VIRTUAL TACTILITY IN AUGMENTED SURGERY

Phase I Phase II Report

By

Rahul Batra
William Kodama
Dhyey Parikh
Yaman Shreshta

The University of Virginia
ENGR 1420

Contents

1 Executive Summary/Introduction

The purpose of this research is to compare current technologies and develop a physical feedback mechanism for Virtual Reality (VR) to increase immersiveness. This technology would aim to target areas of high-risk skills training such as complex medical procedures and high altitude or underwater repair operations. The primary issues that exists are that it is incredibly difficult to efficiently train these occupations for a large amount of people and there is no way to accurately represent various intricacies and variables that may present themselves in attempting to mimic real life scenarios. Virtual and Artificial reality come into play as they are emerging technologies that aim to imitate the real world around us. Already, there are applications such as exploring underground caves without actually being there and airplane simulators without being in the air at all. As further explained in the background section, some key outcomes that would arise from this technology are a reduction in the number of wrong site surgeries annually as well as increase in the doctors trained for executing high risk surgeries. These are just the starting point for a diverse future where we can recreate various scenarios.

Phase I

2 Problem Definition

2.1 Background

First, an in depth background of the market growth of the VR/AR industry was completed to get a better understanding of what improvements were necessary for this technology. Research by Grand View Research was done to breakdown the growth of the market by the year 2025 (see Figure 1: Potential VR/AR Market in 2025). As indicated by the figure and discussed later under the Market/Needs section, the largest part (approximately 32%) of the enterprise and public sector is focused on health-care which came out to a value of a \$5.1 billion industry in 2025. Thus, taking a focus on the health-care market, an analysis on this market was studied to better understand where the focus of VR/AR lies in terms of its major use and where it will be in 2025 (see Figure 1: Health-care VR/AR Market Analysis Breakdown until 2025). As seen in Figure 1 the majority of the VR/AR market in health-care is being used for surgical simulations for training of medical/residency students, diagnostics of health issues, and rehabilitation methods for those facing extreme mental or physical stress. [1]

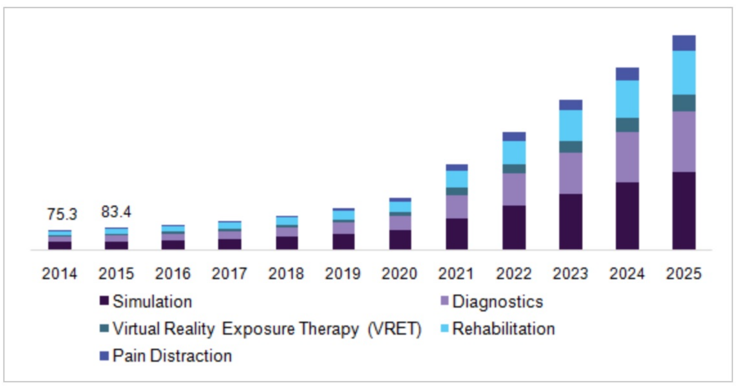

Figure 1: Health-care VR/AR Market Analysis Breakdown until 2025 [1]

Therefore, further honing in on the market breakdown for VR/AR in health-care, surgical simulations for training purposes were set as the new focus as a background for developing a VR/AR related problem. Surgical simulations were set upon as the focus as it is indicated as the largest growing portion of the health-care market for VR/AR, where by 2025 it will be approximately a 1/3 of the uses of VR/AR in health-care. Currently, VR/AR technologies are utilized in simulations for various types of surgery: laparoscopy, endoscopy, cardiac, thoracic, bronchoscopy, etc. After discovering that VR/AR technologies were already used for helping train medical/residency students about the human body and how to perform difficult surgical operations, a better understanding of how current medical students are tested for their competency in clinical work. As seen in Figure 2: Fail Rates of Written and Oral Examinations for Residency Students, a steady fail rate percentage of 20-25% can be seen. While indicating a low percentage of fail rates, a 20-25% is still indicative of some lack of competency of students leaving their residency to go on to perform real surgeries as the written and oral exams are usually only theory and practice based.This number while quantitatively small still indicates that patients will always be under the risk of surgical failure as theoretical knowledge is not always a prime indicator of how skilled and prepared a residency student will be when entering the medical world. [2] This, while not indicating that VR/AR is the best way to assist in training, provides evidence that current methods of testing competency of medical/residency students is not sufficient to ensure that patient risk during surgery will be decreased. Therefore, it is important to look at different options that can be used to promote a decreased risk for patients through better training methods for current medical/residency students.

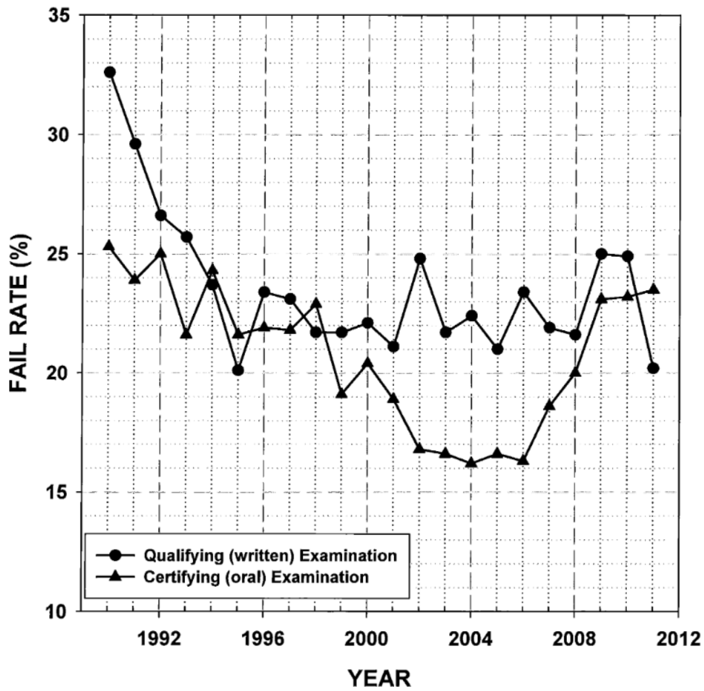

Figure 2: Fail Rates of Written and Oral Examinations for Residency Students [2]

Next, the way surgeons perform today and how their training and lack of current up to date training affects the outcomes of a surgery was looked at. Figure 3: Error Levels and Types in Surgeries demonstrates how there are three error levels faced by surgeons today: skill, rules, and knowledge. These three levels then correlate with two types of errors: lapses and mistakes. Lapses indicate how the skills obtained from training sometimes get faulty and cause execution issues which come with technique or training fatigue as most surgeons today are not constantly training to keep their skills sharp. Mistakes are correlated to strict adherence to protocol or rules and lack of experience of knowledge both of which can also be traced back to the current surgical training methods. [3]

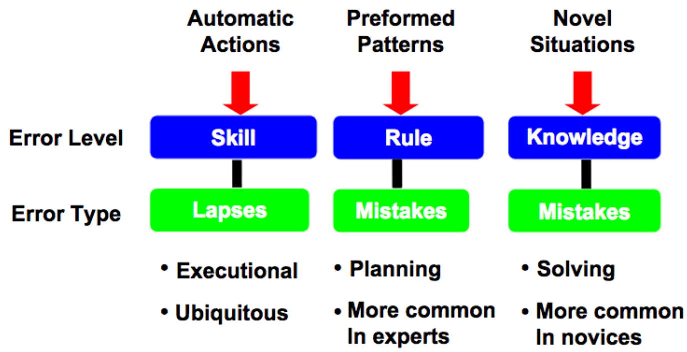

Figure 3: Error Levels and Types in Surgeries [3]

The following Figure 4: Patient Outcome and Patient Safety in Surgery can be linked back to Figure 3, as it illustrates how the error levels and types mentioned previously correlate to a decrease in patient safety and outcome eventually leading to death as the final result. The arrows with protocols and too strict adherence to protocol simply support the notion how current training methods tend to push towards a structured and less flexible method of performing surgery which could be fatal to patients.[3]

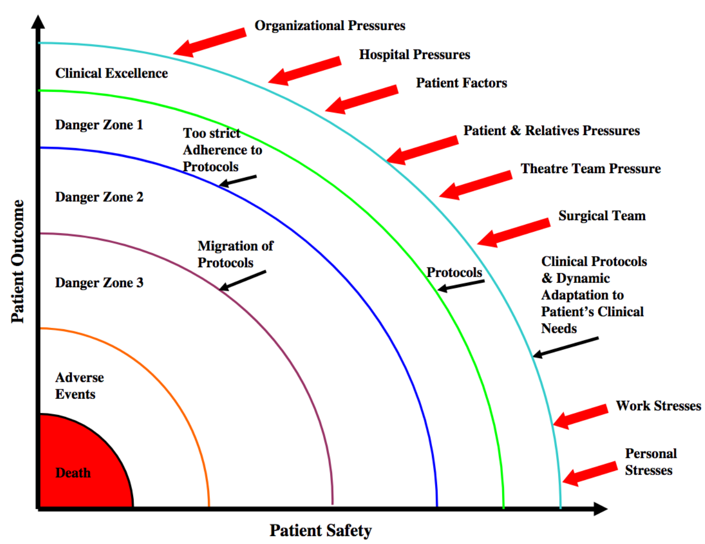

Figure 4: Patient Outcome and Patient Safety in Surgery [3]

Finally, Figure 5: Factors Needed to Improve Surgical Training Methods combines two sets of factors, human and surgical and how these are required to ensure that current training methods are improved upon. The figure suggests that there three surgical competency categories: decision making, team performance, and technical skill. All three of these categories are crucial in determining how safe the patient is and what are potential solutions to improving this safety. For the first two categories, surgical courses and simulations are seen as the best solution while for technical skill there are five options as solutions. From these five options, virtual reality is the most compatible with the solutions for the other two categories of surgical courses and simulations as the purpose of virtual reality is simulating a real environment or situation in a virtual world. Therefore, virtual reality and augmented reality were chosen as the best avenues, as seen by the reason mentioned above, to help improve upon current training issues causing catastrophic results for patients in surgery. [3]

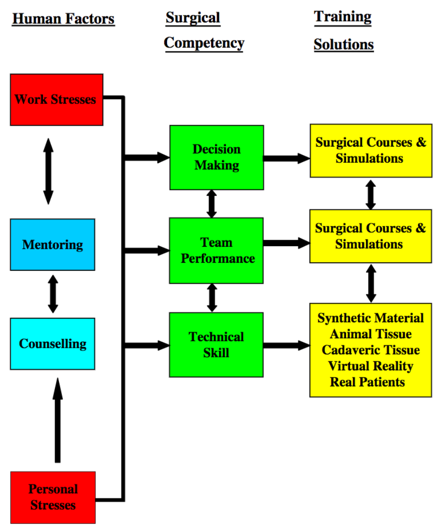

Figure 5: Factors Needed to Improve Surgical Training Methods [3]

2.2 Development of the Problem

After conducting initial background research, the development of the problem statement began. From the background information, we noticed that issues in current medical training methods and risks of failures during surgeries encompassed the broadest range of problems in the healthcare system. We decided that the initial problem statement that we wanted to begin with would be that there are issues in current medical training methods, specifically for residency programs. After developing the initial problem statement, we created a why-why diagram displayed in Figure 6:Why-Why Diagram. The why-why diagram provided a way to expand the number and types of issues that are connected to the initial problem and the issues that stem from it. Beginning with the initial problem, we branched off to problems such as the lack of exposure and experience to practice current and new technique for students and current medical professionals as well as the risk of failure during surgery due to the lack of training and/or preparation. These two problems converged into a mutual issue that there is a severe lack of opportunities to train and practice regularly. From this, we diverted into two possible routes: 3D printing of human organs for practice or virtual reality and surgical simulations. After weighing the two options and their respective problem, we chose to focus on the virtual and augmented reality related problems as they provide the most potential in solving the current issues in existing medical training programs. In addition, virtual reality is more readily available for our group to explore. From there, we looked into the problems with current VR/AR technologies being used in medical applications, discovering the lack of immersiveness and tactile feedback in virtual reality.[4]

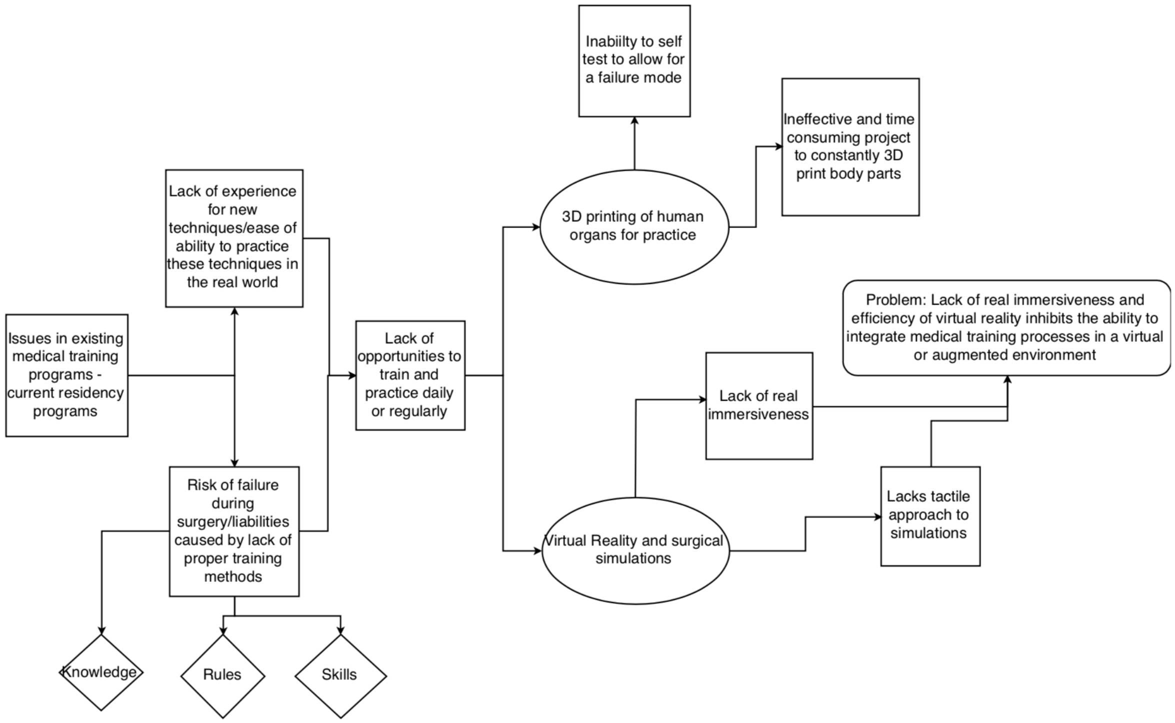

Figure 6: Why-Why Diagram

Using the why-why diagram, we were able to develop the final problem statement: **Lack of immersiveness and efficiency of virtual reality inhibits the ability to integrate medical training processes in a virtual or augmented environment.** And fundamentally, we are aiming to break the barrier between virtual and real which has no specific solution yet.

3 Market/Need

A well implemented solution that can further enhance the immersiveness of Virtual Reality can be beneficial in various markets. When analyzing specifically what possible markets can be impacted, we came to the data presented in Figure 7: VR/AR Market Distribution Chart. The graph showcases the predicted market size of Virtual and Augmented Reality by 2025. It can be visibly seen that the consumer market will for sure be the biggest market to be benefiting from advancement in VR/AR technology, as it is predicted to account for $18.9 billion of the market value which is approximately 54% of the total possible market value. Within the consumer market, the gaming market will be a significant portion of where major VR/AR development will take place in as it accounts for 61% of the consumer market. Even as of currently, the gaming market dominates the market in terms of utilization of virtual and augmented reality and as there are readily available platforms such as the HTC VIVE and Oculus Rift.

However, the market that will be more significantly impacted by the specific problem that was defined, would be the the enterprise and public sector, which based on Figure 7 accounts for 46% of the total market. Furthermore, the most notable aspect of the Figure 7 is that it forecasts that the biggest market within the enterprise and public sector to be the Health-care market, which itself is shown to be worth around $5.1

billion. Therefore, a possible solution to the problem, which was defined as as the lack immersiveness and efficiency of virtual medical training, can therefore have a major impact into this market.[5]

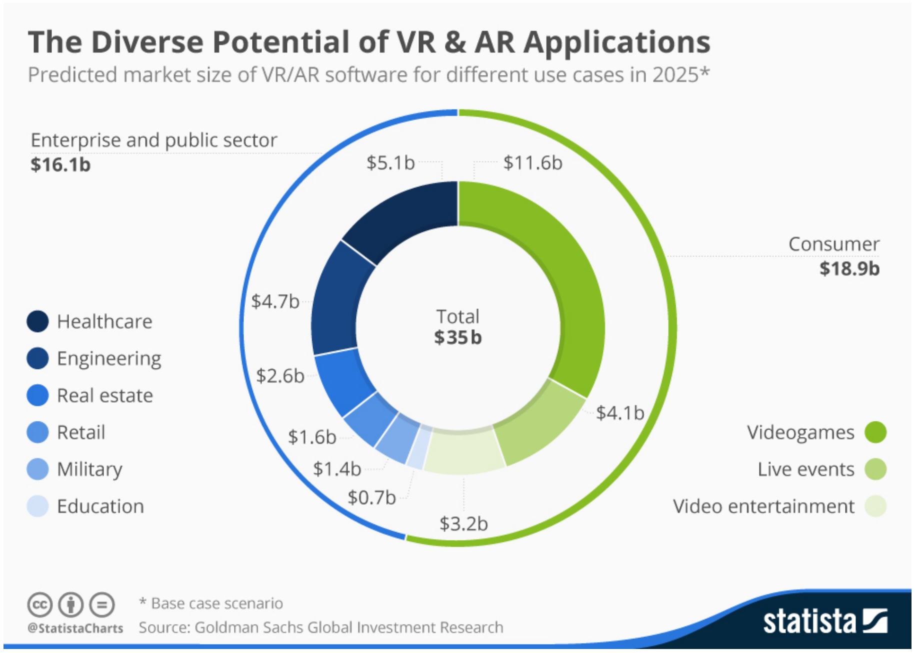

Figure 7: VR/AR Market Distribution Chart [5]

It is important to note that data found in Figure 7 assumes an accelerated uptake scenario in regard to growth of the VR/AR markets. Specifically, the best case analysis by Goldman Sachs estimates $182bn in revenue by 2025 which consist of $110bn in hardware and $72bn in software. These numbers are calculated via the current market valuations of $111bn for notebooks, $62bn for desktops, and $14bn for video games and under the general assumption by 2025 VR/AR technology evolves from a niche device to a broader computing platform.[6]

4 Client/Stakeholders

4.1 Clients

Our clients cover a broad range of fields from medical professionals to VR companies. The defining characteristics of a client of our research and products are that they would directly build virtual and augmented reality applications utilizing physical feedback mechanisms. The goal would be that these applications would result in a closer imitation of reality through alternate means. On the medical side of our clients, they would primarily consist of those performing operations. Some of these would include neurosurgeons, cardiovascular surgeons, and brain surgeons. Students/Residents would also cover a large base of our clients. One of the primary goals of our research would be to reduce technique fatigue which is the loss of skill and inability to learn the latest methods for surgeons and doctors. This is critical to our medical clients as one of the key issues is the lack of continued medical training post residency. The VR gaming community would also benefit directly from our project as they would be able to create games that are more realistic and enjoyable for consumers. Specifically, the additional physical interaction would allow gaming companies to incorporate feedback in novel ways to induce the user towards the desired outcome; whether through training them through a process, or notifying them of an incorrect action.

4.2 Stakeholders

Our primary stakeholders would consist of patients, and general VR consumers as they would benefit from the applications created by our clients. Medical patients undergoing complex surgery would receive a huge benefit as the surgeons and medical professionals will be better trained for the procedure and accustomed to larger range of scenarios. Furthermore, physical therapy patients would also benefit as they could utilize VR and AR systems to stimulate certain muscle groups or assist them in avoiding putting stress on certain body parts. Other stakeholders that would benefit from the applications of our clients would include corporate hospitals and government entities as their costs could decrease due to better care. Stakeholders that would be affected by a failure of a solution would limited as there would be no outcome instead of a negative outcome.

5 Resources

5.1 Consultants/Experts

One major consultant/expert that we have is the 2nd year Rodman, Abhishek Gupta, who taught the AR/VR Rodsem last semester. Abhishek has access and experience with many different VR/AR technologies such as Leap Motion and Hololens which are not available in Clemens Library. Three of our group members took his class last year and were able to gain insight on many different perspectives in AR/VR. We have also reached out to Dr. Victor E. Laubach, a Professor of Surgery, and Dr. Jose Oberholzer, a Professor of Surgery Biomedical Engineering. In our email we asked two main questions for interviewing purposes:

- *What issues do you believe exist in current surgery training methods or how surgery is taught in medical schools/residency programs?*
- *Currently, many medical schools utilize simulations, such as virtual reality, to teach aspiring surgeons how to perform difficult surgeries involved in laparoscopy, cardiac, thoracic, and transplant surgeries. What issues do you believe exist with these simulations, especially in terms of virtual reality, that should be improved upon to better the training offered to those studying surgery?*

Although we have not received a response yet, we plan to try meet them in person. In addition, we plan to reach out to other medical professionals, staff, and students at the UVA hospital as well as outside Charlottesville.

Additional human resources who we want to reach out to include VR experts in the William Robertson Media Center, an ECE professor who teaches two of our group member's Fundamentals I class for ECE, and CS professors at UVA who are interested in AR/VR topics.

5.2 Databases

Our group looked into online databases and documentation to try and understand what resources are already available and are open source. During our search, we discovered a medical VR simulation database and organization, Mechdyne [7]. Mechdyne has led the virtual reality revolution since the 1990s and is recognized as the leading innovator of large-scale and complex VR systems, developing dozens of immersive visualization, 3D, and VR technologies. Mechdyne plays the major role of a middle between anything related to virtual reality and industries [7]. Through partnerships with Mechdyne, businesses and organizations have incorporated virtual reality and immersive visualization to interact with virtual data, improve decision-making, enhance the quality of their discoveries, and augment problem solving. One of their main topics include rehearsal trauma care and new procedures through virtual surgery simulation. In addition, we have also looked into VR documentations for certain VR devices such as Leap Motion and HTC VIVE. We discovered that there plenty of open source code for both technologies and Leap Motion even offers documentation for developers.

5.3 Facilities

One major facility that we plan on using is the Rapid-Prototyping Lab (RPL) located in the Mechanical and Aerospace Engineering Building. The RPL is an available resource open to our group when we begin to prototype. The rapid prototyping lab has multiple 3D printers and materials available that we are able to use given our budget. Specifically, we are going to be mainly working with the PolyJet printer that is 18" x 14" x 6" in size, has a 30 micron resolution, and combined two different types of materials together.

Another key facility is the William Robertson Media Center which is located in the Clemons Library, and it is the only place on grounds that has an open virtual space for students. This virtual space has a HTC Vive setup that we have used and explored with before. The center also provides VR workspaces and stations as well as staff on hand to offer help if needed. Reservations needed for using the workspaces and any of the facilities in the media center are very easy to make and are widely available during the week.

6 Technology

When performing research on prior art and state of the art, only virtual/augmented reality technologies affecting the user's senses were looked at. The reason for not looking at specific technologies that have affected surgical training or applications in other industries was because VR/AR technology does not focus on final use of the tech;instead, it focuses on how to make the user feel as if though the virtual environment is a part of the real world. Therefore, the next sections on prior art and state of the art only discuss the virtual/augmented reality technologies that focus on making the user feel as if the virtual environment is part of the real world, specifically through the simulation of touch.

6.1 Prior Art

Virtual Reality has been a rising force in the past few years, due to its variety of applications in various types of fields and markets. As of right now, the majority of the applications that are out in the market as Virtual Reality are limited by the senses of sight and audio. However, there have been a few prior art that have attempted to add a another layer of immersiveness in virtual reality: the sense of touch. A majority of these prior technologies have attempted to simulate the sense of touch by utilizing various forms of haptic technology, which is defined as a tactile feedback that takes advantage of a user's sense of touch by applying forces, vibrations, or electrical pulses. One prior art, that is a simple example of haptic technology, though not specifically for VR, is the touch pad for the latest MacBook lineups as seen in Figure 8: Haptic Feedback Mechanism for MacBook Force Touchpad. Unlike most traditional touchpads, which are either a physical button or a pad that has to be physically moved to be clicked, the latest MacBook touchpad remains stationary even when “clicked”. It instead uses haptic feedback to simulate the sensation of being clicked, by utilizing small electrical vibrations in the Force Touch trackpad at wherever the user’s finger is placed. The main advantage of haptic technology is that it can add a dimension of touch which is an essential in the advancement of immersiveness virtual reality currently offers. A disadvantage of haptic technology is that some forms of haptic feedback are limited in magnitude and not always able to uniformly distribute the sensation of touch in all directions. In addition, implementation of such technology can get quite expensive and complex, especially when attempting to simulate the feeling of a virtual object directly into the physical world.

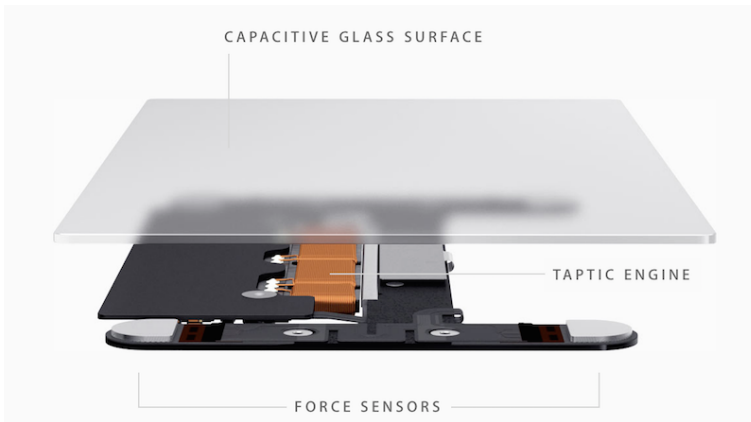

Figure 8: Haptic Feedback Mechanism for MacBook Force Touchpad[8]

6.2 State of the Art

One prime example of a state of the art technology that has attempted to make virtual reality as immersive as possible is the Tesla Suit as seen in Figure 9: The Tesla Suit. The Tesla Suit is is a full body suit that provides various forms of immersive sensations relating to the sense of touch by applying electrical pulses to the user. The suit combines two main electro stimulation systems: Transcutaneous Electrical Neural Stimulation(TENS) and Electrical Muscle Stimulation (EMS). Both of these systems stimulate nerve endings responsible for sensations. The system works in a way such that when the virtual part of the body collides with an virtual object, the suits delivers various forms of electrical pulses of different amplitude, frequency, and amperage to the various electrodes located throughout the suit. The suit can also simulate weight by utilizing these two techniques to stimulate the free nerve endings various motor and sensory neurons. In addition, the suit contains 92 haptic points that cover the larger areas of the body to provide haptic sensations to certain areas on the body. Other features include motion capture and climate control. [9]

One main advantage of the Tesla Suit in comparison to other suit is its full body immersiveness. Unlike most other state of the art technologies that focus on using one form of haptic technology, the Tesla Suit utilizes a variety of them to further simulate more tactile sensations over the entire body. However, due to the wide range of area that it covers, the quality of the haptic feedback mechanism diminishes overall. In addition, the cost of a full body haptic suit is very expensive at a cost of $1,652.21.[9]

Figure 9: The Tesla Suit [9]

Another state of the art that we found is the Hand's Omni gloves as seen in Figure 10: The Hand's Omni Gloves. Unlike most haptic systems, which rely on some sort of vibration motor, the technology behind the Hands Omni gloves instead uses something simpler: air. Within the gloves, small bladders are placed throughout the fingertips and palm, therefore, when the user reaches out to grab something in the virtual game world, the device selectively inflates those bladders, putting pressure on the user's fingertips and palm, evoking the sensation of actually touching a physical object. The main advantage of this design is that it provides an innovative and novel approach on recreating the sensation of touch. One main disadvantage is that most of the bladders places in the glove are still no small enough to simulate different textures and more smaller and intricate objects in virtual reality.[10]

Figure 10: The Hand's Omni Gloves [10]

7 Perceived Constraints

For our project there is an array of various constraints that we expect and will account. These include budget, time, and other design aspects that will in turn affect how we define our procedure and how we implement that efficiently. Specifically, given we only have 3 months our analysis of the problem and project constraints will be instrumental to our end results.

The initial constraint we have for our project is a limited budget of $400. The primary issues with a budget of this size is that we cannot properly test out the various technologies at an optimal scale. Some current technologies for simulating physical feedback in virtual and augmented reality include: inflatable bladders, high frequency vibrating motors, targeted frequency emissions. The benefits of being able to test these technologies would enable us to further understand the problem; Specifically, what aspects are being addresses and where they are lacking. Furthermore, our budget also limits us to the technology we can implement in our prototype. We either have to be extremely diligent in our initial research, planning, and design stages allowing us to utilize more expensive equipment for a complex solution, or we can prototype more while using cheaper technology.

The second constraint for our project is the time frame of 3 months. This constraint factors into a myriad of other issues as we may need approval for certain equipment, to place orders for certain materials, or to properly test our prototypes and all of these will add to our total project time. Furthermore, the time constraint becomes an issue as our team members are taking many other classes that become quite demanding during certain weeks of the year such as finals and midterms which we estimate will reduce our actual time by up to 3 full weeks.

The final perceived constraints were in regards to the our informational and physical resources. Our informational knowledge for current published research virtual and augmented reality is significantly limited as it is still and emerging field with developments and updates being made every day. Furthermore, as we conduct research and consequently implement our ideas, we will not always be able to adapt to the latest technology in an efficient manner. We are also limited by our prior knowledge in Python, C#, and other programming languages when we start implementing the prototype within VR and AR applications. Our physical constraints on the other hand are limited to the rescues that our provided to us in the UVA prototyping labs. Specifically, the size of prototype is limited to max constraint of 15" x 14" by 6". Furthermore, the more complex our design the less efficient and harder it is to print thus our design complexity is limited. Lastly, we can only use a combination of two different materials on the polyjet printers provided. All of these factors contribute to our perceived constraints.

Phase II

8 Exploring the Context

The defined problem about immersiveness of VR/AR in surgical applications and any potential solution goes beyond the notion of medical or technological contexts. Both the problem and the solution can be linked to a variety of other contexts, a few of which include: socio-cultural, economic, organizational, political, and environmental.

8.1 Socio-cultural

In terms of the socio-cultural context, the defined problem and solution can be taken and applied as a medium to connect various cultures and societies in an efficient and seamless manner. A direct immersion in various cultural and historical events can be provided in an instant. An example can be that of wanting to visit the ruins in Greece of the Parthenon or Athens can be done quickly and efficiently with a real-life feel as stated by the defined problem and potential solution. Furthermore, a more social context would be that of performing sociological experiments to simulate how discrimination works against certain groups of people or to recreate certain emotions to better understand human actions.

There are also socio-cultural implications of the proposed problem and potential solution relative to the area of change affected by the problem and solution, i.e. surgical training. One of these implications involves doctor-patient relationships where now the patient's data is being placed in an environment that is not a medical record but rather a virtual simulation. This may end up making patients potentially nervous of telling every detail to doctors prior to performing surgery which may have harmful impacts for the patient, but would still not outweigh the benefits of better training methods for today's surgeons.

8.2 Economic

For the economic context, an important aspect is that of financial data analysis for understanding global and national stock markets and how various variables can affect these markets. Currently VR/AR technology is being used to visualize data and compare numerous various (3+), but the defined problem and potential solutions can take this a step further. With physical feedback added to the current process of VR/AR data visualization, an interaction can be developed between the user and the data being visualized. This would create a more controlled environment for financial analysts along with a full immersive experience and not a user-machine interaction.

The economic implications of the proposed problem and solutions in surgical training involve only the increase in cost of purchasing the solution for clinics across the world for medical professionals to use for training.

8.3 Organizational

Looking at the organizational context, a more industry focused context was looked at. The defined problem and any potential solution would be able to bridge the gap between the corporate or industrial sectors with consumers. VR/AR technology coupled with tactile feedback would enhance the build quality of companies developing cars or other commercial products meant to be ergonomic and high quality. Furthermore, it would allow for companies to display their products in a virtual environment where the problem would address how the consumer could interact with the product and test it without even the need to go anywhere.

As far as the organizational implications of the proposed problem and solutions in surgical training, there would be a large improvement in how accurate medical records would be about a patient. This is because there would be a simulation in virtual reality to cross reference to ensure that the patient was treated for the correct issue and there was not major issue during the surgery when recorded in a medical record.

8.4 Political

Like the economic contest, the political context could be similarly use the defined problem and any potential solution to interact with data with more immersion. However, for the political context it would be for the use of policy development by government officials by understanding how various social and political factors influence society and to improve on these factors to better people's lives.

The political implications for the proposed problem and solutions in surgical training are minute as health-care policies would not be affected besides the inclusion of agreement to have a patient's data used in a virtual reality setting for training purposes.

8.5 Environmental

One of the most important context that was considered was the environmental context. The defined problem and potential solution are a stepping stone towards transforming a real life situation into a virtual one. This process removes most possibilities for residuals or harmful byproducts as a virtual environment would have almost an unlimited sustainability of most objects thus reducing the need of these same objects in the real world. The addition of a tactile feedback mechanism would simply enhance this process.

Furthermore, in surgical training, the proposed problem and solutions would assist in reducing the amount of waste produced by failed surgeries or trained surgeries. This is because medical professionals would be able to train more frequently thus reducing failed surgeries and all the major waste generated from surgery training, such as synthetic materials or human bodies, would be in a virtual environment causing elimination of this waste.

9 Real World Relations

9.1 Observations in VR/AR

Last semester three of our group members had extensive first hand experience with Hololens, Leap Motion, and HTC VIVE during the AR/VR Rodsem with Abhishek. The class mainly focused on the HTC VIVE and we noticed the visual portion of virtual reality is very developed and provides an immersive visual experience. However, the user interacts with the world using two controllers which causes a disconnect in the virtual experience. The experience in games such as Super Hot with the HTC VIVE left people in the class a bit disappointed and frustrated because of the awkwardness and unintuitive way to interact with the virtual environment. Games such as Blocks try to bridge this disconnect by combining the Leap Motion with the HTC VIVE that enable the user to use their hands instead of controllers. However, there was still underlying problems with the tactile immersive experience making it difficult to interact with in game objects at many points during the game.

9.2 Observations in Medicine

A more in depth observation and first hand experience was done by one of our group members who shadowed a radiologist in the INOVA Loudoun Health System in Northern Virginia. During the shadowing time period, the group member had the ability to view a live surgical procedure performed by the radiologist, a spinal tap or lumbar puncture. This procedure is more of a diagnostic sort where a hollow needle, approximately 3.5-4 in long is inserted into the lower back spine of the patient to extract fluid. A lumbar puncture is usually done with infants and the elderly in order to determine deteriorated muscle movement or some sort of paralytic disorder. When viewing the live lumbar puncture, the group member was notified of the risks that go into this surgical procedure, specifically if the needle being inserted is injected into the wrong location on the lower back or if the needle ends up bending causing both internal and external bleeding for the patient.

Next, research was done to understand the other risks involved in this observed procedure. It was found that most of the failed lumbar punctures causing bleeding and trauma have to do with an issue in how the physician performing the procedure was trained or the lack of proper training. As seen in Figure 11: Factors Causing Lumbar Puncture Failures in Children, some of the most common factors included difficulty in judging where to perform the lumbar puncture on the lower back, lack of experience of the one performing the procedure, and a variety of other procedural factors related to what is taught when training medical students pursuing radiology regarding lumbar punctures.[11]

Patient factors		
Age ≤3 mo	2.1 (1.5–2.9)*	2.2 (1.6–3.1)*
Black race	0.9 (0.6–1.2)	0.8 (0.6–1.1)
Parental presence	0.9 (0.7–1.3)	1.0 (0.8–1.4)
Nighttime (8 PM to 8 AM)	0.9 (0.7–1.1)	0.9 (0.7–1.1)
Difficult to visualize spine	1.8 (1.3–2.3)*	1.9 (1.5–2.5)*
Difficult to palpate spine	3.1 (2.1–4.4)*	2.7 (1.9–3.9)*
Physician factors		
Less physician experience with LPs[†]	1.08 (1.01–1.15)*	1.06 (1.0–1.13)
Procedural factors		
No local anesthetic	1.6 (1.1–2.2)*	1.6 (1.2–2.3)*
Procedural sedation	0.9 (0.6–1.3)	0.8 (0.6–1.1)
Advancement with catheter stylet in	1.3 (1.04–1.7)*	1.4 (1.1–1.9)*
Sitting position	1.2 (0.6–2.3)	1.4 (0.7–2.7)
Increased patient movement	2.1 (1.6–2.6)*	2.4 (1.9–3.1)*

*Statistically significant ($P < .05$).
[†]Adjusted odds ratio for each decrease in category of number of LPs previously performed by the physician by using the following ordinal scale: <5, 5-10, 11-20, 21-50, 51-100, and >100 LPs.

Figure 11: Factors Causing Lumbar Puncture Failures in Children [11]

Overall, the live observation of this procedure provided a more deeper understanding on the risk involved in difficult surgical protocols and how if improper training is given to the surgeon or physician could prove to be fatal for the patient.

10 Conclusion

In conclusion, after completing extensive initial background research, an initial problem statement was defined as: ***Lack of immersiveness and efficiency of virtual reality inhibits the ability to integrate medical training processes in a virtual or augmented environment.*** *Once the problem statement was determined, the market which the defined problem and any potential solution would target was analyzed, which included two parts the consumer and enterprise/public sector, the latter of which health-care made up the majority worth $5.1 billion. This led us to determine specific clients and stakeholders in the medical field who could utilize potential solutions to improve on current surgery training methods. Some clients that were found included medical professionals and medical/residency students, whereas stakeholders who could be affected by a potential solution would be hospitals (non profit and corporate) and the VR/AR market. Next, local and online resources were found that were available to assist in solving the defined problem. Prior and state of the art technologies were then looked at to get a better understanding of where the current VR/AR tech was and is in terms of tactile feedback. The final portion of Phase I of the report summarizes the perceived constraints that will be faced when working towards developing a solution to the problem.*

Phase II included exploring the problem and any solutions in a broader context along with any prior to development observations done to solidify the problem. The socio-cultural, economic, organizational, political, and environmental contexts were looked at, where the environmental and socio-cultural were deemed the most important. Finally, some observations that were made in relation to the defined problem included first hand experience with various VR/AR technologies such as the HTC VIVE, the HoloLens, the Leap Motion, etc. A more in depth observation was also made in viewing a live surgical procedure of a lumbar puncture and understanding the risks involved due to a lack or improper training methods for medical professionals.

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