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Haptic Feedback Glove for Arm Rehabilitation

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Abstract. The following document outlines the design process of a haptic feedback glove. The aim of this project is to give the user a haptic feedback once they are in contact with an object in a virtual interactive 3D space. In order to induce a haptic feedback, Unity3D is used to simulate the 3D virtual space, Leap motion is used in order to track the hands of the user and map them on the 3D virtual space. Finally, the signal from Unity is sent to Arduino which is able to produce the signal to initiate the vibration motors and led lights. The purpose of this technology is to help people with reduced motor ability, to perform physiotherapy exercises while playing an interactive game that involves haptic feedback.

Keywords: haptic feedback, Arduino, Sharebot, Unity3D, leap motion and rehabilitation.
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1 INTRODUCTION

Physiotherapy is a common treatment for people with reduced mobility, however nonattendance rates are high across the EU, this can be attributed to several factors; inability to afford the treatment, inability to reach the center or find the time for the session. Attending physiotherapy frequently is not feasible for some patients, therefore, most have to continue the treatment at home without guidance or way of verifying their progress.

Haptic feedback uses vibration as a communication tool when interacting in a virtual space. By using haptic feedback and hand tracking technology it is possible to indicate to the user (through vibrations) if the movement has been successfully achieved. Once the data has been stored it can indicate the progressive improvement of the persons mobility over time, which means both the patient and the physiotherapist can review useful evidence of their progress.

The main advantage of this technology is that it is affordable and portable which means that it can be recommended to those who are not able to go to a center to receive treatment and have to continue their recovery on their own.

2 STATE OF THE ART

In the second half of the 20th century force feedback devices for teleoperation in robotics for nuclear environments were the first haptic interfaces ever used. Later they appeared as well in PHANTOM arm, the Impulse Engine and CyberGrasp glove. In 1990 the Daxterous Hand Master Exoskeleton was developed as a first touch feedback device enabling the user to feel the vibration on his fingertips. Following that many commercial feedback interfaces were invented and due to the rapid development in technology this field is still exponentially growing [10].

Nowadays the haptic systems are widely used in many branches containing tele-robotics, painting, sculpting, military, entertainment, education, and medical applications. The major one however can be found in medicine, changing the way of the interaction with patients, and enabling the evolution of the health science education. Together with Augmented Reality Haptic feedback is often used in robot-assisted surgeries (ex. minimal invasive surgeries, colonoscopy, hystoscopy and dental procedures), behavioral neuroscience, rehabilitation, and medical simulation. Another application can be found in educational purposes like surgical and medical training. Thanks to that the usual time for acquiring the needed clinical skills by the students can be significantly reduced [8,9]. Examples of the devices which are exploiting this technology are: telemanipulators, exoskeletal devices, advanced prosthetics, physical rehabilitation, and intelligent assistant devices [6].

One of the devices used for the rehabilitation purposes is a so-called haptic hand (in a form of a glove) which is the topic of this work. The existing devices exploit different solutions in providing haptic feedback and technology used for orienting the users hand in space. As first example, Jae Yeol Lee et al. proposed the solution of pinch glove, which supposed to be put on the user's hand, with the use of tangible Augmented Reality (AR) interface attached to it. This device enables manipulation of the virtual objects by grasping, pointing, and gesturing. Additionally, the interface, consisting of the alternative instruction suggest possible new gestures that user can do to manipulate the object (basing on the current gesture). Device is equipped with the microprocessor and markers used for tracking the hand. They are attached to the top of the glove. Haptic feedback is provided by motors which are present in the fingertips. Microprocessor, which is connected to the computer via Bluetooth, sends the information to the computer if the user touches one of the patches and searches for the manipulation instruction. Later computer sends the feedback to the user and due to the presence of the markers the 3D location of the hand is possible. For augmenting the virtual object into the real life, the web camera is used [7].

Another proposition of using the technology for enabling the haptic feedback for the user was developed by Tomasso Lissini Baldi et al. In their work they presented the glove which contains wearable haptic devices positioned on the tip of each finger and MARG boards that are used as sensing devices. This boards contain the triaxial accelerometer/ gyroscope and triaxial magnetometer and are used for the estimation of the position. For the design of this device simplified model of the human hand was used enabling two rotations for two joins in each finger (summing with the rotation in the palm the model has 23 degrees of freedom). Two MARG sensors were placed on each finger, and additional one on the palm. For collecting the data from the sensors Arduino nano is used. This information is sent to the computer by 115/200 b/s serial connection. The size of the glove was adjusted for 50th percentile of European man and women (age 20-50). For this work each of the sensors used needs initial calibration which. Device which provides the haptic feedback consist of two platforms placed on the opposite sides of the finger and connected via three cables and springs. Servomotor, which is placed in the upper platform (on the nail) controls the length of the springs moving the lower platform (on the finger pad) displaying the force on the finger pad (haptic feedback). In their paper Tomasso Lissini Baldi et al. slightly modified it, by reducing the weight and changing the size of the motor. This idea is good as the feedback provided to the user is more natural than for example the movement of the motor. On the other hand, the whole device quite big, and the whole tips of the fingers are covered which may the invention not so comfortable for the user to wear [13]. Used in [13] feedback device was preliminary described in [12] and named as cutaneous device which supposed to provide the haptic feedback to the user. As a tracking sensor, commercially available, Leap motion controller was used [12].

In [20] the Virtual reality is used for the rehabilitation purposes. The VR tasks (pinching and lifting) are implemented by using Unity software. Haptic feedback was also provided to the users by the force acting on their fingers in the box. The device that enabled pinching was in a form of the box, connected to the computer with the game, where the user could put their fingers and perform the tasks.

As indicated in [21] the most common practice for the haptic systems gloves was to apply the internal sensors such as accelerometers and gyroscope. Thanks to that, this system could exploit highly sensitive motion tracking. In this work the authors composed the glove from the elastomer-based triboelectric tactile sensors and piezoelectric haptic mechanism simulator. Five PZT chips were placed at the tip of each finger to perform the haptic feedback. The glove case was 3D printed and was design in such was to support all the sensors and mechanical stimulators. Also, the VR was used in this case to enable the user full experience.

Despite the available technology and progress already made, there is still a lot of devices which are not yet commercialized and are facing various challenges mainly connected to the design, interaction with the human beings and real time graphical and haptic rendering [6]. Looking at some of the existing solutions, of haptic hand, different ways are used to orient the user's hand in the space and for providing the haptic feedback. Most of them make the glove design quite robust and what is more putting it on the hand of the user difficult, especially for the people that are dealing with disabilities of any kind. The design solution proposed in this paper tries to overcome those issues making the glove more wearable and easier to put on. Additionally, the production process is cheap which means that the glove can be designed especially for any type of hand.

3 DESIGN SPECIFICATION

The purpose of this project is to help people with reduced mobility or a disability specific to the arm region with the aim of improving their mobility by introducing the possibility to perform self-guided virtual rehabilitation. Currently in EU for a population of 100000 people there are around 118 physiotherapist with increasing demand [19].

The haptic gloved is aimed to a wide range population, from people that have suffered a stroke and need to regain motor ability, to those recovering from a surgery in such location or were born with a motor disability. For this reason, a principal aspect of the project was to ensure older age groups and younger age groups were able to equally use this product. Therefore, the design described is lightweight, economic, and ergonomic in order to ensure accessibility.

4 DESIGN PROCESS

For the design we focused on simplicity and accessibility for the user. Thus, the model was inspired by the exoskeleton of the hand.

Velcro was proposed as a securing system as it allows a larger range of people to be able to utilize the product. Additionally, Velcro is an easy system that one person alone can manage to put the device on without assistance (depending on the level of their mobility), this is important as perhaps the rehabilitation of the patient will take place at home where this person might not be accompanied. Velcro is a hook and loop system, the hooks engage into the loop which in turn provides a closure mechanism [18].

4.1 Design Development (CAD)

The bracelet and fingers were designed in Inventor [4]. The size of each finger is taking into consideration to fit the average size of a person's hand. At the top of every finger there was a place for the motor and along the middle a place for the wires as seen in figure 1. Additionally, we designed thin covers for each finger to protect the motors from the environment.

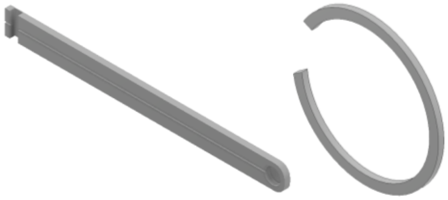

Figure 1: First design of finger and bracelet.

Subsequently, we created a ring support for the Velcro as well for the finger as for the bracelet (Figure 2) in order to position the Velcro.

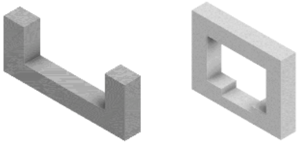

Figure 2: Velcro supports.

Finally, due to a lack of space on the bracelet for the fingers, they were modified to be thinner as shown on the Figure 3 Additionally, the shape of the bracelet was also changed to a more comfortable one as shown below. Additionally, the top (cover) part of each finger was adequately modified, these modifications were done after evaluation of the initial prototype.

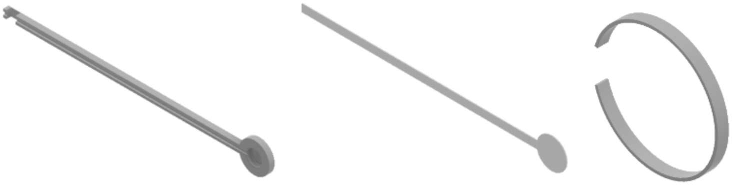

Figure 3: Final design of the fingers and bracelet.

The elements were assembled in Inventor and the result can be seen on the Figure 4.

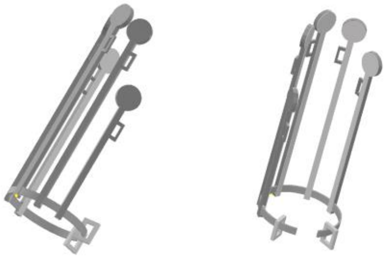

Figure 4: Assembly in Inventor.

5 3D PRINTING

5.1 Material Choice

The procedure for manufacturing is 3D printing, the recommended material for this purpose is TPU. Thermoplastic polyurethane (TPU) is any of a class of polyurethane plastics with many properties, including elasticity, transparency, and resistance to oil, grease, and abrasion. Technically, they are thermoplastic elastomers consisting of linear segmented block copolymers composed of hard and soft segments [1]. This material is suggested primarily due to its elastic behavior which is need for this application.

5.2 3D Printing

The designed parts in Inventor (Autodesk)[4] were prepared for the 3D printing. Firstly, they were exported to the .stl files, remembering to choose the correct units (mm) and later they were imported to the Slic3r software. After choosing the correct settings the g-codes were created and put into the 3D printer which was the Sharebot Next Generation [11]. The whole printing procedure is depicted in the Figure 5.

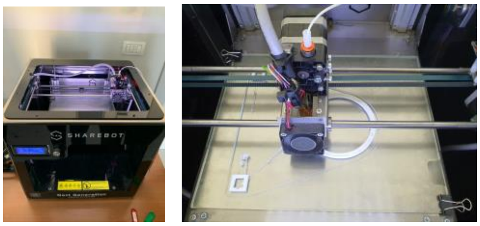

Figure 5: (a) 3D-printer (b) printing the bracelet.

The physical assembly was composed of two major steps the first setting up the electronic circuit connected Arduino.

The soldering process had to be repeated several times, the light installed in the bracelet is a three-tone led which means there are 4 wires which are connect to the Arduino circuit. Additionally, each finger has a vibration motor which means that there are two wires that are to be connected to the Arduino circuit.

The second step of the physical assembly was to put the circuit together with the 3D printer pieces. To assemble the pieces, it was necessary to first insert the motors in the 3D printed fingers then mount them on the bracelet and cover them with a layer of TPU. Once this process has been done for all the fingers hooks are placed at the bottom part of the fingers, to hold the Velcro in place.

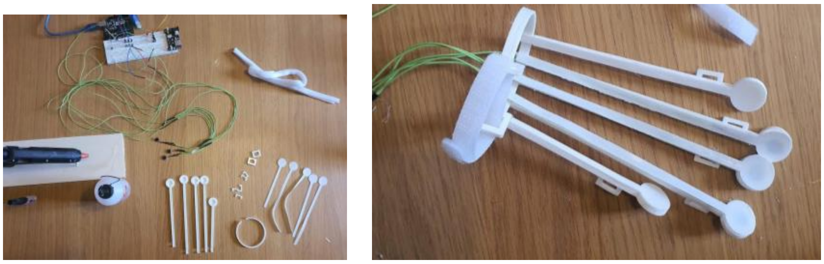

Figure 6: (a) Set up for physical assembly (b) Final assembly of the haptic glove.

The result obtained should look like an exoskeleton which has all the wires coming out from one centralized point. This is to avoid the user getting tangled with the wire which can inevitably lead to rupture of the circuit (figure 6).

6 UNITY3D AND LEAP MOTION

We used unity Unity3D [15] to create an interactive platform for the user. Unity is program which allows the creator to generate, command and produce games amongst other features found within the application.

Unity3D contains prefabricated assets that are compatible with leap motion. This asset contain an interaction module which has defined different contact and collision within the game. The application consists on shapes that can be touched, thrown or scaled by touch. This is especially important as it is in this module where the Arduino code will be installed. The aim of our project is to create an interface where the leap motion [14] controller can map the hand. Once the hand interacts with Unity3D interface a trigger is sent to the Arduino circuit [2] which will give the user the feedback.

In order to personalize the environment to fit our requirements we took two examples the Interaction object scene (interactive shapes) and the Basic UI scene (interactive buttons). In both cases we assigned colors to all shapes and buttons that can be interacted with. This color is respectively licked to the Arduino code that will activate the corresponding color of the haptic glove. Finally, when putting it all together we can create an interface that receives data from leap motion transfer into the virtual space in Unity3D and as able to transmit a signal to Arduino to simulate a haptic feedback.

6.1 Unity Oculus Rift

To provide the user with a more immersive 3D experience it is possible to introduce oculus rift [16]. In the photo below, the user wearing the oculus rift googles can be seen, exploiting the application. In the right part of the photograph the sensor is depicted which is tracking the movements of the user's head. In the Figure 7 the users view is shown when looking straight.

Figure 7: Oculus rift application.

6.2 Unity AR

Unity AR it is possible to create an application which allows for augmented reality; this created with the intent show the assembly of the designed in Inventor. By using the Vuforia [17] which is an augmented reality software development kit that enables to create the augmented reality applications. It uses the camera of the computer (in our case) to recognize and track the planar image in the real time as seen in figure 8.

Figure 8: Marker.

7 ARDUINO CIRCUIT

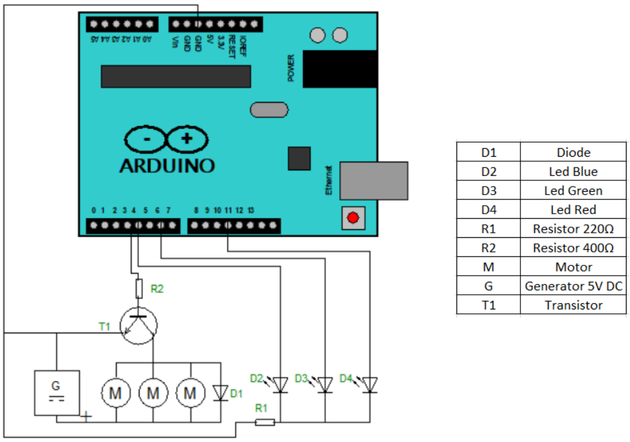

Figure 9: Arduino circuit.

To produce vibration (haptic feedback), we used mini motors that require 5V DC supply. This motor, such as all the type of motor, absorb a significantly level of current. Arduino is not able to supply all the needed current; therefore, to avoid Arduino failure. It is suggested to insert an external power supply. To control the motor, we use a Transistor command from Arduino. To control the transistor, we choose to use a PWM Digital Pin of Arduino to set a vibration value. This is an important aspect of the project as it allows the patient to adjust the settings of the haptic feedback.

The motors work for a few seconds every time that a patient touches a virtual object. This means that our circuit is under a significant stress. To avoid problem and circuit failure it is suggested to insert a diode. This will sustain the variation voltage, as it is able to discharge the voltage level. Finally, an interesting component is the digital pin as it will be ablet to give visual feedback to the user once it is in contact with an object.

The schematic electrical circuit can be seen in figure 9.

8 INSTRUCTIONS OF USE

Figure 10: (a) haptic feedback glove in use (b) suggested setup.

In order to be able to fully use this program, there are some requirements the first is to have as a minimum two USB ports available and power source. Then it is required to download Unity (18 to latest versions compatible). It is additionally necessary to download Arduino interface and finally the leap motion controller adapter. All the programs mentioned are free source and can be downloaded from the internet.

To setup the device the first step is to connect the Arduino circuit to an electricity source then connect it to your computer the Arduino file can be found under Arduino carpet in Unity3D folder. Open this script and download it to the Arduino circuit it should make the lights of the LED and motors go off. Subsequently you must connect to leap motion to your computer. Once all the steps have been completed it is now simple to press play and enjoy the experience of haptic hand as seen in figure 10.

9 IMPLEMENTATION

As part of this project, we had the possibility to work with ASPOC Association - Association for the Development of Cognitive Potential [3]. ASPOC is an association of parents of children with cognitive disabilities. They provided the possibility to introduce this technology to people with reduced mobility. The aim of the exercise was to introduce the technology and allow the people to perform the exercise with such game. The simplicity of the platform once installed allowed the users to quickly understand how to interact with the system. The haptic feedback allows the users to comprehend with better accuracy the placement of the object in the 3D environment. Finally, visual feedback made it look like a game which motivated the people to continue interacting with the objects hence performing the exercises (figure 11).

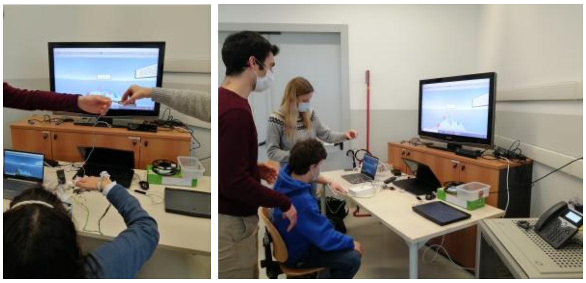

Figure 11: Haptic feedback glove in use with members of ASPOC.

10 EVALUATION

In order to evaluate the effectiveness and usability the system usability scale (SUS) has been implemented. SUS is a synthesized questionnaire that is given to the participants, it is then requested to rank the questions from 0-40 these values are multiplied by 2.5 to get 0-100 ranking. These values are interpreted in terms of percentile ranking a score above 68 are considered above average.

Considering the ASPOC team, 13 students were tested (age range: 19 to 24) 6 with Down Syndrome, 4 with Autism and 3 with some mental retardation. In this case to have a better learning outcome for the students it was decided to test the application first with the help of a 52-inch screen guiding them to understand all the important aspects about the process and then, individually, the students had the possibility to use the device and the application. For a subjective point of view this activity was very interesting for all the Aspoc Students tested since they were really happy and interested in the applications, especially about wearing and having the haptic experience through the device. All the students were excited about the possibility to see and interact with a virtual entity that clearly is not a common activity. Before having a quick look at the tests results it is important to highlight the some of the students that have tested the application do not have problems related to the input gestures. After trying the application all the students have completed the 10 questions of the SUS.

Questionnaire	Percentile ranking
1. I think that I would like to use this system frequently.	72.50
2. I found the system unnecessarily complex.	76.25
3. I thought the system was easy to use.	86.25
4. I think that I would need the support of a technical person to be able to use this system.	76.25
5. I found the various functions in this system were well integrated.	83.75
6. I thought there was too much inconsistency in this system.	71.25
7. I would imagine that most people would learn to use this system very quickly.	92.50
8. I found the system very cumbersome to use.	65.00
9. I felt very confident using the system.	86.25
10. I needed to learn a lot of things before I could get going with this system.	71.25

Table 1: SUS results.

Table one shows the percentile ranking of the of the responses to the following questionnaire. It can be seen that in most aspect the product excels is considered to above average. The lacking feature is the cumbersomeness of the system. This arises from the complexity involved to setup the product. In further stages of development an application can be created in order to simplify the installation process. Overall, the system can be deemed adequate for our target market as the strongest feature is the ability to learn the system quickly followed by its ease of use and the confidence using the system. As in initial prototype we can conclude the working principle has been demonstrated.

11 CONCLUSIONS

This project included a design, manufacturing, assembling and game development of the haptic feedback glove for rehabilitation purposes. The design was chosen mainly due to its simplicity and fulfilling the stated constraints. 3D additive manufacturing was proposed as it is a cheap and fast way of prototyping.

In this work, we developed a glove and a software to facilitate rehabilitation in patients that lost temporally their motor ability. This system has proven to be cheap and transportable, and it will allow patients and physiotherapist to remotely follow the users progress.

This project was developed considering several aspects, starting from make a system easy to manufacture, comfortable, ergonomic, and safe. The system was able to adapt to certain parameters to fit with the patient's necessity, such as the intensity of vibration and mobility restrictions, hence, the use of Velcro. These make our system versatile and able to be adapted to several cases of reduced mobility.

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