Virtual Reality in Augmented Surgery

Phase IV Project Report

Project Output and Documentation

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Executive Summary/Introduction

In this paper, our group will be discussing how the testing was conducted and evaluated throughout the Phase IV part of the project. Each section is split into multiple sub-sections due to the parallel aspects of the project that our group's members worked on in tandem with one another. The methodology and changes to each of the iterative designs for each aspect of the project will be discussed in detail. The final product or the current state of the project, given the time and funding constraints, will be revealed as well as the future plans that we plan to take after this semester concludes. Finally, the designs for environmental sustainability will be discussed and how our product affects environmental sustainability and how it minimizes environmental impact compared to already existing technologies and solutions.

Testing and Evaluation/Reflection

1.1 - Note

Our group's testing and evaluation of different designs and prototypes were largely observational given the heavy lack of time between the prototyping and final presentation phases. In addition, our group did not have much customer reliance when testing our prototype due to the lack of feasibility to reaching out to medical professors and doctors at UVA without any external aid or connections. Another note regarding this is that, we just recently got into contact with the Robertson Media Lab who are willing to work closely with us after this semester and have begun providing us the connection and expertise to take this project further.

The areas in our project that were tested are divided into the three categories below: Wrist cuff, 3D environment, and virtual reality. We decided to divide the results of the testing and evaluation portion into three parts due to the unique differences between their development, testing, and evaluation during the project.

1.2 - Wrist Cuff

When testing and evaluating designs for the wrist cuff, our group was testing and evaluation for ease of use, simplicity, costs, and functionality. Wrist cuff designs and iterations discussed later in this paper were tested and evaluated by each member of the group, and observations were made and discussed evaluating each iteration. The ease of use of the wrist cuff refers to the comfort and ability to interact with the cuff, and whether it is user friendly and intuitively easy to use. Details such as the cuff's texture, weight, edges, and size were all taken in consideration by each group member. Simplicity refers to the practicality of the design as well as including the aesthetic aspect of the cuff. Our group did not want an over complicated design that was not visually appealing to look at or use; therefore, we tested each design to see if we could simplify the design or improve the aesthetic appearance of the wrist cuff without losing functionality. In addition, our group focused on keeping costs low for the wrist cuff by reducing material costs. Finally, we held functionality as a high priority because we wanted to create a wrist cuff that worked the way we envisioned it to. The wrist cuff had two key functional purposes: The wrist could rotate without any of the strings of the 3D Environment getting tangled, and that it could be place snuggly on the wrist. The effectiveness of the wrist cuff to perform these two actions were tested and discussed for each iteration discussed later in this paper.

1.3 - 3D Environment

We mainly tested the 3D environment within the past two weeks before the final presentations and were constrained by the time and funds available to us. When initially testing and evaluating designs for the 3D environment, our group sought out the architecture school resources and expertise, specifically Melissa Goldman and the TAs in the school's workshop. Melissa Goldman and the TAs at the workshop gave us many tips on how to improve the design that we sketched before hand. Our group focused on creating a proof of concept design that was sturdy and simple at a low cost. We needed the frame to handle forces in every direction without breaking and it needed to be made quickly at a low cost due to our time and funding constraints. However, because of these constraints, there was only one physical iteration created which we will discuss later in this paper. After a prototype of the frame of the 3D environment was made, we tested the range of motion and amount of force exerted within the 3D environment and observed how the frame behave. During testing, our group noticed and discussed flaws that the 3D frame had under stress and use. Since the frame was made out of PVC pipes and wood, the frame would often creak and bend when put under stress. In addition, the servo and string systems attached to the sides were unstable when put under stress as the connections were made using heavy duty duct tape and super glue. Although the 3D environment we created was a progressive step in the correct direction, further testing and improvements are needed in the future to improve the design to be safe, sturdy, and completely functional.

1.4 - Virtual Reality

Much of the virtual reality testing and evaluation remains as our next step after this semester concludes. Some of the tests that we did conduct for the virtual reality portion of our project includes a mathematical analysis of the relationship between the range and height of the leap motion's vision. The result of our mathematical analysis are displayed in Figure 1 below and our group goes further in depth in our mathematical analysis paper. In summary of our mathematical analysis, our group was determining the range of motion of the leap motion in relationship to the height and comparing that against the values that are said by the seller. We found the values to be roughly the same, but the any variations or the differences that was present may be due to the surrounding lighting or hardware variability.

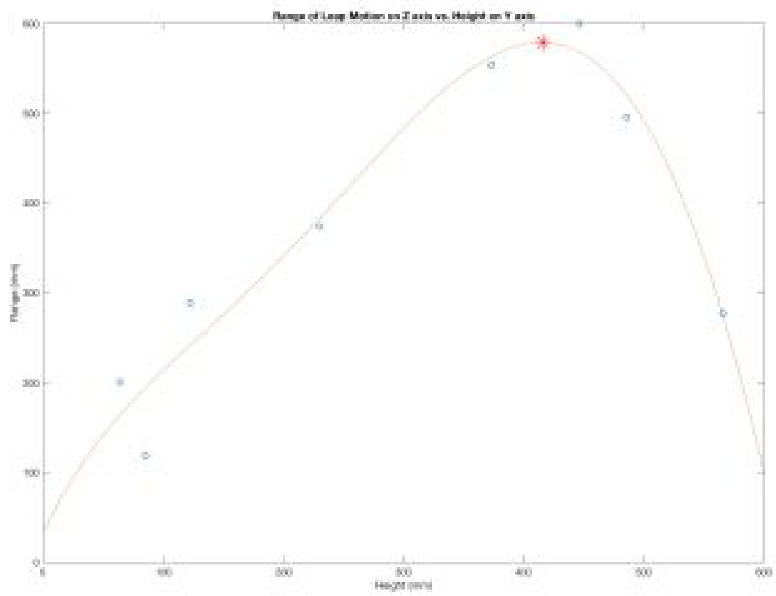


Figure 1: Mathematical Analysis Graph of the Solution Indicating the Optimized Height above Leap Motion for Maximum Range

Much of the virtual reality portions of our project are very current, and after meeting with the Robertson Media Lab on April 25, 2018, we are now working closely with them on the virtual reality portion of the project. With their aid and expertise we will be able to conduct latency tests, compatibility between the many different systems, and force tests with the 3D environment in virtual reality. These are the types of test our group wants to evaluate as we continue our project beyond this semester.

Iteration

2.1 - Wrist Cuff

The physical design for the of the wrist cuff took various iteration throughout the project. As we creating the design of the wristband, we determined various sets of requirements. The main requirement, which we based the base design was that it must be able to be restrict the motion of the users had when integrated in conjunction with the 3D Environment, while still allowing the user to have a flexible range of motion. We utilized Autodesk Fusion 360 to better visualize the wristband and interactive improve upon it.

The first iteration of a 3D model of the wristband, as seen in Figure 2a, matched the initial sketch where a circular path was modeled in between two outer cylindrical portions containing two spherical bearings with holes in them to attach to the strings on the containment unit. This first design of the wrist cuff allowed users the ability to rotate their wrist/hand without the entanglement of strings. This opened doors to further range of motion that was allowed in our apparatus for hand restriction. However, it was realized that spherical bearings would be difficult to 3D print due to their small size and circular shape causing a lack of multiple points of contact to the bed on a 3D printer even with support or raft structures.

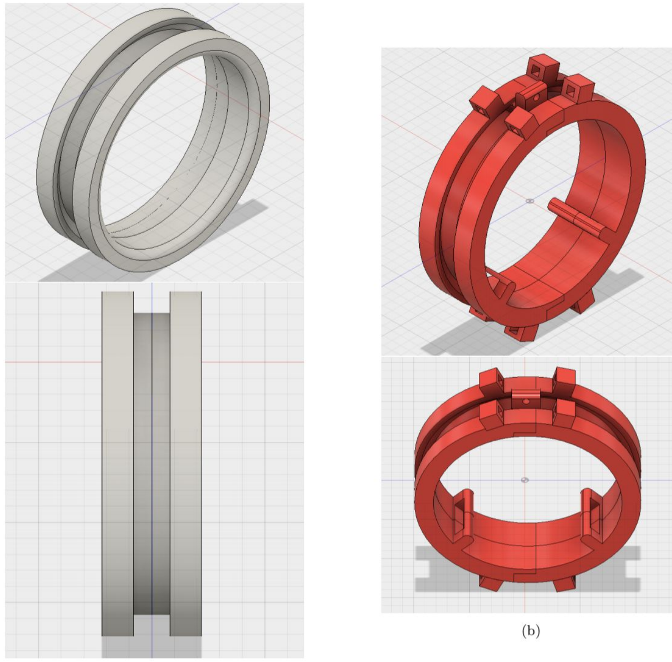
(a)

(b)

Figure 2: Initial Designs for the Wrist Cuff

Therefore, the next iteration of a wristband with the same circular pathway replaced the spherical bearings for a cylindrical sliding components and two clamps to hold the two portions of the band together. Figure 2 b illustrates a new cylindrical sliding component and the two clamps. The reason behind the clamps was to replace screws as they would have caused fracturing in 3D printed parts 13 versus using snug clamps to simply slide onto the two wristband portions. The first issue with this second iteration was the complexity of printing the sliding component due to its curved edges. Also, another issue was the two portions of the wristband not in contact with each other which would cause potential wobbling movement of the band when being used.

The first two iterations had shown how the two portions of the wristband needed to be in contact to lessen the potential of wobbling or sliding movement caused by extreme use and how a sliding component needed to be more simple for 3D printing. Figure 3 a illustrates a basic model of the wristband with now two portions connected in the middle with an outside pathway for some sort of sliding component. Now, with a simpler base wristband model, the next and final 3D model iteration contained only additions. As seen in Figure 3 b, these additions included a more rectangular sliding piece with a top portion containing a hole for tying a string through. Another addition was two protrusions on the inside of band with rectangular holes to place in an additional Velcro strap for wrist size adjustment for the user and to firmly lock the wristband to the users wrist, which we realized was necessary in order for the user to be able to rotate their wrist/hand freely. The final component of this last iteration was it being cut into quarters with zigzag cuts and four protrusions on each side with square holes through each. This was done to allow for the user to slide in their hand (which is larger than wrist) through the wrist cuff and then tighten together the pieces afterward. In addition, it simplified the 3D printing processes.



(a) (b)

Figure 3: Modifications and Final Design for Wrist Cuff

In order to bring this 3D model into reality, 2 integration of printing was done. The first one was printed with high impact polystyrene or HIPS, due to its impact strength, from the Alderman Maker Space. However, many issues came up, due to the materials sensitivity to changes in temperature when printed on a heated bed of a 3D printer, causing the print to warp and disform. Therefore for the next iteration of printing, we utilized the Rapid Prototyping Lab, which 3D printed with a higher quality material, Acrylonitrile butadiene styrene (ABS). This print was of high quality and ultimately became the final print of the wrist cuff.

2.2 - 3D Environment

The purpose of the 3D environment was to house the wrist cuff and the restriction mechanism. The 3D environment as of currently has gone through two main iteration. The first iteration was a box shaped environment, as can be seen in Figure 4. This design utilized, PVC pieces as the foundation of the the environment. In the bottom side of the box, are clamps to stabilize and hold the environment in place. Placed in the side and at the top is the servo and ratcheting spring mechanism, as can be seen in

Figure 5, which acts as our locking mechanism. Each of this locking ratcheting spring contains a string that stretches out to the wrist cuff, in which the user can place their hand. Based on what commands are received from the microcontrollers, the servo motors can be altered in order to lock or release a certain axis of motion. This design was then taken into account and a physical prototype was produced as can be seen in Figure 6. The only alteration with the physical prototype that can be seen is that the box idea was scrapped and changed into a frame to reduce the the amount of unnecessary materials used.

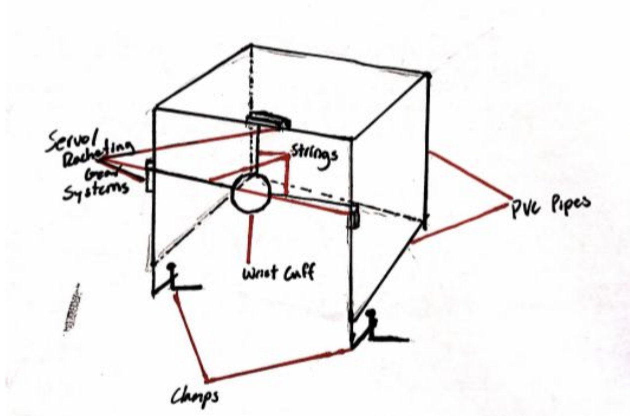


Figure 4: Initial Sketch for the 3D environment

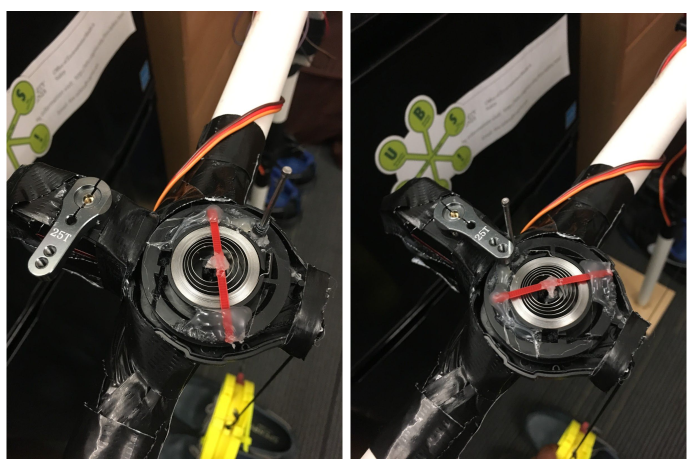


Figure 5: Locking Mechanism: (Left Image: Unlocked Mode, Right Image: Locked Mode)

Figure 6: Physical Prototype of the setup of the apparatus

After constructing the physical prototype, various design flaws became apparent. One flaw was a frame design was highly unstable and unable to withstand the heavy range of motion the contraption required. In addition, the choice of material for the frame was weak therefore adding to the unstability. To combat this, one idea we had was first changing the material of the frame to be some form of lightweight but sturdy metal such as aluminum. In addition, we agreed, that adding slanted support to the front and back of each side of the frame will help stabilize the frame from backward and forward motion. In terms of the locking mechanism, we saw ample opportunities, that we could take in account to further improve on the design. The main problem that resides in the current design is that, the locking mechanism is binary: it's either lock or release. However, considering, that in real life, when interacting with object, there can be a variety of forces that can be felt. Therefore, to simulate that sensation, and to also improve the flexibility of the locking mechanism, the next iteration to it would be to change it to a clamping mechanism, that can vary the amount of force applied to the string.

2.3 - Virtual Reality

Due to the limited time frame, not many significant iteration happened in terms of the virtual reality aspect of the project. The first iteration we had was the progress of the leap motion. Utilizing python and various other packages, we were effectively able to detect our hands and also produce a visual output of the data collected from the leap motion as can be seen in Figure 7. As can be seen by the image, there are various point of data located throughout the hand and also up to the elbow. Utilizing this data, there are various ways of manipulating data when integrating this with an virtual environment.

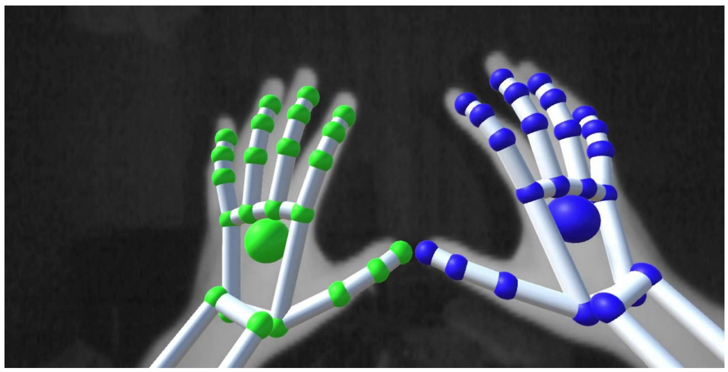


Figure 7: Visual Output of what the Leap motion is detecting

One example of manipulation that we did, was determine if you hands/fingers are grasped closes together or not. Utilizing the 3D location data from the leap motion on each finger, we made the value 1 represent the fingers being grasped closed and any number less than 1 to signify that the fingers are not grasped, as can be seen in Figure 8.

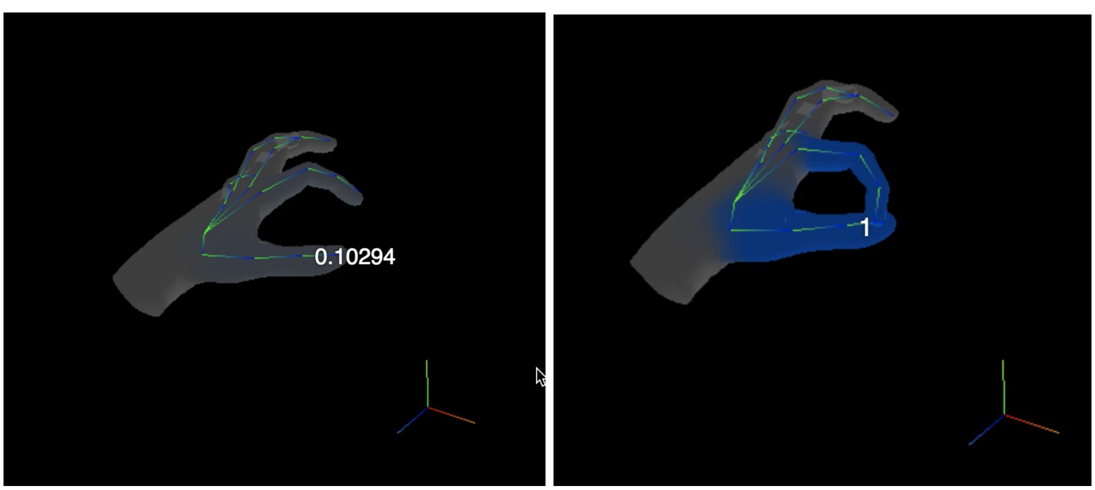


Figure 8: Determining if fingers are grasped closed or not

Another aspect of our project that we wanted to implement was the ability to utilize actual tools in the physical environment and simulate them into a virtual environment. Therefore, for the second iteration to our virtual reality aspect of the project, we focused heavily in simulating specified objects detected from the leap motion into the virtual world. As of currently, we are able to simulate small objects such as a pen or a pencil, as can be seen in Figure 9.

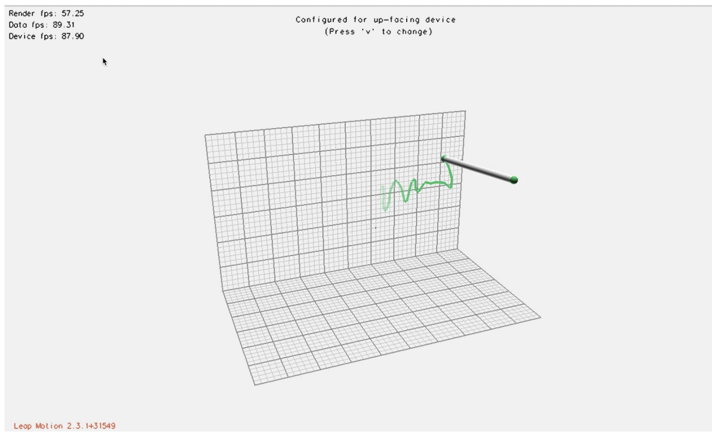


Figure 9: A Virtual Image of the Detected Pen using the Leap Motion

As for our next iteration, we are currently talking with the Robertson Media Center in Clemons Library to rent out the HTC Vive and as well as the Unity Software, so we start developing the virtual environments. Once we develop the virtual environment and integrate the leap motion with it, our next focus would be to implement the hand restricting apparatus we created, which will function by processing the data from the leap motion and virtual environment through a microcontroller such as the arduino that we are using. In addition, we were able to also obtain the expertise and support of various staff in the Robertson Media Center in Clemons Library as of last week. Therefore we will be working with them extensively in creating the virtual environment for the next phase of the project.

Final Design

3.1 - Overview

After iterating through various designs and prototypes for each part of our proposed solution we finally arrived at our current design. The design can be broken down into three main components as discussed above: the wrist cuff, the 3D environment, and virtual reality.

The final design for the wrist cuff involves a circular band potentially made out of plastic that can be fit around different wrist sizes as mentioned above in the iterations section. Manufacturing would be using injection moulding techniques to make the designed wrist cuff. This would allow for a proper restriction of the hand in a virtual space while maintaining a free flowing hand motion when not restricted. As the product reaches the final stage, the wrist cuff would ideally be two pieces of the whole 3D environment, one for each hand, with internal motors that allow for finer control of the hand. These internal motors would focus on a smoother movement of the wrist cuff when still and also for proper restriction at the wrist and not just restriction enforced by the 3D environment. This final design meets the design criteria of ease of use as a user simply needs to place their wrist through, footprint and weight due its small size, and safety as there should be no harmful effect to the user from wearing a wrist cuff.

The final design of the 3D environment would involve a similar design to our current frame discussed in the iteration section. However, improvements such as making the frame out of aluminum will be discussed, modeled, and constructed for an improved prototype as soon as we secure funding or grants. Currently, the funding process involves speaking with Alex Zorychta in the Engineering and Society department. Moving forward, discussions will ensue regarding entrepreneurial competitions coupled with research grants that can be utilized to gain funding to have a final product of the previously discussed final design for the 3D environment. In addition, adjustments to the servo and string system still need to be further planned and prototyped as we are not currently satisfied with the current system in place. Such changes include a clamping mechanism to restrict the strings directly or adding more servos and strings to increase the amount of control that the environment has in 3D space. This final design meets the design criteria of durability with the materials going to be used to make the environment, ease of use through a simple frame design with no complex shape or structure, and aesthetic through the seamless integration of servos and string systems within the frame.

The final design for the virtual reality component of the project would be the successful integration of the HTC VIVE and Leap Motion to our system. The combination of the HTC VIVE and Leap Motion would allow us to create a virtual environment as well as actually tracking hand and finger motions in 3D space. Our group is working closely with the Robertson Media Lab, specifically Arin Bennett and Will Rourk, after this semester concludes to pursue the virtual reality components of this project and have plans on integrating the system as a whole within the next few years. This final design for virtual reality addresses the design criteria of residuals through eliminating the need for excess equipment normally needed in a real workspace and delay through iterative improvement on utilization of the HTC VIVE with the Leap Motion.

Design for Environmental Sustainability

4.1 - Note

According to the World Health Organization, approximately 85% of waste produced by health-care related activities is non hazardous while the other 15% is hazardous waste that can be considered toxic, infectious, or radioactive. While these are broader percentages produced by health-care related activities, they are inclusive of the waste and materials thrown away from operating rooms of surgeons in training and normal day to day operations. This waste mostly includes reusable stainless steel surgical tools, disposable cotton products (drapes, gowns, blue wraps), anesthetic products, and plastic surgical gloves. These are all also used when performing trained surgeries as they are tools commonly used by all surgeons.[1] Current research also shows how this waste contributes to the 2,000 tons of waste per day produced by operating rooms. Furthermore, surgeons today mention how approximately /$1,000 are wasted per day on potentially reusable supplies, which could amount to hundreds of thousands of dollars saved for the number of surgeries performed by surgeons in a year.[2] In order to produce a final design that would help prevent the aforementioned waste generated from operation rooms, a set of DFES guidelines were utilized throughout the design process combined with a life cycle analysis of the final design. These guidelines and the life cycle analysis really helped create a sense of how to develop a final design that does not only help the group of stakeholders we had set in the Phase I/II report but other people as well. Through the DFES guidelines used in the design process, it was ensured that the final design would not have heavy implications on the environment as the goal of the product to be sustainable overall indicated through the use of virtual reality which is a technology that promotes conservation.

4.2 - Assessment of Environmental Impact

The design for environmental sustainability approach was integrated throughout the solution development phase in order to obtain a final design that would encompass environmental, social, and economic principles. In terms of the planet, the final design hopes to reach the goal of eliminating excessive waste generated by hospitals and medical schools in terms of performing failed surgeries or training medical students. For people, the final design aims to create a more immersive workspace that can allow a better passage of information to the user. Finally, for economic prosperity, this device aims to flourish the virtual reality industry leading to an increase in jobs to produce the final design as an integrated product combined with current virtual reality technologies.

The final assessment of environmental sustainability was estimating the total CO_2 emitted per unit of product. Having only started developing the product, there is no realistic estimate that can be produced currently about the final design regarding CO_2 emissions. However, it is possible to estimate the emissions from the virtual reality and wrist cuff components. For the virtual reality component it is estimated that the CO_2 emitted per unit of product will be approximately 300 to 500 ppm for outdoor air and 1000 to 1200 ppm for indoor spaces as indicated by the ASHRAE 62.1 standard used by virtual reality headset manufacturers.[3] For the wrist cuff component, its production is dependent on 3D manufacturing which has estimated CO_2 emissions of 402 to 485 ppm demonstrated for in chamber 3D printing for ABS plastic parts. [4]

4.3 - Reduction of Environmental Impacts

Using the DFE guidelines, a specific plan was designed to reduce the environmental impact of the final design. In the life cycle stage of materials, the DFE guidelines of sustainability of resources and healthy inputs/outputs were followed. For sustainability of resources, the final design focused on using materials that were renewable and recyclable, such as aluminum frames, and the energy to be used was going to be common electricity to run the electrical components of the final design. In healthy inputs/outputs, there are really no toxic or hazardous materials to be used in the final design as discussed currently. In terms of production and the guideline of minimal use of resources in production, it is not sure how many resources may go into virtual reality production, but the 3D environment really does not require many resources as it simply a frame and the wrist cuff is going to be manufactured using plastic. For distribution, the packaging of the product will be a normal packaging with a cardboard box with styrofoam base to protect the product which will be designed as foldable to ensure that less packaging is need to distribute the product. In the use part of the life cycle the first guideline of efficiency of resources during use is extremely prominent as everything will mostly in a virtual environment for the user to use. For appropriate durability it is hoped that the final design will be made of study material requiring low maintenance but the virtual reality headset being used may need maintenance but that would be handled by that manufacturer of the headset. Finally for recovery, the final design will include a system of joints that connect the major components of the frame together ensuring easy disassembly and compactness.

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