband?*
- *Can selection and manipulation tasks be performed using Myo armband?*
- *How can Myo armband enrich the selection and manipulation tasks?*

The two first sub-questions were answered by the literature review conducted in chapter 2, that covers Myo technology, its resources and limitations, and related works. To answer to the last two sub-questions, we proposed two selection/manipulation techniques using Myo: Soft-Grab technique and Hard-Grab technique, and find out which one is preferred. The following points explain atomic interaction for selection and manipulation along with their challenges (as outlined in the subsections 2.2 and 3.2), used to design those techniques.

- Selection/Manipulation:
 - Pointing and selecting objects
 - Positioning
- Possibility of determining which one in the scene is heavier.

These points provide a set of tasks that will cover essential aspects for each interaction type (selection and manipulation) and at the same time they will challenge each technique. They are the base to measure the usability of both techniques and ensure that any usability problem would surface under the test sessions.

3.2.1.2. Participants

According to (Nielsen J. , 2012) in usability tests, going from 5 to 10 participants greatly increases the expected level of problem discovery, but going from 15 to 20 participants has far less impact and more waste of resources and time, he recommends that it is better to do 3 studies with 5 users each one, than doing one big study with 15 users. So, in this study a total of ten participants were recruited, between 25-35 years old. Each one voluntarily participated in one test session. 50 % of them had experience with 3D interactions and video games, and the other 50 % had not (or very little experience). None of them had previous experience with the Myo armband. Two of them were left handed and the others eight right handed, so the Myo was used in the preferred hand of the user and that hand was used throughout the test as the hand using the interaction technique.

3.2.1.3. Task list

The following task list was used throughout the user tests. In each task the boxes are restored to their original position, blue, red, green, from left to right.

1. Explorative (think-aloud) Tasks
 - a) Select the box from the left extreme (the blue box) lift it and put it down in the same place.
 - b) Select the box from the center (the red box), lift it and put it down in the right extreme.

In the following tasks the user was instructed to not think-aloud, so that an estimation of the time to complete tasks without interference could be measured

2. Soft-Grab Test Tasks:
 - a) Select the green box (right extreme), and put it besides the blue box in the left extreme.
 - b) Sort the boxes by colors, from left to right, red, blue, green.
 - c) Sort the boxes by colors, from left to right, red, green, blue.
 - d) Sort the boxes by colors, from left to right, green, red, blue.
3. Hard-Grab Test Tasks:
 - a) Select the blue box (left extreme), and put it besides the green box in the right extreme.
 - b) Sort the boxes by colors, from left to right, red, blue, green.
 - c) Sort the boxes by weight from left to right, from less heavy to heavier.

3.2.1.4. Session outline

- Participant's Reception;
- Moderators' presentation;
- Application of the Pre-use questionnaire to characterize the profile of the participant user;
- Moderator reads introduction script;
- Participant performs each task with each interaction technique;
- Moderator observe the test execution and take notes;
- Post-use questionnaire for usability assessment;
- Post-use interview;

The order of the applied tests was modified for each user to avoid that the learning of the users influenced in the general result of the test.

3.2.1.5. Test environment, equipment and logistics

The user test sessions were performed in a separate room at the Pontifícia Universidade Católica do Rio de Janeiro. A laptop was used as the test platform: 8Gb

RAM, 1T HD, 2GB Graphic Card, with Windows 10 operative system. The Myo armband was connected to the laptop by Bluetooth. The Myo model MYO-00002-001 and the SKD version (0.9.0). The virtual environment was designed and implemented in C# using Unity3D 5.6 and Visual Studio Community 2015. The moderator observed all the time the user's interaction.

3.2.1.6. Data and evaluation measures

The data collected was used to complete two evaluations: first the usability of each individual interaction technique, and secondly the general preference (comparison) of the two interaction techniques. Each aspect of usability (as described in section 2.1) was evaluated and measured as follows:

Usefulness

- Number of completed tasks:
 - A task can fail, be completed, or be completed with help.
 - A task is considered a failure if it the time limit is exceeded.
 - A task is considered complete with help if the user needs any prompting after the initial instructions.

Efficiency

- Measured completion time for each task.

Effectiveness

- How effectively could the user select an object?
- How effectively could the user manipulate an object?
- Did the interaction technique behave as the user expected?
 - Each of these points is measured through the think-aloud, while the user is performing the tasks, along with the specific questions about manipulation and selection asked in the post-test interview.

Learnability

- How hard was it for the user to learn how to use the interaction technique?
- Did the user have a hard time to understand?
 - Measured through the post-test interview and think-aloud comments.

Satisfaction

- What are the user's perception, feelings and opinions about each interaction technique?
 - Measured through the post-test interview and think-aloud comments.

3.2.2. Pilot Test

The pilot test was divided into two parts. The first part was designed to discover and set up test variables like the valid range of gesture strength. The second part was a completed test execution to remove any visible imperfections from the test process, the data collected in these executions were not considered in the final results.

3.2.2.1. Setting up test variables

This experiment has the objective of determining the average range of force that the users can do when closing the hands. Users were measured while they close the hand with force (Figure 17), and relax the hand again. With the obtained data were extracted the maximum of all the minimums values and the minimum of all maximums values to determinate a possible range of force valid for all users. This range was mapped to a scale of virtual weights, so the users can move the boxes by applying a determinate force in the scale in the Hard-Grab Technique.



Figure 17 Fist gesture with force

This experiment was repeated two more times, instead close the hand with force, the users have a rubber ball or a hand grip (Figure 18) in the hand to squeeze it (Figure 19). The obtained ranges and the user comfort of the three experiments were compared and the results were used to setup the tests.



Figure 18 Rubber ball and hand grip



Figure 19 Fist gesture holding a rubber ball and a hand grip

3.2.2.2. Pilot Test Results

The pilot test showed that instructions had to be clear on two things: first, the user must wait for the complete task description before starting, and second, the user had to make it clear when they considered themselves done with a task, to ease measuring completion times.

Additionally, the task of order the boxes by weight showed that the difference between the associated weights to the boxes was too small and even when the users knew there was a difference they could not finish that task, so the weights were altered to be more different. The pilot test also showed that the script used by the moderator had to have enough space to write comments, completion times and if any selection errors occurred.

4 Analysis of the data and results

This chapter describes the results of the user's tests, starting with the achieved usefulness and the measured efficiency for each task included in the test. It follows the qualitative feedback on the perceived effectiveness of each interaction technique. Then, the observed learnability of each technique along with comments from the users are detailed. Lastly, the stated satisfaction of the users on which technique they preferred overall, and for each interaction task, is shown.

The tasks were divided in three groups: Explorative, Soft-Grab Test Tasks, and Hard-Grab Test Tasks. The Explorative tasks were not measured; they were the tasks that the users always did first. The objective of these tasks was let the user understand how to use Myo armband.

The tasks in the Soft-Grab group were designed to measure the Soft-Grab Technique and the Hard-Grab group of tasks was designed to test the Hard-Grab Technique. The order of the applied tests group was modified for each user to avoid that the learning of the users influenced in the general result of the test. As presented in section 3.3.1.1, 10 participants took part in the tests.

4.1 Task Completion: Technique Usefulness

This section details the achieved task completion for each task in Soft-Grab group and Hard-Grab group, including reasons for failure.

The Soft-Grab tasks group consists, in general, in selecting a box, and positioning it in another place using Myo gesture recognition system. The group has 4 tasks. The first one was to take a box from the right extreme and put it in the opposite extreme, and the other three were sort the three boxes by color, each time with a different arrangement. Table 1 shows the number of users that completed each task.

	Task Completed	Task Completed with help	Task Failed
Select the green box (right extreme), and put it besides the blue box in the left extreme.	8	2	0
Sort the boxes by colors, from left to right, red, blue, green	7	2	1
Sort the boxes by colors, from left to right, red, green, blue	10	0	0
Sort the boxes by colors, from left to right, green, red, blue	10	0	0
Total of Task Completed	35/40 = 87.5%	4/40 = 10%	1/40 = 2.5%

Table 1: Soft-Grab Tasks Completion

Users/tasks group	Completed all the tasks	Need help in at least one task	Failed at least one task
Count of users	7/10	2/10	1/10

Table 2: Completion: Users/ Soft-Grab group

The failure in the second task occurred due to the user misunderstanding the task instructions, this user had very little experience with 3D interactions and he/she was 35 years old.

The four times when a user needed help to finish a task happened for two users only, and were in the same two tasks. Both right handed, 27 and 30 years old, with an average experience in virtual reality games. Both were confused about the way on how to close the hand to select the boxes and maintain the hand closed to keep the box selected. In both cases, they expected that once they select the box, it will keep selected even if they open the hand. The moderator had to read again the part of the

script where explained how to perform the task. They claim that they had forgotten that part. From the ten users, just three could not complete the all the group of tasks without any help.

The tasks in the Hard-Grab group, in general, involves selecting a box, and positioning it in another place using Myo gesture recognition system and the proposed method to calculate the strength applied to the gesture. The group is composed by three tasks, the first was to take the box from the left side and put it in the right side, the second was to sort the boxes by colors, and the last was to sort the boxes by weight. It is important to note that in this scenario each box has a virtual weight associated.

	Task Completed	Task Completed with help	Task Failed
Select the blue box (left extreme), and put it besides the green box in the right extreme.	9	1	0
Sort the boxes by colors, from left to right, red, blue, green.	9	0	1
Sort the boxes by weight from left to right, from less heavy to more heavy.	7	2	1
Total of Task Completed	25/30 = 83,3%	3/30 = 10%	2/30 = 6.6%

Table 3: Hard-Grab Tasks Completion

Users/tasks group	Completed all the tasks	Need help in at least one task	Failed at least one task
Count of users	7/10	3/10	1/10

Table 4: Completion: Users/ Hard-Grab group

In this group of tasks the same user failed in two tasks of sorting the boxes, due to precision of the selecting part of the tasks. The user clearly struggled to reach the minimum strength and maintain it to don't release the box. The same user completed with help the first task of getting one box from one place and move it to another. To complete the first task, he/she selected the box and could not put it in the indicated place before releasing the box, so the box went down in the middle of the other two boxes, then the user asked if he/she could select it again and put it in the indicated place. The answer was positive and the user completed the task. The other two user who need help to complete task, had trouble with the sort by weight task. They sorted wrong the boxes, then they selected each box again to measure the weight of the boxes and they corrected the arrangement. They asked if they can correct their arrangement but since they did explicit announced that they had finished the task the moderators let them do it. From the three users that could not complete the task without help or did not complete it, two were right handed and one left handed.

In terms of completion we did not see any important difference between the two techniques and both had good rates of achievement. Also, it was clear that the users who did not complete the tasks were those with less experience in virtual reality environments. To be right handed or left handed did not influence in the performance and completion of the task.

4.2 Task Time: Technique Efficiency of Use

Efficiency was measured by tracking the completion times of the group of tasks: Soft-Grab and Hard-Grab, where the user was instructed not to think-aloud. The other tasks were not considered since they were explorative in nature. This section shows the average completion time for each interaction technique. Failed tasks were not counted, neither was counted the time when the user stop to ask for help or to make a question. The tasks were grouped by technique used and the skill required by the user. We calculated the average and the standard deviation for each group, the

standard deviation and average values were rounded to one decimal. The table 5 shows the results.

Techniques/Tasks	Move one box from one place to another (seconds)	Sort the three boxes by color (seconds)	Sort the three boxes by weight (seconds)
Soft-Grab	12,6 ± 3,8	25,6 ± 5,7	-
Hard-Grab	18,3 ± 2,4	29,5 ± 4,9	39,8 ± 3,2

Table 5: Tasks Execution Time

The first two groups of tasks were completed faster with Soft-Grab technique, but it is important to note that some difference in time execution was expected due to the nature of the techniques. Also, it is important to note that the difference was not so big. Some of the average values of Hard-Grab technique collide with outsider values of Soft-Grab technique, making those hard-grab values to be inside the range of the standard deviation of Soft-Grab technique.

Another interesting point of these measures, is that even when the measure of the task “Sort the three boxes by weight” could not be compared with the Soft-Grab technique due the nature of the techniques, its average time and standard deviation shows that its execution time do not differ so much from the task of “Sort the three boxes by color”, and the delay time was expected because the user had to select all the boxes to know which one were heavier, and sometimes they need to do that more than once.

4.3 Technique Effectiveness

The effectiveness of the interaction techniques was measured qualitatively by how well the user could use the techniques to select and manipulate virtual objects, based on the think-aloud process, the observed behavior, and the post-test interview results.

Selection and positioning were very similar in both techniques. The difference resides in the strength that the user must apply to the gesture to select the object. Besides that, the key to select an object was pointing it and making a fist gesture, and for positioning the user must point to the new place with the object selected.

With Soft-Grab technique, the major trend was that the grabbing motion felt natural or comfortable, imitating the way a user would grab an item in real life. Also, they like that pointing to the box to indicate selection was easy and precise. Two users said that the pointer will be better if shown in the scenario; we had shown them the ray connecting the pointer with the box, and not just highlight the box when it was in the ray interception. Two users said that, at first, they expected that once they select the box, it will remain selected until they spread the fingers of their hand, and the techniques require that they maintain the fist gesture to maintain the box selected, so when they relax the hand, even if they did not the “fingers spread” gesture, the box was deselected.

In another case the user had trouble to set up the pointer to the front making the “fingers spread” gesture. He said:

User: It was very hard to setup the pointer, it doesn't recognize very well that my hand was open and I had to do that at the beginning of each test, so it was a little uncomfortable.

The moderator notes that the user has made the “finger spread” gesture very differently in the calibration session and in the test sessions he had troubles to setup the pointer because he doesn't remember how to put his hand.

Another point that emerged in the interview was the vibration feedback. The users almost agree and use almost the same explanation for it. They said that at the beginning they could not differ between the three types of vibrations or what they mean, but after two or three times it was very helpful to them to know what is going on. For example, one of the users commented about it:

Moderator: Did you see that the Myo vibrated some times?

User: Yes! I noted.

Moderator: Did you figure out what the vibrations were for?

User: Well, at the first task I didn't know, but after that, I realized that it happens when I got or I dropped the box, and it was very helpful even when I let the box fall accidentally and the bigger vibration was activated I knew that I had loose the box and I needed to get it again.

With the Hard-Grab technique that includes the measure of the strength applied to the gesture, the major trend was that it felt very realistic, but it was also more difficult to achieve the selection. One of the users said about the visual feedback:

User: To select an object It felt real, but it was wired because the right bar was a little distracting... I stopped to watch it because it was not helping me and I focused on the boxes. I knew that I got the box when the vibration was activated and I could move it. Maybe if each box has its own bar under it like in video games it would be better.

Both techniques were effective to select and position the objects, and they reach the objective of giving to the user the sensation of reality.

4.4 Technique Learnability

The major trend for the learnability of both interaction techniques was that the basics for each technique were easy to understand. The major problem was with the Hard-Grab Technique, to learn to measure the force that the user was doing to select the box, and how to maintain the force inside that range to maintain the box selected. Another issue was that the users had not clear that if they drop a box they could take it again, until they must. Some of they don't let the box fall in the first task, so in the sort by color tasks they need to put the boxes in different places and they try to put it in the final place since the beginning because they did not know that they can pick up the box letter and move it to another place. In the tasks of sort by weight, some of them were insecure because they need to lift and put down all the boxes to know the weight, but in general it takes just a few seconds for them to discover it.

The most difficult interaction was to select an object with the Hard-Grab Technique. In the formulary, we ask them to evaluate the effort they do to learn how to do each interaction (selecting and positioning) with each technique, where 0 means “It was the easier thing I had learn in my life” and 10 means “It was the hardest thing to learn in my life.”. The average result is shown in Table 6. Soft-Grab was slightly easier in selection interaction than Hard-Grab with one point of difference. But in Positioning the boxes the difference was quite bigger with 3 points of difference, confirming what’s the users tell in the interview.

Average effort to learn the technique.	Soft-Grab	Hard-Grab
Selecting	4	5
Positioning/translation	3	6
Overall	4	6

Table 6: Average effort evaluation results

In general, it was observed a fast learning process; the users were more comfortable with each task, independently of the order of the test applied. The first tasks were always more difficult than the rest of the tests. Though, the Soft-Grab requires less cognitive effort than Hard-Grab from their point of view.

4.5 Technique Satisfaction

With the Hard-Grab Technique, the necessity of make more force or less force to select the box, was in general very well received. The common opinions about it were that it was more difficult, but they could do it and it felt realistic, the users were in general excited about it:

User1: I wish this exists in the games I play.

User2: It would be so better if you can use a Myo each hand, to do more things the objects.

When the moderator asks them which technique they prefer the majority answer the Hard-Grab Technique. Table 7 shows how many users prefer which technique for each interaction and overall. Positioning interaction was controversial because some of the users that preferred the Hard-Grab technique to selection, affirm that to move the box they would prefer to maintain the fist gesture, but not to have to maintain the force because the arm gets exhausted and at the end they had the hand tired. So, they prefer a combination of both techniques.

Interaction/Techniques	Soft-Grab	Hard-Grab	Both
Select	2	7	1
Translation/Positioning	6	3	1
Overall	3	7	0

Table 7: Preferred interaction technique

4.6 Discussion

The usefulness of the techniques was measured by the tasks completion. In terms of completion we did not see any significant difference between the two techniques and both had good rates of achievement, in both cases seven of ten users completed the tasks without help, and just one user failed in some task with each technique. Also, it was clear that the two users who failed some task were those with less experience in virtual reality environments. To be right handed or left handed did not influence in the performance and completion of the task. However, it is important to note that those users who need help to complete some task, and asked to the moderator about the specification were less focused than the others on the test while the script was been read. The user that failed the task from Soft-Hard group, failed due to

misunderstanding the task instructions. In Hard-Grab Technique the user failed due to precision of the selecting interaction of the tasks. The user clearly struggled to reach the minimum strength and maintain it not to release the box.

Technique efficiency was measured by tracking the completion times of the tasks. The Soft-Grab tasks had less completion times than Hard-Grab tasks, but the difference was ± 6 seconds that due to the difference of complexity of the techniques is acceptable. An interesting point of Hard-Grab technique, is that even when the measure of the task “Sort the three boxes by weight” could not be compared with the Soft-Grab technique due to the nature of the techniques, its average time and standard deviation shows that its execution time do not differ so much from the task of “Sort the three boxes by color” and the delay time was expected because the users had to select all the boxes to know which one were more heavy, and sometimes they need to do that more than once.

The effectiveness of the interaction techniques was measured qualitatively by how well the user could use the techniques to select and manipulate virtual objects, based on the think-aloud process, the observed behavior and the posttest interview results. Both techniques were effective to select and position the objects, and they reach the objective of giving to the user the sensation of reality. Two users told that they would prefer that we had shown them the ray connecting the pointer with the box, and not just highlight the box when it was in the ray interception. Two other users said that, at first, they expected that once they select the box, it will remain selected until they spread the fingers of their hand, and the techniques requires that they maintain the fist gesture to maintain the box selected, so when they relax the hand, even if they did not the “fingers spread” gesture, the box was deselected. With the Hard-Grab technique, a user said that the right bar was confused, and he/she would prefer that each box had its own bar under it, like in video games. The general trend about the vibration feedback was that at the beginning they could not differ between the three types of vibrations or what they mean, but after a few times it was very helpful to them to know what is going on.

The major trend for the learnability of both interaction techniques was that the basics for each technique were easy to understand. The major problem was with the Hard-Grab Technique to learn to measure the force that the user was doing to select the box, and how to maintain the force inside that range to maintain the box selected. In general, a fast learning process was observed, and the users were more comfortable with each task, independently of the order of the test applied. The first tasks were always more difficult than the rest of the tests. Though, the Soft-Grab requires less cognitive effort than Hard-Grab from their point of view.

In the satisfaction measure we evaluated which technique the users prefer for each interaction, and overall. Survey results show that for selection the preferred technique was Hard-Grab, though for positioning the preferred was Soft-Grab. In general, they preferred the Hard-Grab technique. Interview results shows that the trend was that the users were excited about the realistic feeling that give them the Hard-Grab technique, nevertheless, they affirm that to move the box they would prefer to maintain the fist gesture but not to have to maintain the force because at the end they had the hand tired. So, they prefer a combination of both techniques.

After this analysis, we conclude that both techniques had high usability grades, demonstrating that Myo armband can be used to perform selection and manipulation task, and it can enrich the experience making it more realistic by using the possibility of measuring the strength applied to the gesture and the vibration feedback system. Although, from the interviews, we note that the user's muscle's fatigue is an important factor to be consider in future studies to evaluate the usability of interaction techniques that use the force applied to the gesture.

5 Conclusions

This study aimed to answer to the following research question:

Has MYO armband high grade of usability for manipulation of 3D objects in Virtual Reality Environments?

To limit the scope of this research question, only interaction consisting of selection and manipulation was included in the study, navigation was not considered.

Then, the objective of this work was to evaluate the use of the Myo armband as a device for selection and manipulation of 3D objects in virtual reality environments, aiming to improve the user experience, taking advantage of the possibility of calculating the force applied to a gesture, and the possibility of use the Myo vibrations as a feedback system.

We divided the main question into four sub-questions:

- *What resources of MYO can be used in Virtual Reality Environments?*
- *What are the limitations of the MYO armband?*
- *Can selection and manipulation tasks be performed using Myo armband?*
- *How can Myo armband enrich the selection and manipulation tasks?*

We conducted a bibliography review that covers Myo technology, resources and limitations, related works, and basic concepts and about Interaction in VRE, to answer the two first sub-questions, also, we wanted to know how to design interaction techniques for VRE and to correctly evaluate their usability.

To answer the last two sub-questions, this study proposed two techniques (called Soft-Grab and Hard-Grab techniques) based on the result of the literature review. Those techniques were designed to test and explore the capabilities of the Myo armband as interaction tool for input and feedback in a VRE.

In the literature review, we found that in advanced technologies, related to virtual reality, hand gestures and motions became one of the most used input methods, making the interaction techniques much more immersive to the users. Classification of interaction techniques is necessary to be able to organize and compare interaction techniques in virtual environments. There are different approaches to interaction technique classification. One of the more complete works about classification of interaction techniques was presented in (Bowman & Hodges, 1999). The techniques proposed in this work will be classified following the taxonomy presented in their work.

Additionally, we saw that the feedback system in simple interaction techniques consist on sending visual and audio information from the computer to the user. Haptic feedback can augment the users' immersion and the users' senses. In haptic interaction, the difference is that physical energy flows bi-directionally, from and to the user. Vibration feedback augments haptic feedback, making simulations of high-frequency contact, texture, and issues like puncture, more realistic.

After design and classify the interaction techniques, we needed to evaluate them. One of the concepts more important to evaluate a system in general is its usability. Usability can at first impression appear to be a one-dimensional measure, but usability is a complex composite measure that can be decomposed into the five components: Usefulness, Efficiency, Effectiveness, Learnability and Satisfaction. Therefore, to measure Usability, there are important aspects to observe: if the users achieve their specific goal, how quickly a user can finish a task, if the product behaves in the way that users expect it to and how ease the users can use it to do what they intend, how hard or easy it is to understand the system, and for last, the users' subjective opinions of the system, if they like it or dislike it.

Another important fact was the device's resources and limitations. Myo armband is equipped with a nine axis IMU, that provide the special information of the arm, it contains eight EMG receptors too, that capture the electromyography signal of the muscles of the arm. The Myo's SDK can recognize just five pre-set gestures

including fist, double tap, finger spread, wave left, and wave right, from the EMG information. Also, expose that EMG information to the developers. Another feature is the vibration system. Myo's vibration system consist in three different vibrations: short (23.5 ms), medium (45.6 ms), and long (100.5 ms).

Were reviewed related works with Myo. All of them used Myo's predefine gesture set and they did not use the resource of the vibration system to improve the user experience. Is important to note that all of them, focus their efforts in the recognition of the gesture and do not take advantage of the intensity of the electrical activity like a variable to measure the force applied to the gesture. Additionally, we did not find any study about usability of Myo for selection/manipulation of 3D objects in VRE. Majority of them used the Myo as input for navigation techniques, or were not related to VRE.

This work proposed two selection/manipulation techniques (Soft-Grab and Hard-Grab techniques) using the Myo's SDK to capture and analyze the special and gestural data of the users. Additionally, to take advantage of the new resources that Myo offers, we used the intensity of the electrical activity obtained from the EMG raw data, and we simulated the force that the user was applying to the virtual object. Also, we created a feedback system that include visual and haptic feedback, using the vibration system of Myo.

Soft-Grab Technique makes use of the gesture recognition and the nine axis IMU sensor of Myo. In this technique, to select an object the user must point with his/her arm to the object and make a fist gesture with the hand. The object will be still selected until the user releases the fist gesture by relaxing the hand. To translate the object to another position, the user must to select the object first and while it is selected the user must point to the new position, the object will move following the pointer movement in the (x, y) plane.

Hard-Grab Technique can be seen as an extension of Soft-Grab Technique, based on it; the difference resides in that the user need to apply a force to the gesture to select the object. The strength needed varies for each object and is mapped to a virtual weight so the select and positioning interactions are affected by the weight of the

objects. An object is selected when the user reaches the necessary strength to lift the object. To maintain the object selected the user must maintain the fist gesture with a strength within a small range around the activation point.

To calculate the strength applied to the gesture we used the mean of the eight EMG raw channels of the Myo and then the mean of those values in a window of ten samples, right after the detection of the gesture. Then we did a pilot test, with ten users, to measure the average range of the users' fist gesture's electrical intensity. We observed that the force applied by the users was proportional to the electrical intensity of the muscles when they were doing the gesture. Based on that observation and on previous works about gesture recognition and EMG data (Chen, et al., 2007) (Polsley, 2014), we decide to use that intensity as quantity measure of the applied force. With the obtained data were extracted the maximum of all the minimums values and the minimum of all maximums values to determinate a possible range of force valid for all users. In the real world, the Weight is equal to Mass multiplied by the Gravitational Acceleration, and equals to the Gravitational Force.

$$W = mg = F_g$$

To suspend an object you must exert a force slightly greater than F_g , in the opposite direction to the F_g , since in these scenarios we don't have Friction Force. Therefore, the users' average range of forces was mapped to a scale of virtual weights, thus, in the Hard-Grab Technique, the users would move the object by applying a quantity of force in the scale.

The feedback system in these techniques was divided in two kind of feedback, visual and haptic, and they were given to the user at the same time. The visual and haptic feedbacks were designed as follows. When an object is pointed, there is a visual feedback by highlighting the object with yellow color, and when the object is out of ray of the pointer, it returns to its original color. When it is selected, a light border appears and when it is released the border disappears. At the same time, when the pointer ray collides with an object, the Myo's short vibration is activated, when it is selected is activated the medium vibration, and when it is released the large vibration

it activated. In Hard-Grab was incremented a lateral bar in the right to indicate to the user the strength the user was applying to the gesture.

We evaluated the proposed techniques by conducting user tests with ten users, between 25-35 years old. 50 % of them had experience with 3D interactions and video games, and the other 50 % had not (or very little experience). None of them had previous experience with the Myo armband. Two of them were left handed and the others eight right handed, so the Myo was used in the preferred hand of the user and that hand was used throughout the test as the hand using the interaction technique.

We analyzed the usefulness, efficiency, effectiveness, learnability and satisfaction of each technique and we conclude that both techniques had high usability grades, demonstrating that Myo armband can be used to perform selection and manipulation task, and it can enrich the experience making it more realistic by using the possibility of measuring the strength applied to the gesture and the vibration feedback system. Although, from the interviews, we note that the user's muscle's fatigue is an important factor to be deeply analyzed in future studies.

We conclude that MYO armband has high grade of usability for selection/manipulation of 3D objects in Virtual Reality Environments. Myo seems to have a promising future as device for interaction in VRE, more than just for navigation and selection/manipulation, also as device for input force, offering new ways of interact in VRE, and many possible applications like immersive training apps, video games, and motor rehabilitation system, where the possibility of measure the force applied to the gesture may have a significant meaning. Then, more extensive studies are needed to determine all the advantages and possible uses of the Myo as interaction device in VRE.

5.1 Future Works

There are some future works that can enrich this study, since the use of the device as force input is an unexplored field, and it has many aspects that we did not cover yet.

The other future works come up from the test process, posttest survey and the interview with the users.

5.1.1. Deeper study of the Myo's potential

We propose as future work, a deep study of the Myo potential as interaction device in VRE, especially as force input device, to understand the differences between the force applied by each user, and to test with more users to be able to get more significant statistic data. Another factor that need to be deeper explored and analyzed is the relationship: fatigue of the users' muscles vs realistic weight simulation, and its influence in the usability of the device.

5.1.2. Propose and study two hands interaction

One of the most asked for the users was the possibility of using two Myos, one in each hand, to be able to use both hands. We speculate that having two Myos would give us the possibility of implementing with the other hand the translation in the z axis and the rotation of the object. The wave in and wave out gestures can be used to move in the z axis a selected object, and the fist gesture and the IMU sensor can be used to rotate the object, but this will require a deeper study.

5.1.3. Study a new combining technique

In Satisfaction questions in the tests, users suggest that they would prefer having a technique that combines both techniques proposed in this work, in which they can select the object like in Hard-Grab and make the positioning interaction like in the Soft-Grab technique, because they feel that maintaining the force needed to keep the object select made their hands to be tired at the end of the test. An interesting future work is to test if the interactions will have better results with that combination.

6 Bibliography

Argelaguet, F., & Andujar, C. (2013). A survey of 3D object selection techniques for virtual environments. *Computers & Graphics*, 121-136.

Bowman, D., & Hodges, L. (1997). An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments. *Proceedings of the 1997 symposium on Interactive 3D graphics. ACM*, 35-ff.

Bowman, D., & Hodges, L. (1999). Formalizing the Design, Evaluation, and Application of Interaction Techniques for Immersive Virtual Environments. *Journal of Languages and Computing*.

Chen, X., Zhang, X., Zhao, Z. Y., Yang, J. H., Lantz, V., & Wang, K. Q. (2007). Multiple hand gesture recognition based on surface EMG signal. *Bioinformatics and Biomedical Engineering. ICBBE 2007. The 1st International Conference IEE*, 506-509.

Chien, H. F., Hu, N. T., Tsai, P. S., Wu, T. F., & Chen, J. Y. (2016). Study on the use of wearable devices to control objects in virtual reality. *Advanced Materials for Science and Engineering (ICAMSE), International Conference. IEEE*, 646-648.

Cruz-Neira, C., Sandin, D., DeFanti, T., Kenyon, R., & and Hart, J. (1992). The Cave: Audio Visual Experience Automatic Virtual Environment. *SIGGRAPH*, 64-72.

Dam, P., Braz, P., & Raposo, A. (2013). A study of navigation and selection techniques in virtual environments using microsoft kinect®. *International Conference on Virtual, Augmented and Mixed Reality. Springer Berlin Heidelberg*.

Frisoli, A., Rocchi, F., Marcheschi, S., D. A., Salsedo, F., & Bergamasco, M. (2005). A new force-feedback arm exoskeleton for haptic interaction in virtual environments.

Eurohaptics Conference, 2005 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2005. World Haptics 2005, 195-201.

Haque, F., Nancel, M., & Vogel, D. (2015). Myopoint: Pointing and clicking using forearm mounted electromyography and inertial motion sensors. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 3653-3656.

Hirata, Y., & Sato, M. (1992). 3-Dimensional Interface Device for Virtual Work Space. *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 889-896.

Jung, J., Park, H., Hwang, D., Son, M., Beck, D., Park, J., & Park, W. (2014). A review on interaction techniques in virtual environments. *International Conference on Industrial Engineering and Operations Management*, 1582-1590.

Kerber, F., Lessel, P., & Krüger, A. (2015). Same-side Hand Interactions with Arm-placed Devices Using EMG. *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems. ACM*, 1367-1372.

Mann, S. (2001). Intelligent image processing. *John Wiley & Sons, Inc.*

McCullough, M., Xu, H., Michelson, J., Jackoski, M., Pease, W., Cobb, W., & Williams, B. (2015). Myo arm: swinging to explore a VE. *Proceedings of the ACM SIGGRAPH Symposium on Applied Perception*, 107-113.

Mine, M. (1995). ISAAC: A virtual environment tool for the interactive construction of virtual worlds. *UNC Chapel Hill Computer Science Technical Report*.

Mine, M. (1995). Virtual environment interaction techniques. *UNC Chapel Hill Computer Science Technical Report*.

Nguyen, T. T., & Duval, T. (2013). 3-Point++: A new technique for 3D manipulation of virtual objects. *3D User Interfaces (3DUI), 2013 IEEE Symposium*, 165-166.

Nielsen, J. (1994). Usability engineering. *Elsevier*.

Nielsen, J. (2012). How many test users in a usability study. *Nielsen Norman Group 4.06*.

- Nuwer, R. (2013). Armband adds a twitch to gesture control. *New Scientist*.
- Nymoer, K., Haugen, M. R., & Jensenius, A. R. (2015). MuMYO–Evaluating and Exploring the MYO Armband for Musical Interaction.
- Petrovski, A. (2014). Investigation of natural user interfaces and their application in gesture-driven human-computer interaction . *IEEE. Information and Communication Technology, Electronics and Microelectronics (MIPRO) 37th International Convention*, 788-794.
- Phelan, I., Arden, M., Garcia, C., & Roast, C. (2015). Exploring virtual reality and prosthetic training. *Virtual Reality (VR), 2015 IEEE*, 353-354.
- Polsley, S. (2014). An analysis of electromyography as an input method for resilient and affordable systems: human-computer interfacing using the body's electrical activity.
- Poupyrev, I., & Ichikawa, T. (1999). Manipulating objects in virtual worlds: Categorization and empirical evaluation of interaction techniques. *Journal of Visual Languages & Computing*, 19-35.
- Poupyrev, I., Billingham, M., Weghorst, S., & Ichikawa, T. (1996). The go-go interaction technique: non-linear mapping for direct manipulation in VR. *Proceedings of the 9th Annual ACM Symposium on User Interface Software and Technology*, 79-80.
- Poupyrev, I., Weghorst, S., Billingham, M., & Ichikawa, T. (1997). A framework and testbed for studying manipulation techniques for immersive VR. *Proceedings of the ACM symposium on Virtual reality software and technology*, 21-28.
- Premaratne, P., & Nguyen, Q. (2007). Consumer electronics control system based on hand gesture moment invariants. *IET Computer Vision 1.1*, 35-41.
- Rautaray, S., Kumar, A., & Agrawal, A. (2012). Human computer interaction with hand gestures in virtual environment. *Perception and Machine Intelligence. Springer Berlin Heidelberg*, 106-113.

Riillo, F., Quitadamo, L., Cavrini, F., Saggio, G., Pinto, C., Pastò, N., . . . Gruppioni, E. (2014). Evaluating the influence of subject-related variables on EMG-based hand gesture classification. *Medical Measurements and Applications (MeMeA), IEEE International Symposium*, 1-5.

Roth, S. D. (1982). Ray casting for modeling solids. *Computer graphics and image processing*, 109-144.

Rubin, J., & Chisnell, D. (2008). *Handbook of usability testing: how to plan, design and conduct effective tests*. John Wiley & Sons.

Sathiyarayanan, M., & Mulling, T. (2015). Map Navigation Using Hand Gesture Recognition: A Case Study Using MYO Connector on Apple Maps. *Procedia Computer Science*, 50-57.

Sathiyarayanan, M., Mulling, T., & Nazir, B. (2015). Controlling a Robot Using a Wearable Device (MYO). *International Journal of Engineering Development and Research. IJEDR*.

Sobhi, A., Leroy, L., & Bouaniche, A. (2016). Reducing Gestural Interaction Physical Stress in Virtual Environments: an Experiment. *ROCHI-INTERNATIONAL CONFERENCE ON HUMAN-COMPUTER INTERACTION.*, 50-57.

Stone, R. J. (2001). Haptic feedback: A brief history from telepresence to virtual reality. *Haptic Human-Computer Interaction. Springer Berlin Heidelberg.*, 1-16.

Ugulino, W., Cardador, D., Vega, K., Velloso, E., Milidiú, R., & Fuks, H. (2012). Wearable computing: Accelerometers' data classification of body postures and movements. *Springer Berlin Heidelberg*, 52-61.

Ware, C. (1990). Using hand position for virtual object placement. *The Visual Computer*.

Wolf, M. T., Assad, C., Vernacchia, M. T., Fromm, J., & Jethani, H. L. (2013). Gesture-based robot control with variable autonomy from the JPL BioSleeve. *In Robotics and Automation (ICRA), IEEE International Conference*, 1160-1165.

Zhang, X., Chen, X., Li, Y., Lantz, V., Wang, K., & Yang, J. (2011). A framework for hand gesture recognition based on accelerometer and EMG sensors. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE*, 1064-1076.