A Touch-based Configurable Gamepad for Gamers with Physical Disabilities

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Abstract: In modern videogames, interfaces and interaction design play a major role in user experience. As of today, in-game interaction is mainly performed through industry-standard devices. These devices can be either general purpose (e.g., mouse and keyboard) or specific for gaming (e.g., a gamepad). However, gaming interaction devices are not usually designed for people with physical disabilities. In this paper, we first explore issues related to the use of standard gaming devices from gamers with physical disabilities and then we propose a solution by means of an innovative game controller device. This game controller is build using a touch screen interface. The touch screen interface can be configured based on the user needs and will be accessible by gamers which are missing fingers or are lacking control in hands movement.

1 INTRODUCTION

In these last years, the role of video games in our lives is changing. As a matter of fact, they are now also regarded as viable digital artefacts to deliver interactive stories, teach new skills (edugames), perform physical exercise (exergames), and much more. Given this new role for games, the way we use to interact with the media (and its design) is of paramount importance for an optimal user experience. While for the design part we already have a consolidated literature, the devices used to perform the interaction itself are – sometime legacy – industrial standards. These devices range from general purpose tools, inherited from office automation activities (e.g., mouse and keyboard), to gaming specific tools (e.g., gamepads). These devices have been designed with limited consideration for gamers with physical disabilities. As an example, it is almost impossible for a player missing the left hand to effectively use a standard gamepad. A keyboard is a more viable solution, but nonetheless it might put a serious disadvantage on the player.

In this paper, we tackle the problem of providing a good gaming experience to players with physical disabilities. In particular, we focus our research on gamers which are missing – or have difficulties using – a hand or part of it. The contribution of this manuscript is twofold: firstly, we provide insights for a deep understanding of the problem; secondly, we propose a novel gamepad, accessible to gamers with physical disabilities of the hands. The controller we propose is designed to also take advance of a touch device to be easily reconfigurable to cope with the user's needs.

The remainder of this paper is organized as follows: In Sec. 2 we analyze existing literature addressing the same problem, while in Sec. 3 current commercial solutions to support physically impaired gamers are presented. Section 4 describes the One-Hand Controller, our proposed solution, discussing its hardware and software architectures. In Sec. 5 results from user tests are summarized and Sec. 6 concludes the paper.

2 RELATED WORK

Game development was born into research labs in the late '50s, with the game *Tennis for Two* by Willy Higinbotham of the Brookhaven National Lab. It is no surprise that even the developers of *Spacewar!* (1961) declared that controls available on the DEC-PDP-1 were not adequate for a game (Graetz, 1981). As a result, Spacewar! has been the first game augmented with an external ad-hoc control system (Commings, 2007).

Moving now to recent literature, there is a vivid interest in game accessibility (Yuan et all, 2011)

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(Westin et all, 2011) (Rowland et all, 2016) and the Independent Game Developers Association (IGDA) published in 2004 a set of guidelines for gaming accessibility. Unfortunately, these guidelines focused mainly on visual impairments. The guidelines have been then extended in 2006 by (Ossmann and Miesenberger, 2006).

The scientific community is contributing to this important topic in two ways: devising guidelines for accessible game design, and providing innovative devices for disabled gamers.

With respect to guidelines for accessible game design, in (Ossmann et all, 2008), we can find a study about making classic games accessible to disabled gamers. In this work, a middleware between the game and the I/O subsystem has been created using a descriptive language. This result aims to demonstrate that – technically – any game can be made compatible with any kind of device. Unfortunately, this approach seems to be too invasive for the game core architecture because it requires for the (assistive) I/O device to have a direct interface with the hosting game engine. This interface requires the development of a game engine specific to the device and, in turn, to the supported disability. Another contribution along this same line (Grammenos et all, 2009) led to the creation of a game that, with specific changes to game mechanic and logic, can be adapted to any kind of player's disability. A very specific scientific contribution is presented in (Hernandez et all, 2013), where the design of fast-paced action-oriented games for children with cerebral palsy is discussed. In this paper, a participatory design process is used to prove the feasibility of the approach and provide a set of recommendations to achieve action-orientation and playability.

To address the introduction of innovative devices, the research here is mainly focused on making standard controllers available to impaired people through physical adaptation and integration with additional sensors, such as in (Iacopetti et all, 2008) and (Fanucci et all, 2011). Unfortunately, their approach seems to be a bit intrusive and cumbersome to setup for the average player due to the additional wiring and sensors unsupported by the console vendor. Nevertheless, these contributions proved to be an interesting solution to support some cognitive disabilities.

Other researchers are working to completely exclude the physical interaction with a controller. To remove the physical interaction, it is possible to adopt BCI (Lopetegui et all, 2011) or EMG (Watanabe at all, 2010, Kawala et all, 2015) technologies.

The combination of the two approaches above, may result in using a sensor system in place of a controller like in the case of the *VoodooIO Gaming Kit* (Villar et all, 2007). In the VoodooIO Gaming Kit, players are allowed to place physical inputs as they need on a conductive fabric.

Solutions provided from outside the scientific community are also available, we address them in the next section.

3 CONTROLLERS SUITABLE FOR PHYSICAL DISABILITIES

A physical disability is defined as a limitation on an individual's physical functioning. This limitation may regard mobility, dexterity or stamina. A gamer suffering from mobility or dexterity limitations may experience issues in interacting with a video game. As an example, the player may not be able to provide specific inputs (or combinations of them) due to inability to press multiple buttons at once or move a finger between two positions in a timely manner. These limitations can make the gaming experience unbalanced at least, if not even completely frustrating (Tollefsen and Loude, 2004) (Brown et all, 2015) for the gamer.

To overcome the aforementioned limitations, impaired players usually look for specific input devices. On the market, many devices have been proposed by gaming-oriented companies to improve (or make possible) gaming experience of physically impaired players.

The *ASCII Grip* controller (1996), is a device originally designed for the fourth generation of game consoles. This controller is conceived to let gamers play using only one hand while merging all interaction under the control of 5 fingers (Fig. 1).

A similar solution to the ASCII Grip is proposed by the *DragonPlus RPG DuoCon* (2008), where all the controls of a standard gamepad are placed on a tabletop case and the player can set the hand on top of an ergonomic support.

The *One-Handed Ergonomic Palm Game Controller* (2010) is also available on the market. This controller adopts the concept of tabletop case and all controls are located at the end of a palm-resting platform to avoid straining the hand (see Fig. 2). While this proved to be just a variation of a gaming keypad, the interesting feature of this product is its compatibility. As a matter of fact, it supports PCs as well as several modern consoles up to Playstation 4 and Xbox One.

Figure 1: ASCII Grip controller.

Figure 2: One-Handed Ergonomic Palm Game Controller.

An interesting step forward to support one-handed gamers is represented by the *eDimensional Access Controller* (2008). As we can see in Fig. 3, like the previous one, also this controller extends the concept of tabletop case but, differently from the Palm Controller, is providing a modular architecture. Each control set can be plugged in any socket to tailor the controller to the player's specific disability.

Most probably, the best commercial example of controller to support disabilities is the *NES Hands Free Controller* (1989) by Nintendo. This controller was designed for gamers totally unable to move the hands. This device must be strapped to the chest and hooked to the neck of the player (Fig. 4). For movements, the gamer can use her chin to move a joystick while buttons are simulated by blowing in a small pipe.

Other opportunities for disabled players lie on the use of motion tracking devices such as *Microsoft Kinect* or *Wii Remote*. These control systems can be useful, but are usually tight to specific game mechanics. Mainstream games are either specifically designed to use them (e.g., *Just Dance* for Xbox) or require the use of a standard controller. As a result, a user cannot just play any game but only a specific subset, which may not be compatible with her specific disability.

Figure 3: eDimensional Access Controller.

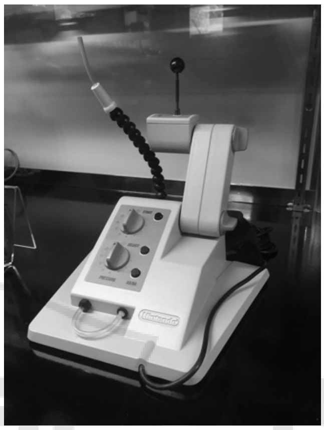

Figure 4: NES Hands Free Controller.

Along with big companies, we can also observe the constant growth of non-profit organizations helping disabled players, such as Ablegamers and OneSwitch. These organizations offer an interesting ground for homebrewer to create tailored solutions for single users.

4 OHC: A NOVEL AND ACCESSIBLE GAMEPAD

Designing a game or a device to cope with all possible disabilities is very difficult, but not impossible, as discussed by (Ossman et all., 2008). In this paper we are going to focus on gamers suffering from mobility issues in the upper limbs. In particular, our research targets players which are missing one hand (or part of it) or have severe limitations in the mobility of their dominant hand.

Starting from the above considerations, and taking inspiration from existing devices on the market, we designed the *One-Hand Controller* (OHC). OHC is similar in philosophy to the eDimensional Access Controller, but it leverages on a mix of analog and digital inputs. Analog inputs are providing legacy compatibility with mass-market video games, while digital inputs can be built on top of a configurable touch interface to provide a configurable buttons layout.

A touch interface has been selected because of three important advantages over current hardware solutions. First, it allows a flexible and fine-tuned re-configuration. This is the same goal of the eDimension Controller but without any constraint in controls size and location. Second, in a next stage of the project, it might be feasible to substitute the touch surface with a tablet or smartphone already owned by the player, thus achieving a consistent cost reduction. Last, as a prototype, a touch interface allows fast prototyping of controls layouts and easy data collection about hand posture and touch misses.

The digital buttons layout of OHC can be finely tuned to the gamer's requirements; moreover, it can also be specific to each video game. A concept design of the OHC device can be seen in Fig. 5. As it can be observed, the device is completely symmetrical; this way it can be easily flipped to support both right- and left-handed players.

Figure 5: One-Hand Controller Concept Design.

In the following subsections, we are going to describe hardware and software architectures of the OHC prototype we built.

4.1 Hardware Architecture

OHC is built around a 7" LCD multi-touch touchscreen equipped with an analog stick and two pushbuttons. The touchscreen supports up to five fingers at once and the analog stick is two-axis thumbstick. The controller hardware is managed by two interoperating microcontrollers: a Raspberry PI 2 and an Arduino Leonardo. A scheme of the hardware setup is reported in Fig. 6.

The Raspberry PI microcontroller is in charge to drive the LCD touchscreen using the onboard Display Serial Interface (DSI). Using the DSI, the 7" LCD can be driven at 25 frames per second. The Arduino Leonardo alone would not provide enough bandwidth to drive such a large display. Moreover, the Raspberry is also in charge to collect user inputs. These user inputs include both touches on the screen and the external thumbstick with pushbuttons. Unfortunately, there are no analog inputs on the Raspberry GPIO bus. Therefore, we were forced to use an Analog to Digital Converter (ADC) to convert the thumbstick position. To perform this conversion, we used an MCP3008, but any 10 bits converter supporting 5V digital outputs can be used.

The Arduino Leonardo oversees managing the communication between OHC and the gaming PC. Leonardo has been used since it natively supports USB slave mode, and libraries to emulate mouse and keyboard are ready available. This way, the Raspberry PI can decode user input and use the Arduino to remap the result to legacy inputs for the game. Raspberry PI alone is not able to perform this task because it – as a system-on-chip computer – can only work as a USB Host.

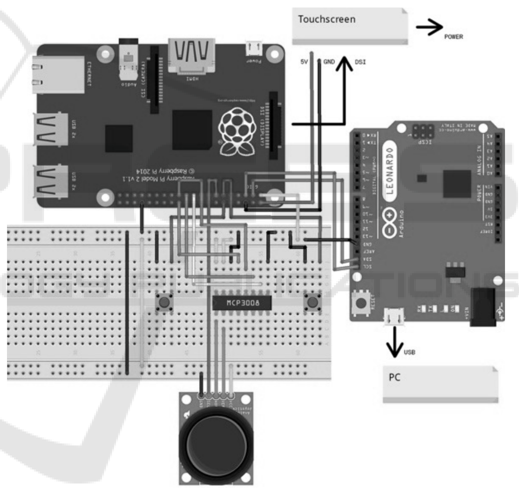

Figure 6: One-Hand Controller board scheme.

Figure 7: OHC prototype.

A picture of the physical prototype we used for experiments can be seen in Fig. 7.

4.2 Software Interface

The software architecture is designed with the user experience in mind. As a matter of fact, its main task is to virtualize a legacy controller starting from the touchscreen and thumbstick inputs. This task must also be performed with minimal delay.

When first turned on, the OHC software will perform a calibration. As a first step, the user is asked if she wants to (or can) use the buttons and thumbstick. Then, the user will be prompted to lay her hands on the touchscreen in a comfortable position. Starting from the detected touches, a default layout will be proposed, based on the number of available fingers. This layout will be aligned and stretched based on fingers' position. The layout can also be modified later for a better gaming experience.

The internal software supports multiple profiles. This allows several users to share a single device. Moreover, each user can store multiple layouts under her profile. As a result, each player can store a specific layout for each game, depending on personal taste and disability. For severe disabilities, or difficulties in coordinating fingers, macros are supported and a single tap can be associated to multiple inputs (see also next section).

The configuration menu can be accessed at any time from the controller itself. The controller touchscreen will provide menus to calibrate, configure controls, and save/load configuration without a requesting additional software on the PC/console (see Fig. 8). This feature allows OHC to be more flexible and portable. Currently, there is no direct feedback provided to the game. This means that, during configuration, the game is not going to pause automatically, but it is possible to switch configuration/layout in any game while playing. Switching configuration automatically based on game status is not yet supported.

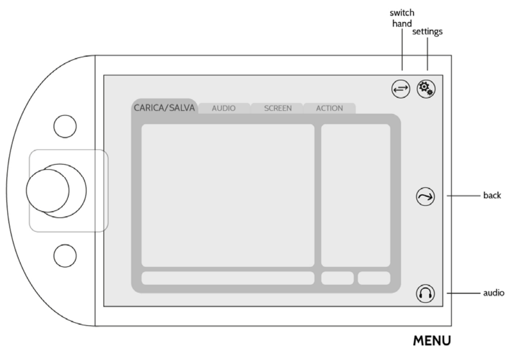

Figure 8: Configuration menu layout.

Finally, OHC can support gestures. Gestures are programmable combinations of command the user can associate to given touch patterns. When enabled, an area of the touchscreen can be reserved to gesture recognition. Gestures will be detected by the Raspberry PI and translated into a sequence of keystrokes and movements. Currently, we support single, double, and triple touch, rotation, swipes, and two-fingers scrolling.

4.3 User Interaction

The Graphical User Interface is the most critical part of the OHC software. As a matter of fact, the GUI must be flexible enough to meet a huge range of user requirements. Moreover, it should also be easy to maintain and extend. For these reasons, we decided to leverage on the computational functionality of Raspberry PI and to implement it using Python and the Kivy framework (Kivy, 2011). Kivy supports the Tangible User Interface Objects (TUIO) paradigm to manage inputs from the touchscreen in a standard way.

The OHC GUI is implemented by composing visual widgets in a hierarchical way. Each widget is taking care of a specific kind of input. An overview of the implemented input widgets is reported in Fig. 9. When performing calibration, one or more widgets are assigned to each finger. Based on selected finger and feedback from the user, the widget will be rotated and stretched to maximize comfort and encompass any movement constraints the gamer may have. Fingers and hand discomfort are reduced by

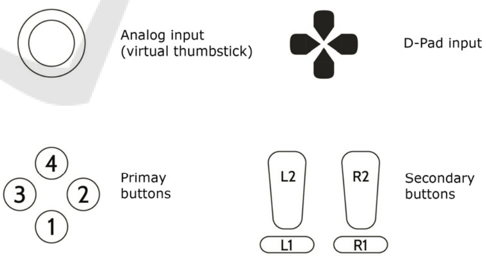

Figure 9: Basic GUI widgets.

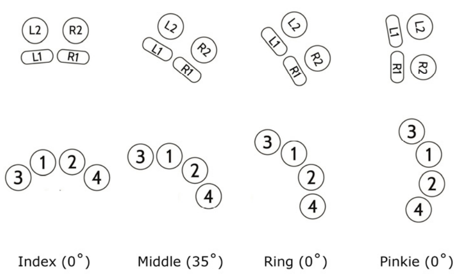

Figure 10: GUI buttons deformation based on fingers.

deforming the widget in a way to place each button very close to each finger landing point. Moreover, widgets position should help an easy switch between controls. Figure 10 shows default finger-based transformations applied to primary and secondary buttons.

Nevertheless, additional considerations are required to address missing or not usable fingers. To cope with every possible kind of disability, we designed specific default interfaces for each case. For every variant, a default widget-finger association is proposed and the actual interface is the result of the deformation and the relocation of widgets basing on the information collected during calibration. Extra care must be devoted to understanding and detecting situations where widgets are too close to each other, hence becoming cumbersome, or, due to mobility constraints on one or more fingers, the widgets position may cause strain. When two widgets are too close the controls may not be effective, especially if the assigned finger has a reduced mobility. Strain may be caused by physical conditions, considering that different fingers are sharing muscle and nerve connections. Default interfaces proposed to users having only four or three fingers are reported in Fig. 11 and Fig. 12, respectively. In the figures, the greyed areas indicate the working area for the touchscreen, while the large dark dots are fingers positions detected during calibration. The working area and the interface position are calculated starting from these dots.

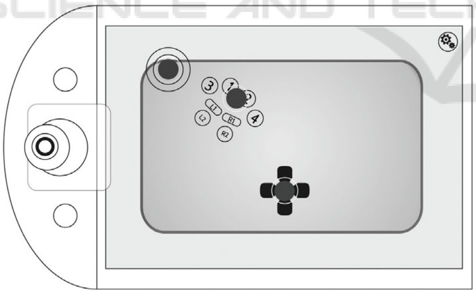
Figure 11: Default interface for 4 fingers.

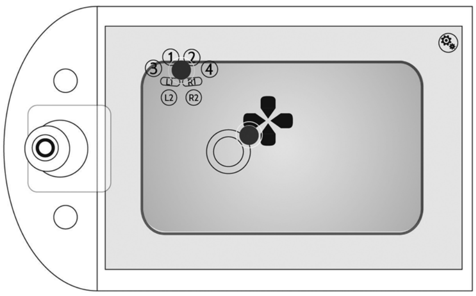
Figure 12: Default interface for 3 fingers.

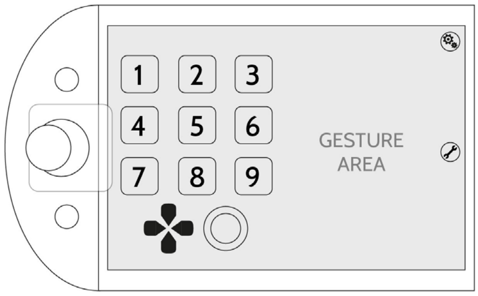

Figure 13: Default interface for one finger or no hand.

In the case of players having only one finger or missing the hand, the interface must provide a gesture area and should be customized by the user. In this case, we are proposing a dialpad instead of primary and secondary buttons. The result is shown in Fig. 13. This last case is where macros definition can be very useful. Macros can be used to associate a single gesture or a dialed number to complex movements or to a sequence of inputs on a standard controller.

5 USER ACCEPTANCE TEST

To evaluate the usability of OHC, we performed a test on a sample of fourteen players, of both sexes, both with and without disabilities, in the age range 20-25 years (they were students graduating in Computer Science). We included testers with no disabilities, not only as a control group, but also and mainly because we wanted to understand whether a device designed with a very specific audience in mind, could be perceived as an effective alternative to commercial controllers also by the average user. To each tester, we asked to setup the controller on a PC and play *One Piece: Pirate Warriors 3* (developed by Omega Force and released in 2015), an action-based game featuring simple hack'n'slash mechanics. This game was selected because its difficulty is quite low. As a matter of fact, we wanted to reduce the possibility to collect negative feedbacks on the controller performances, due to a frustrating user-experience deriving from the game.

After the test, the users have been asked to fill a feedback form and to sustain an unstructured interview, aimed at collecting both qualitative and quantitative data. The form was composed by five sections, aimed at collecting demographical data, feedbacks about the hardware and the software, the users' acceptance rate and problems arise during the testing session.

The part of the test about the *device setup* was intended to verify the hardware compatibility and

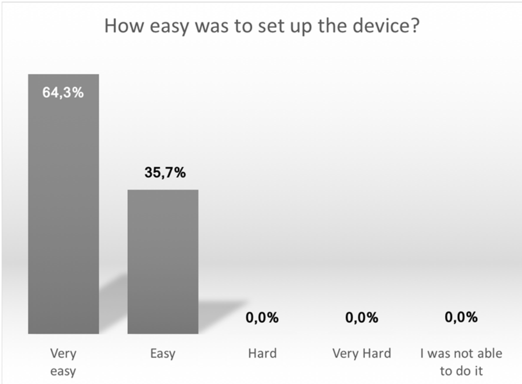

Figure 14: Easiness in setting up the device.

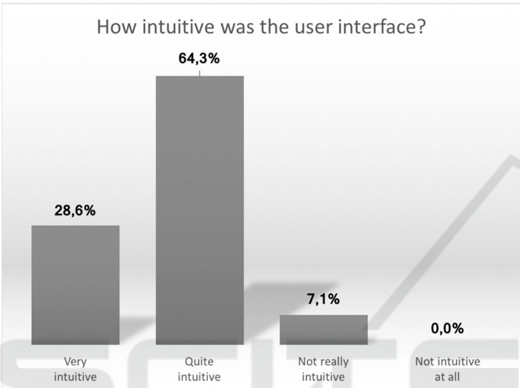

Figure 15: GUI intuitiveness.

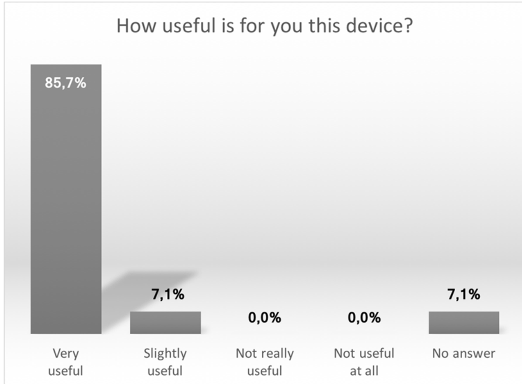

Figure 16: Usefulness of the device.

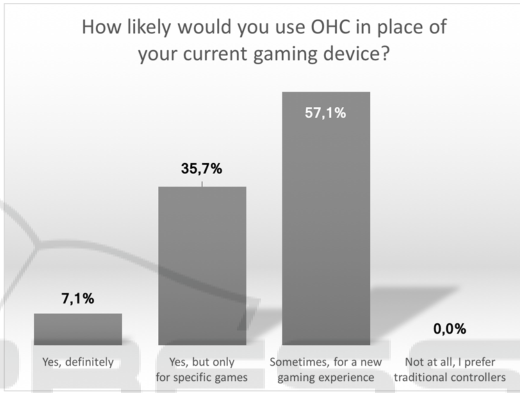

Figure 17: Willingness to adopt OHC as main gaming device.

integration with legacy drivers. In particular, we had to check the Arduino acting as a USB slave device on different hardware configurations. Results are reported in Fig. 14. From the feedback, it seems no user had any major problem in connecting OHC to her computer. Actually, more than half of the group reported an installation without any problem. This is an interesting indication about OHC connecting easily with current retail hardware.

The following section of the test was about the *effectiveness of the interface*. This is a critical point for the whole project. Results are plotted in Fig. 15. From this standpoint, users are hinting that there is still space left for improvement. Most of the testers found the interface intuitive, but still improvable. After performing some interviews on the topic, many users felt positive about the calibration process and the reason for the relative lack of usability may sit on the widget graphical appearance. This is quite understandable, since in its current state, the prototype is proposing a very basic black and white interface, with no help menu.

The next part of the test investigated how *useful is the device* for the user. Our aim was to understand to what extent users (both with and without disabilities) would like to have a controller which can be configured following the user's preferences. Surprisingly enough, as reported in Fig. 16, not only the users with disabilities claimed OHC was useful, but more than 85% of the test group replied that OHC was very useful for their needs. No one was negative about the controller.

The last part of the testing session investigated the *willingness of the users to substitute with OHC their current retail PC gaming controller*. It has been clearly stated in the feedback form to avoid comparison with a console controller. As Fig. 17, shows, there is a general interest in adopting OHC.

The outcomes of the feedback surprised us: on one hand, we did not expect non-impaired users to like so much our prototype, while on the other hand, we find it curious that, such a small fraction of the sample affirmed that they would substitute their controller with OHC. For sure, further investigation is required on this specific aspect.

6 CONCLUSION AND FUTURE WORK

In this paper, we addressed the problem of accessibility of gaming devices to gamers with physical disabilities. In particular, we have been focusing on disabilities affecting upper limbs. As a viable solution, we designed and prototyped OHC - One-Hand Controller: a highly configurable controller mixing analog and digital inputs and leveraging on a multi-touch display. By using a touch interface, we can finely adapt to the gamer's requirements. After building a prototype, we performed tests on a group of students. The prototype received favorable feedbacks, despite the fact a minority of users is willing to adopt it as their main gaming device.

In the future, we are planning two main improvements: a better graphical interface and the addition of haptic feedback. The interface will be reworked from a graphical standpoint, but we are also going to provide a better widgets placement considering the *FFitts law* [sic] (Bi et all, 2013). For the haptic feedback, since OHC is a tabletop device, we are considering adding external actuators.

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