Annotated Bibliography

Argelaguet, F., Hoyet, L., Trico, M., & Lécuyer, A. (2016, March). The role of interaction in virtual embodiment: Effects of the virtual hand representation. In *Virtual Reality (VR), 2016 IEEE* (pp. 3-10). IEEE.

This research explores the link between agency and ownership of hands in virtual reality. A user's hand was represented in three different forms, abstract (a sphere), iconic (a model) and realistic (a human avatar hand), and the user was required to complete a few tasks with each type of hand. The first task was moving an object and the second task was placing the hand behind a spinning saw. The results were determined using quantitative measures of how the user's hand moved as well as qualitative measures of a subjective questionnaire given to the user after they completed a task. The results show that the sense of agency was strongest for the least realistic hand (the abstract one) most likely because the user felt like they had more control over it, whereas the more realistic hand was more imprecise. However, ownership of the hand was determined to be the strongest for the realistic representation of the hand, most likely because the user could identify with the looks of the hand more. This research directly relates to mine since it also uses the LeapMotion sensor and an Oculus Rift. In addition, looking at the questions the researchers used, gave me a good idea for what I could ask in a subjective survey afterwards in order to measure the user's agency and ownership in response to the virtual environment.

Ban, Y., Kajinami, T., Narumi, T., Tanikawa, T., & Hirose, M. (2012, June). Modifying an identified angle of edged shapes using pseudo-haptic effects. In *International Conference on Human Haptic Sensing and Touch Enabled Computer Applications* (pp. 25-36). Springer Berlin Heidelberg.

Ban et al researches pseudo haptics by trying to manipulate what users visually see and feel. Using a viseo-haptic system, they had the user touch an object while displaying their hands on the screen touching a similar object with a different shape or texture. The object the user was feeling had edges parallel to the floor, while the object they saw on the screen had edges at angles to the floor. Most of the users believed that the actual object's edges had some angles, and the researchers determined that the angels between the edges could range from -35 to 30 degrees without the user noticing. This supports the idea that a visual stimulus effects how a user processes haptic feedback, which applies to the research I am conducting. This research also used a good system and algorithm to be able to measure the difference a user felt by comparing variables $S_{physical}$ S_{visual} $S_{perceived}$ (S being shape).

Botvinick, M., & Cohen, J. (1998). Rubber hands' feel'touch that eyes see. Nature, 391(6669), 756.

This research is widely known for its discovery of the three-way interaction between vision, touch and proprioception. The researchers hid the hand of a subject out of sight and replaced it with a rubber replica of the subject's hand. The rubber hand was then simultaneously stroked with a paint brush while the actual hand was beings stroked and afterwards using a questionnaire and a few follow up experiments researchers found that many of the test subjects began to feel like the rubber hand was their own. This so-called rubber hand illusion has carried over to the age of virtual reality in which many researchers similarly have determined that humans can feel agency over a virtual body part or avatar.

Bruder, G., Interrante, V., Phillips, L., & Steinicke, F. (2012). Redirecting walking and driving for natural navigation in immersive virtual environments. *IEEE transactions on visualization and computer graphics*, *18*(4), 538-545.

Research was conducted to determine how a user can be redirected during locomotion in a virtual environment. Psychophysical experiments were conducted and compared between how well a virtual environment can redirect the user in the physical world when walking and driving an electric wheelchair. The results show that redirected walking-and-driving approaches can easily be realized in a virtual environment and that the advantages of walking in confided spaces can be combined with the advantages of using vehicle based self-motion for longer distance traveled. Reading about this research's two-alternative forced-choice (2AFC) method of quantifying how effective redirection was in virtual reality, helped me better understand one possible way I could collect data in my research regarding a user's ability to distinguish between objects in a virtual environment compared to a real environment.

Fiore, L. P., & Interrante, V. (2012, September). Towards Achieving Robust Video selfavatars under flexible environment conditions. In *International Journal of Virtual Reality (special issue featuring papers from the IEEE VR Workshop on Off-The-Shelf Virtual Reality)*. 11(3),

33-41.

This research article investigates a method by which the user's presence in a virtual environment can make the virtual environment feel more real world. The disadvantage of most Head Mount Displays (HMD) is that they don't allow the user to see themselves which makes the user feel as if they were observing the virtual world rather than experiencing it. To fix this problem the researchers created a video-based see-through HMD (VSTHMD) to display the virtual environment while capturing parts of the real-world. The goal was to be able to have the camera in the HMD to distinguish between the user's body and the background. Then an algorithm was developed to segment parts of the user's body into the virtual environment, so essentially the user could see his or her arms and legs in the virtual reality. Some problems the researches ran into included distinguishing the user's body from background objects that were the same color as the user's skin tone, and capturing different perspectives of the user's body positions in a 3-dimensional space to accurately represent those motions in a virtual environment. After numerous experiments the research concluded that simple frame differencing and Gaussian mixture model approaches using a 3D room model can work under certain conditions, yet can have unclear or blurry output. This experiment shows that a first person view of the virtual environment is more immersive in virtual reality, and I used this idea in my research project by creating a virtual environment that is viewed in first person.

Gandrud, J., & Interrante, V. (2016, July). Predicting destination using head orientation and gaze direction during locomotion in VR. In *Proceedings of the ACM Symposium on Applied Perception* (pp. 31-38). ACM.

Virtual reality (VR) is becoming more prominent in advanced graphic technology and one aspect of virtual reality is tracking the eyes' gaze. This research paper discusses an experiment done in which the eye's gaze and head orientation was tracked and the results show these two features could potentially predict the future destination of a person in locomotion in VR. This study has a couple participants walk through a hallway in virtual reality and enter one of the two doors that are at the end of the hallway. The whole time the participants are walking through the hallway, their eyes' gaze and head's orientation is being tracked and recorded. The results of all the participants show that they are more likely to choose the door their eyes' gaze had a smaller angle to. This research paper initially caught my attention, and eventually led me to research in Dr. Interrrante's virtual reality research lab.

Godoy, J. E., Karamouzas, I., Guy, S. J., & Gini, M. L. (2016, February). Implicit Coordination in Crowded Multi-Agent Navigation. In *AAAI* (pp. 2487-2493).

This research article looks at how various agents would navigate through each other in a crowded environment. In crowded environments, the motion of each agent is mostly constrained by the motion of nearby agents. In the approach proposed by this research paper, called Coordinated Navigation (C-Nav), agents take into account the velocities of their neighbors and optimize their motion accordingly. The algorithm for each agent looks at if its own motion is constraining the motion of its neighbors and adjusts accordingly. Besides for this fact C-Nav also takes into account the goal of the agent and tries to move the agent closer to their goal. The C-Nav scales to work for hundreds of agents and it was experimentally tested to validate its superior performance to other approaches like ORCA and ALAN. This project was conducted by one of the professors I interviewed whose lab was a candidate for a potential research lab I was interested in joining.

He, L., Li, H., & Li, M. (2016). Optomechanical measurement of photon spin angular momentum and optical torque in integrated photonic devices. *Science Advances, 2*(9), e1600485.

In the article "Measurement of photon spin angular momentum and optical torque in integrated photonic devices" experiments are conducted measuring the angular momentum and optical torque of a photon. The light matter interaction in photonic devices leads to optical forces which can induce an optical torque. The angular momentum and optical torque of a photon in photonic devices has remained unexplored to date. This research demonstrates a measurement of the optical torque on a photon and determines that the sign and magnitude are determined by the polarization state of the photon. This research could possibly lead to improvement in the optomechanical functions in a photonic integrated device. This project was conducted by one of the professors I interviewed whose lab was a candidate for a potential research lab I was interested in joining.

Karamouzas, I., & Guy, S. J. (2015, May). Prioritized group navigation with formation velocity obstacles. In *Robotics and Automation (ICRA), 2015 IEEE International Conference on* (pp. 5983-5989). IEEE.

The research conducted in this article comes from the applied motion research lab at the University of Minnesota. They researched how group formation can be taken into account during group navigation of a set of robots through static and dynamic obstacles. In this approach, the user prioritizes various formations of the robots. Then during each planning cycle, the formation of the robots is computed based on the priority and the safe travel of the robots to their goals. This new velocity-based navigation approach was called Formation Velocity Obstacles (FVO). Like previous velocity based approaches FVO anticipates and prevents collision by accounting for the future motion of nearby objects. However, unlike previous approaches, FVO allows the robots to change formation to orient themselves along the directions of travel while avoiding obstacles and accounting for the user-defined priority values of each formation. This project was conducted by one of the professors I interviewed whose lab was a candidate for a potential research lab I was interested in joining.

Kilteni, K., Bergstrom, I., & Slater, M. (2013). Drumming in immersive virtual reality: the body shapes the way we play. *IEEE transactions on visualization and computer graphics*, *19*(4), 597-605.

This research changed a user's skin color in an immersive virtual environment and determined how it would affect the user's sense of ownership. In the virtual environment, the users played a West-African Djembe physical drum with their hands. 36 Caucasian participants were tested and it was determined that their behavioral response and agency over the virtual body varied depending on the skin tone. Researchers concluded that behavior and cognition can be effected by how a virtual body is portrayed in a immersive virtual environment. In regards to my research, this study is another example of how virtual reality is being used to test a user's response to another body.

Kim, T. H., Persaud, R., & Kim, C. H. (2008). Silicon odometer: An on-chip reliability monitor for measuring frequency degradation of digital circuits. *IEEE Journal of Solid-State Circuits*, 43(4), 874-880.

As the use of the electrical circuit grows, it is becoming ever more necessary to measure the degradation of an electric circuit. Due to old age, temperature sensitivity and specific observed effects (such as the negative bias temperature instability (NBTI), hot carrier injection (HCI), and time-dependent dielectric breakdown (TDDB)), degradation of a circuit is an ongoing problem. In order to address this problem, it is necessary to be able to reliably measure the amount chip degradation. This article develops a technique using two ring oscillators instead of one to achieve a 50 times higher sensing resolution than that of prior techniques. The technique proposed in this paper also controls potential environmental factors that can vary the measurement such as temperature drifts between different sampling points on a chip. This technique can possibly help better understand the effects of NBTI and can ultimately assist in building age tolerant systems. This project was conducted by one of the professors I interviewed whose lab was a candidate for a potential research lab I was interested in joining.

Klatzky, R. L., Lederman, S. J., & Reed, C. (1987). There's more to touch than meets the eye: The salience of object attributes for haptics with and without vision. *Journal of experimental psychology: general*, *116*(4), 356.

This research looked into the salience of objects based on various attributes for haptics. They had subjects close their eyes and try to sort objects of various attributes into different bins. They tested texture, size, shape and hardness and determined shape and texture were easier to discriminate than hardness and size. This could apply to a research project I may potentially conduct because it shows how people might not be able to tell the difference in size when they feel an object in virtual reality and when they feel it with their hands in real life. This provides support for testing of size in virtual reality, by proving that for haptics size is one of the most indistinguishable attributes of an object.

Kokkinara, E., & Slater, M. (2014). Measuring the effects through time of the influence of visuomotor and visuotactile synchronous stimulation on a virtual body ownership illusion. *Perception*, *43*(1), 43-58.

This research focused specifically on visuomotor (VM) and visuotactile (VT) synchronous stimulation in virtual reality to examine how these forms of stimulation effect the ownership illusion over a virtual body. In addition, this research is set apart from others in the same area because it uses a new method other than the common

questionnaire to measure ownership. The users were to verbally report when they felt a break in the ownership illusion while they were in the virtual environment and the amount of times they subjectively felt a break was recorded. Most valuably, this research contributes to the background of my project by supporting the idea that visuomotor stimulation (i.e. moving while in virtual reality and having the virtual avatar move simultaneously) can effectively create the ownership illusion. This means the hand tracking that is used in my project would effectively be able to make the user feel like their hands in virtual reality are actually theirs.

Lecuyer, A., Coquillart, S., Kheddar, A., Richard, P., & Coiffet, P. (2000). Pseudo-haptic feedback: Can isometric input devices simulate force feedback?. In *Virtual Reality, 2000. Proceedings. IEEE* (pp. 83-90). IEEE.

This article tests the stiffness JND (Just Noticeable Difference) of users discriminating between a virtual and real spring. It determined the JND to be 13.4% which indicated that the users visual feedback created an illusion that the spring took a different amount of force to compress than it actually did. This compliments my research by providing good ways to measure discrimination of an objects attribute, like using JND and graphing its attribute using the Weber function. In addition, this research supports the idea that vision could create an illusion, which may extend over to feeling of an object.

Magdy, A., Alghamdi, R., & Mokbel, M. F. (2016, May). On main-memory flushing in microblogs data management systems. In *Data Engineering (ICDE), 2016 IEEE 32nd International Conference* (pp. 445-456). IEEE.

Searching microblogs occurs through main-memory indexing. If the search doesn't have enough results on the main-memory it resorts to the disk drive to collect the needed number of microblogs. Searching through the disk is much slower and less efficient the main-memory. This article proposes a kFlushing policy that increases the efficiency of any given search query. K in this case stands for the amount of memory allocated for each search. If the amount for one search is above K a certain amount of memory is flushed to the disk drive. This paper develops an algorithm that smartly selects the top-k microblogs to flush. The freed space from all this flushed data is used to accumulate more data that can then be used to answer more queries from memory contents. The kFlushing policy overall flushes memory that is less likely to degrade the memory-hit ratio. The memory-hit ratio the number of times the memory needs to be used in searching compared to the number of times the disk needs to be used. So, a higher memory hit ratio is good, because that means the short-term memory was used more often when searching which saves time and makes the system more efficient. The tests done in this research proves that kFlushing improves the memory hit ratio 26-330%. This project was conducted by one of the professors I interviewed whose lab was a candidate for a potential research lab I was interested in joining.

Mardani, M., Mateos, G., & Giannakis, G. B. (2015). Subspace learning and imputation for streaming big data matrices and tensors. *IEEE Transactions on Signal Processing*, 63(10), 2663-2677.

In Big Data analysis, extraction of latent low-dimensional structure from high-dimensional data is very important. However large data sets are becoming increasingly more difficult to analyze, as they become more heterogeneous and incomplete. This paper discusses a developed algorithm that can unravel latent data from an incomplete stream of data. After the algorithm was developed it was tested with internet data and cardiac MRI data. Both tests confirmed the efficacy of the developed algorithm and its superiority to similar alternatives. This project was conducted by one of the professors I interviewed whose lab was a candidate for a potential research lab I was interested in joining.

Maselli, A., & Slater, M. (2013). The building blocks of the full body ownership illusion. *Frontiers in human neuroscience, 7*, 83.

This research conducted a few experiments and analyzed neural and cognitive mechanisms behind the self-perception regarding how the full body ownership illusion is created and enhanced by analyzing the responses of users to systematic changes in visuotactile and visuosensimotor contingencies, as well as visual perspective and visual appearance. They concluded that when a subject is synchronously stimulated by a tactile feeling in real life and the virtual world, they are more likely to experience the ownership illusion. In addition, if they are viewing a virtual body in first person perspective with a similar appearance to their own body, their sense of ownership increased. This does not mean the user cannot feel the ownership illusion if their body is not exactly like the virtual avatar, however the more similar it is the stronger the illusion becomes. In relation to my research, this research supports my experimental setup. It proves that under my setup the ownership illusion should be able to take place,

meaning that if I keep all other variables constant, like the first-person perspective and the appearance of the hands, I should be able to effectively test whether haptic feedback in itself will increase one's sense of ownership over the virtual hands.

Parsons, T. D., McPherson, S., & Interrante, V. (2013, March). Enhancing neurocognitive assessment using immersive virtual reality. In *Virtual and Augmented Assistive Technology (VAAT), 2013 1st Workshop* on (pp. 27-34). IEEE.

In this article, researchers work on applying virtual reality to neuropsychology. This potential application to the medical field could improve many lives by enhancing neurocognitive assessment. Currently, the standard paper-and-pencil measures of neurocognitive assessment is not far reaching enough. It can assess basic memory, learning or reasoning but it cannot test measures about how well a patient will respond in a real environment. With virtual reality, a phycologist can test how a patient will respond or react in different situations they may face in life. This will better prepare the patient for what they may face in a real environment if the patient is recovering from a psychological disease, or it will help psychologists test if a patient has a psychological disorder. This article describes task performances that are required in a grocery store and the researchers created a Virtual Environments Grocery Store (VEGS) virtual environment as an example of how an assessment using an immersive virtual reality can assess for various attributes of task performance that may be helpful in to better understand person's neuropsychological state. This shows a potential medical application of a more immersive virtual environment.

Plonski, P. A., Vander Hook, J., & Isler, V. (2016). Environment and solar map construction for solar-powered mobile systems. *IEEE Transactions on Robotics*, 32(1), 70-82.

In robotics, solar power energy could be used substantially better if a robot were to detect which areas have sunlight in which areas don't have sunlight. In this project, the researchers create an algorithm to classify different areas of an environment as sunny or shady and estimate the magnitude of the solar power. The algorithm uses the height of objects near it and the time of day. If the robot knows the height of an object near it and the time of day it can create a good estimate of where around the object, the shadow is. The robot can then create a path for itself that allows it receive the most sunlight. After the algorithm was created it was given to the robot and the robot was able to create the solar map and path itself. The algorithm was heavily tested with various values before it was given to the robot and used out in the field. This project was conducted by one of the professors I interviewed whose lab was a candidate for a potential research lab I was interested in joining.

Rautaray, S. S., & Agrawal, A. (2015). Vision based hand gesture recognition for human computer interaction: a survey. *Artificial Intelligence Review*, *43*(1), 1-54.

This literature review covers a lot of different information on how Human Computer Interaction evolved with hand gestures. It classifies various technologies behind tracking like those that use a depth sensor, tracking gloves, a camera etc. Most importantly, I think this research has a very dense applications section. It describes how hand gesture tracking on computers can have applications from Robotics, Computing and Information visualization to Medical environment and adaptive treatments. Reading into these various applications will broaden my understanding as to how big of an impact my research could potentially make.

You, D., Rayadurgam, S., Heimdahl, M. P., Komp, J., Kim, B., & Sokolsky, O. (2015, November). Executing Model-Based Tests on Platform-Specific Implementations (T). In *Automated Software Engineering (ASE), 2015 30th IEEE/ACM International Conference on* (pp. 418-428). IEEE.

In safety, critical systems it is important that software runs correctly, otherwise lives may be endangered. One variance that can cause an instability in software is the platform it is running on. The research this paper discusses tries to create a way for model-based tests to run consistently on various platform specific implementations. One problem that needed to be overcome was the issue of false positives and negatives. Generally, when the model-based test runs on a different platform many false positives occur. Previously proposed approaches however end up acting too permissive when dealing with the false positives which increases false negatives in the software. This research was able to develop an adaptive approach to minimize false positives and false negatives of a model-based test on various platform specific implementations. In order to do this, the researches had to do a lot with software testing to root out non-determinism caused by various platform specifications. In order to test the software, the software was mutated many times and tested with thousands of inputs. The less times the software gave incorrect outputs the more reliable the software was. Most of the faults in the software however were caused by run to run variations in timing of different parts of the software and hardware. For example, if you have multiple

applications running on a computer each application would function at a different speed than if they were running alone, because all the applications share the same hardware resources. Eventually however, the researchers were able to create a framework that captures the timings of different hardware components, allowing them to establish an adaptive approach to executing model based test on platform specific implementations minimizing false negatives and false positives. This project was conducted by one of the professors I interviewed whose lab was a candidate for a potential research lab I was interested in joining.

Essay

Approximately 10 of the readings were completed before I had decided a lab in which I wanted to join. These reading span various subsects across of computer science and introduced me to how many areas of study there were under computer science that I could pursue in the future. Often, I chose research papers on an area that I did not know much about.

Learning about a subject for the first time meant there were many terms I was unfamiliar with and I often had to pause my reading to search up and understand some concepts. Eventually, however I became well learned with the terms and was able to make my way through the research papers. The whole process of reading one research paper took at least one to one and half hours. Although, each paper is only about 8 to 10 pages, the material each one covers is very dense and takes careful reading and though to understand.

Reading so many research articles also helped me familiarize myself with the scientific process. Each paper was structured in a similar way, starting with an abstract then introduction, and ending with an analysis, discussion, and conclusion. After a couple papers, I was able to predict what information each section would have about the topic. This is a valuable skill, because if I am looking for something specific in a research paper, like the method they used of testing their hypothesis, I know that I can jump straight to that section, like the "Experimental Design" or "Experimental Procedure" section.

Furthermore, the many different research papers I read expanded the breadth of my knowledge in computer science. I learned about different areas, from robotics, to big data, to software design, to hardware testing. Being able to dabble in all these different areas in computer engineering and computer science allowed me to acknowledge the breadth of computer science as well as determine how different areas of computer science interact with each other as well as other disciplines.

After interviewing the authors of those research papers that I read, at the University of Minnesota in the Computer Science and Engineering department and the Electrical and Computer Engineering department, I decided to research in a visualization and graphics lab and I began reading research papers that dealt with virtual reality. Initially when I was starting my project, I read research papers from very different virtual reality studies just to see how large the area of study was. Virtual reality is a relatively recent and popular topic and there were many different parts of virtual reality that were being researched.

One aspect of virtual reality research papers that I enjoyed reading about, was the applications section. It was very interesting to see how virtual reality could change the world as we know it and revolutionize various aspects of our lives. In the medical field, mental treatment could become a lot better and physical pain could be minimized by psychological means. In areas of communication, people could eventually be able to travel the world or meet with their long-distance relatives in a virtual environment. In education, many professionals such as astronauts, oceanographers or surgeons could be trained and practiced in virtual environments.

As I began to gain a clearer picture of what I wanted my project to be I began to read research papers that dealt with haptics and/or agency and ownership in virtual reality. In haptics, many different research projects were testing pseudo-haptics or how a virtual environment can be manipulated to be different without the user being able to tell the difference using the sense of touch. This kind of research dealing with sensorimotor perception in virtual environment intrigued me, and is a reason why I decided to include haptics as one of the areas of virtual reality that I wanted to study.

In regards to agency and ownership, researchers were manipulating many different things in virtual environments to see their effect on agency and ownership. Some tried changing the task the virtual avatar was doing, some tried manipulating the way the virtual avatar looked, some manipulated the perspective at which the user viewed the virtual avatar and virtual environment. I was fascinated by how a user feels over their virtual avatar could vary depending on such small details.

After reading virtual reality literature in haptics and self-perception, I concluded that my project would combine both areas of virtual reality studies and try to determine the effect haptics had on agency and ownership. I had not come across any research papers that are studying this exact relationship that I outlined, so I felt confident that my research could positively benefit the advancement towards creating a more immersive and effective virtual environment.