How does the implementation of virtual reality improve the training of astronauts, with in particular the oculus rift head mounting device?

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Table of contents

Table of tables

Table of figures

Preface

The reason why the topic virtual reality training for astronauts has been chosen is, because aerospace has always been a fascinating subject to me. There are still mysteries in space that have not been discovered yet. Astronauts are being send to the unknown, with the experience they have gained on earth. The environment, in this case planets, astronauts go to could be so extremely different than earth, that one must wonder how does someone actually prepare for such differences or the risks that are being involved during missions. I found this particular interesting and was determined to find out which simulations are available for the astronaut and how does it prepare the astronaut for the real mission. Also after actually worn the oculus rift head mounting device, I was interested how this tool can make a difference in the field of space.

Learning perspective

I found out that there are many simulations astronaut must go through. Every aspect has its own simulations. But what especially got my focus is the oculus rift. I went to the view day of the European Space Agency. Here I came in contact with the oculus rift, where I could try the Head mounted device (shown in figure 1). The scenario that was being used is the Roller Coaster scenario. Here the user sees the environment were the roller coaster is and when the screen got activated the user could see in every direction. I could turn my head every direction and my view at the screen responded immediately. Also the sensation can be compared to an actual roller coaster. When moving downwards you actually feel like going downwards. After experiencing oculus rift myself I can really understand that this can be a good tool for training astronauts. Also the graphics were poor, but I learned from this research that it is one of the downsides of virtual reality and experiments are already made for improvement in this aspect. At first I started with the intention of looking into the simulations that prepare astronauts but soon I realize that virtual reality is an important aspect in this field and usually is connected with the simulations. I have learned that virtual reality is still trying to become better but are already showing promising results.

Figure 1: Me using the oculus rift

1. Introduction

This article is written to gain insight into the world of virtual reality with the purpose of training astronauts. This has proven to be an important discovery not only at financial aspect but also for live saving scenarios. Astronauts don't have to go to actual space without the proper experience.

Virtual reality has been defined over the years multiple times, but the main purpose is to interact with what is seen on a screen instead of only watching what is on the screen. By actually interacting with the screen, a new world has been opened for human life. In chapter 1 the definition of virtual reality is given and discussed further of how virtual reality has made an impact on the world.

Virtual reality is a concept which can be used in many different ways. This article focusses on the application of virtual reality in the training of astronauts in the form of simulations. In chapter 2 an explanation is given how simulations can be applied in the field of astronaut training and a short history of virtual reality is given.

Chapter 3 offers a inside of the virtual reality laboratory. This laboratory was established to enhance the experience of astronauts during training. Interaction with the virtual world offers a method where the mouse and joystick became irrelevant.

The usability and effectiveness of virtual reality is given in chapter 4. Here three different case studies are given to see which type of training is preferred. The first case study discusses general simulations, the second case study discusses cave, which is a automatic virtual environment. Also this chapter introduces the oculus rift head mounting device. It describes how Oculus rift could be an important asset in the training by using a case study. The effect and how oculus rift can be used in a particular scenario is mentioned.

To understand how Oculus rift works the technical perspective is explained in chapter 5. Here all the software and the technical aspects that the oculus rift offers are mentioned. Also the positive points and negative points of using 3D graphics are explained.

Oculus rift and virtual reality are not yet fully optimized giving users the real life experience. Graphics are still poor which cause the environment being felt artificial and un-real. These points are considered in chapter 6. The future perspective is discussed and possible solutions are explained.

At least the conclusion is mentioned in chapter 7. Here the research question: How does the implementation of virtual reality improve the training of astronauts? is answered. Also points that are necessary for astronaut training but are still lacking is mentioned in this chapter.

2. The definition of virtual reality.

Nowadays computers are used worldwide on a daily base. We cannot live without them anymore. But to take this a step forward, a new challenge has arise called virtual reality. Interacting with what is actually seen on the screen instead of just watching it, has been made a huge difference in human life. Ivan Sutherland was the first person who suggested a concept in 1965 to make everything on the screen realistic, with the necessary feedback.[1]

The term virtual reality has been described in several different manners. For instance the term could be approach in a philosophical way or an abstract way. When using virtual reality one gains first hand experience in a realistic concept, where the experiences are equal to the experiences gained in the real world. This is being achieved by giving the person the impression that he or she is using actual real objects.[2]

There are two terms which are essential when describing virtual reality which is also called Virtual environments. Telepresence and cyberspace are closely connected to virtual reality, this because telepresence can be defined as simulating a realistic environment giving the illusion the person is actually present at the real environment. On the other hand Cyberspace is linked with entertainment systems and the world wide web.[1]

Virtual reality makes use of sensory technology. This means that human senses are central. When a person takes action in a virtual environment, the reaction of this environment should be realistic. This is difficult to obtain, because often only several senses are being triggered with information that is usually not synchronized and the quality is low.[1]

There are three different types of virtual reality of implementing sensory technology to trigger human senses. The first one is called the Window on World (WoW) system. This system uses only the screen to present the image of the world. This will not cover many senses of the human. The second one is the improved version of WoW and will cover more senses, because instead of just using the screen it actually uses the motion parallax effect. This means a tracking systems is used which simulates the experience of being present. The last one which is called Immersive systems is the virtual system in its whole. All the senses of the particular person is being triggered by the computer generated world. This is obtained by using audio but also sensory integration. Also the location and direction of a person facing is being recreated by using HMD, which simulates a stereoscopic view of the environment.[1]

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[1] Virtual Reality History, Applications, Technology and Future. Tomasz Mazuryk and Michael Gervautz. Institute of Computer Graphics. Vienna University of Technology, Austria

[2] The Reality of Virtual Reality. Myeung-Sook Yoh Post-doctoral researcher at CSLI, Stanford University & Philosophy Department of Ewha Women's University in Seoul Korea. Proceedings of the Seventh International Conference on Virtual Systems and Multimedia (VSMM'01).2001 IEEE

Virtual reality is being used for different applications. Medical, educational but also training applications could improve the skills of a particular person, for instance preparing astronauts.

3. Virtual reality as application for training astronauts

The precedent of virtual reality in the application training astronauts, are flight simulations. Pilots including astronauts needed a solution to train themselves on a secure and economic approach. This is where the “Link machine” came into play. American Link developed in 1929 the link machine which would provide flight test training from the ground. This would give pilots a advantage, because training did not include actually flying anymore. This development improves on financial aspect but also making flying more secure. As of today a diversity of simulators are available for astronauts to prepare by implementing different kind of tasks,[3] for instance to be familiar with the switches and buttons that will be present in any shuttle, the pilot uses a simulator similar to the cockpit of the shuttle. Also a virtual reality-laboratory is available where astronauts can train to walk in space.[4]

The space flight training simulator makes use of the interface framework from a real aircraft, but also computer emulation is being used. The use of both methods is a human-machine system which is called semi-physical simulation methods. Physical technology is another method and is based on actual instructions. The third type is called digital simulation technology. This virtual instrument is implemented by a computer real-time graphic simulation equipment. These methods are all part of the soft instrument system, which is a component of the flight training simulator for the preparation of astronauts[5]

The digital simulation technology consider three different principles for implementing the digital simulation method, computer information, images and graphics techniques. These principles are interface equivalence principle, information equivalence principle and operating equivalence principle. Software is being used to develop real-time image interface. This interface should be similar to the real instrument.[6]

Astronaut training combines different types of simulations. Each have their own function. Virtual reality is a system which can be implemented into a simulation together with graphics systems.[7] 3D graphics and images plays an important role for preparing astronauts. Seeing the environment beforehand becomes a real advantage. Not only for training but also for

3 HE Ning, CHAO Jian-gang, SHEN Jun-yi. Space Flight Training Simulation Project Technology Research. 2010 Second WRI World Congress on Software Engineering.

4 Mark Traa.Ruimtevaart - Lisse: Rebo productions, cop 2005. -319p

5 HE Ning, CHAO Jian-gang, SHEN Jun-yi. Space Flight Training Simulation Project Technology Research. 2010 Second WRI World Congress on Software Engineering.

6 ibid

7 Charles J. Gott, David J. Homan. Application of Virtual Reality Technology, Including Force Feedback, for Astronaut Training. Simulation and Graphics Development Branch Automation, Robotics, and Simulation Division. NASA Johnson Space Center.

avoiding catastrophics or unnecessary risks. Space motion sickness and spatial disorientation are two common complaints astronauts struggle with during spaceflights. Virtual reality could decrease the severity of these complaints, because issues and objects, which are identical to the ones during spaceflight, are being presented to the astronaut before spaceflight. This approach gives the astronaut insight of what to expect during spaceflight and how to handle certain situations.[8]

4. The Virtual Reality Laboratory

For the purpose, mentioned in the previous chapter, a Virtual reality laboratory was established by Bowen Loftin and Chris Dede. Although the before mentioned simulations gave astronauts the proper training, virtual reality provided an approach where the astronauts could actually interact with the environment, so that devices such as a mouse or a joystick are no longer needed, because the astronaut could just obtain something with his own hands. Because sensation is something difficult to obtain, sounds are used as force feedback, for instance when somebody is touching an object a certain sound is heard. Force feedback is needed for giving the person a more realistic experience. When the person sees the object and also hears a sound when touching it, the sensation becomes more realistic even though he or she might not even feel the sensation. Just like simulations, virtual reality provides several different training aspects.[9]

Another training that is more advanced than just obtaining items and basic interaction with the environment, is actually doing real maneuvers around a space station. An astronaut would most likely make a space walk around the station for some additional repairs. Such simulation trainings are provided by the physics and electronics Laboratory (FEL), which is located in the Netherlands Organization for Applied Scientific Research (TNO). For making it possible to provide virtual reality in training simulations the FEL uses specific components. For the head mounted displays magnetic sensors are used for the purpose of movement tracking, also specific hardware and software is used. The head mounted display shows the astronaut the environment, in this case the space station. Also some thrusters are shown for maneuvering forward or backward. Although this would seem quite easy to operate, actually accessing the cargo bay in the space station in virtual reality seems to be a real test. [10]

The European Space Agency (ESA) modeled the Columbus Space Station into a virtual environment. By doing this, astronauts could interact with the station as if they were there. Then can pick up items, but also conduct experiments inside the station. This would not only give the astronauts a proper training, but also let them know what to expect and on financial

[8] Kenneth J. Stroud, Deborah L. Harm, and David M. Klaus. Preflight Virtual Reality Training as a Countermeasure for Space Motion Sickness and Disorientation. Aviation, Space, and Environmental Medicine Vol. 76, No. 4 April 2005

[9] *Immersive training systems: Virtual reality and education and training. JOSEPH PSOTKA.U. S. Army Research Institute, ATTN: PERI-IIC, 5001 Eisenhower Avenue, Alexandria, VA 22333-5600, U.S.A. Instructional Science 23:405-431.1995*

[10] *European Activities in Virtual Reality.Jose Encarnaçăo and Martin Göbel, Lawrence Rosenblum. Januari 1994*

aspects it saves money. Also the Columbus Space station could be evaluated. Weak points could be discovered from the ground instead of actually going to space.

5. Case study: usability and effectiveness of virtual reality

For proving virtual reality with particularly the oculus rift can make a change into the training of astronauts three case studies are considered and closer looked at. The case studies consists of a training method without using virtual reality, a training method using virtual reality, and a training method for using the new development under virtual reality namely the oculus rift.

5.1 Case study 1: Simulations

Simulations were the first tool for astronauts to gain experience. The simulations provide a specific environment where different tasks should be conducted such as flight monitoring, operation, control, communication, maintenance and research. The training simulator consists of the real aircraft interface environment combined with computer emulation. This combination is called semi-physical simulation. By combining the two the astronaut in training receive the proper experience with a known environment where the computer emulation offers training. In table 1 the advantages and disadvantages are given for using simulators. When the user is in the simulator he or she will experience the same sensations of being in a actual spacecraft. The simulator makes the same movements and responds also in a same way.

Advantages	**Disadvantages**
Being in a actual aircraft interface environment	Fixed location
Pressing actual buttons	Very expensive
Feeling sensations when simulator is active and responds as an actual spacecraft	Motion sickness
high resolution	Cannot turn the screen when turning the head.
No cables for hindrance	

Table 1: Advantages and Disadvantages of simulators

The use of simulators are very effective but it can be more improved by using virtual reality together with simulators. For instance using a HMD while being in a simulator. This would enhance the experience for astronauts.[11]

[11] Space Flight Training Simulation Project Technology Research. CHAO Jian-gang, SHEN Jun-yi, HE Ning. 2010 Second WRI World Congress on Software Engineering

5.2 Case study 2: Cave automatic virtual environment

A virtual environment which is suitable for learning and is used by astronauts is called Cave (automatic virtual environment). This application actually uses 3D images and projects these images around the user, when movement is detected by using screens. This gives the feeling as if being in a virtual room instead of just a screen. The Cave enhances the virtual experience since the resolution is high (HDTV) but also the images are full-color. Also the cables connected to the HDM are thin and carries less weight with it. It is proven that the cave offers more user experience with the use of six screens. In table 1 the advantages and disadvantages are given for the use of Cave[12]

Advantages	**Disadvantages**
High resolution	Fixed location
Cables on top of HMD (no cable hindrance)	Very expensive
large angle of view	Takes a lot of space
The errors that occurs when head rotation is established is less sensitive	not portable
Delays are excluded because the images seen are instantly paired with the head tracking.	Having only either input or output
Ability to mix VR imagery with real devices	

Table 2: Advantages and Disadvantages for Cave

Astronauts considers cave a successful tool. The stress and fatigue that is accompanied with the specific tasks are ailments the astronaut in training suffers when using cave. This gives the astronaut the appropriate training and experience when dealing with task under these kinds of circumstances. The negative part is that cave is a big systems and requires space, which makes it not portable. Cave is also a very expensive system and is restricted by its location and only having input and output.[13]

[12] Surround-Screen Projection-Based Virtual Reality:The Design and Implementation of the CAVE. Carolina Cruz-Neira, Daniel J. Sandin, Thomas A. DeFanti. SIGGRAPH '93 Proceedings of the 20th annual conference on Computer graphics and interactive techniques. Pages 135-142

[13] ESA CAVES: TRAINING ASTRONAUTS FOR SPACE EXPLORATION. Loredana Bessone, Kristina Beblo-Vranesevic, Quirico Antonello Cossu et all. Karst and Caves: Social Aspects and Other Topics – oral 2013 ICS Proceedings

5.3 Case study 3: The oculus rift head mounted device

A new development that made its way into the world of virtual reality is called oculus rift Head Mounted Display (HMD). The Oculus rift provides any location that is desired by using the HMD, but gives the feeling of actually being physically there. This makes it a powerful tool for learning purposes. The reason why this application is promising is because, other similar applications are considered more expensive.

In table 2 the advantages and disadvantages are compared to each other. Although the oculus rift is not optimised yet, for instance the graphics could be better, it does show potential in many fields.

Advantages	**Disadvantages**
Locations which seems to be unreachable could be made reachable by using Oculus rift.	Movement is limited due to cables connecting the HDM with the computer
It is at a financial aspect beneficial since oculus rift is produced with a low budget	Potential source of motion sickness
Could be applicable in multiple aspects like gaming, education or medical studies.	Resolution is currently 640x800 pixels per eye.
More advanced than similar systems which are considered expensive	No movement, fixed at one place
Delays are excluded because the images seen are instantly paired with the head tracking.	
The head mounted device offers a method where the distractions are limited, for instance someone standing in front of your view. (visible area fully covered)	

Table 3: Advantages and Disadvantages of Oculus rift.[14]

The Oculus rift can be a method for aiding in virtual co-location. This means that a collaboration is established where professionals are virtually present at the same location where others are actually physically there. By doing this the person who is virtually present can help the other as if he was actually there, making it a better solutions to interact with each other.

[14] Reiners, T. and Wood, L. and Gregory, S. and Baestians, T. 2014. Experimental study on consumer-technology supported authentic immersion in virtual worlds for education and vocational training. Perth, WA, Curtin University of Technology.

For instance with astronaut training virtual co-location is essential for the training. Virtual co-location depends on augmented reality (AR). This is necessary for building spaces to make the collaboration possible. In these particular spaces the interacting people but also the relevant objects will be present.

For these trainings, the astronaut wears the oculus rift which is connected to the AR computer system. The goal for the astronaut is to perform certain tasks, with the help of the resources: human-oriented and computer-oriented. These resources can be sustained at the same time. The astronaut will receive instructions of all the steps of the procedure that needs to be conducted in order to achieve the task. These instructions are given by using visual appearances in the HMD.[15]

By using the virtual co-location and oculus rift, complex problems can be solved as if all the persons were actually physically at the same location. This can make a difference when catastrophic failures occurs in actual space. The astronaut would need to use the oculus rift and would visually understand what he or she needs to do in order to fix the problem. The virtual co-location can be of assistance to help the astronaut in need.

[15] Reiners, T. and Wood, L. and Gregory, S. and Baestians, T. 2014. Experimental study on consumer-technology supported authentic immersion in virtual worlds for education and vocational training. Perth, WA, Curtin University of Technology.

6. Technological perspective of the oculus rift

The oculus rift is similar to any other HDM, but the differences is that oculus rift has more features for multiple purposes. The first intent of oculus rift was focused on gaming. Therefore the HDM has head tracking efficiency and renders 3D. The screen is very close to the eye which make the experience more effective. The screen which is the front of the oculus rift is a 60 Hz LCD 7-inch screen. At the moment the resolution of this screen is per eye 640 x 800 pixels. This is very low considered the now a day screens. Therefore companies are aiming at a 1080p resolution, which is already being prototyped. Figure 2 shows how oculus rift works. The head tracker is attached to the head of the user. The user looks through the lenses and observes the environment that he or she sees at the moment. The head tracker and the 3D scene are rendered and the final rendering is send back to the screen.

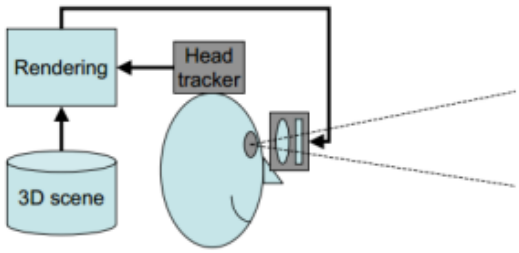

Figure 2: HMD virtual reality

In table below the pro and cons of 3D graphics are considered. Now a day 3D is very popular, but there are also some negative points. For astronaut training the positive points exceeds the negative points, because the goals is to achieve the most realistic experience which can be obtained by using 3D graphics.

use of:	**pro**	**con**
3D graphics	full experience, more closer to the real experience.	more expensive, than standard graphics
	Better learning visualisation, the person would actually see how an object looks	Can be a distraction, sometimes a simple image would suffice.
	places that seem to be impossible to go to in real life is more of a experience in 3D than 2D	Takes longer to render.

Table 4: pro's and con's of 3D graphics

In the table below all the aspects from the different development kits are considered. The SDK of the oculus rift has an open source code which makes it possible to alter the code for personal use. This kind of freedom will be appreciated by a certain group of users, who wants to have a different use of the oculus rift.[16]

Oculus rift development kit Contains:	**Oculus rift device and Software Development Kit (SDK) Contains:**
Oculus rift Head set	Mac OS 10.6 or higher
Control box	Linux (Ubuntu 12.04 LTS)
Straps attached over the head for stability	Windows (Vista, 7 or 8)
Vision lenses (3 different ones with each a different focal length)	2 GB RAM
HDMI cable, USB cable, DVI cable	2.0+ GHz processor
DVI adapter	Direct3D 10 or OpenGl 3 compatible video card
5-Volt power supply	

Table 5: Oculus rift kits and their contents

[16] Katchhi, Shrutik, and Pritish Sachdeva. "A Review Paper on Oculus Rift." (2014).

7. Future perspective

Virtual reality is not yet fully optimized. The goal is to achieve such an environment where no interface is needed. This means that every action the user performs would be as natural as if it were in real life. But this seems to be a difficult task, for instance the graphics are very poor and technical problems still arise, this because a powerful language, just like C++, is needed for the interactions.

Virtual reality needs to be improved to gain a full experience which can be compared to the real world. Human factors are advised to make the system more satisfying and instinctive.

Even though HMD is very promising it still lacks some technical aspects for delivering a full real life experience. The resolution is very low and should be optimized, for instance the oculus rift contains lenses with 640 x 800 pixels per eye. With such a low resolution the virtual world will become unreal and “virtual”. A solution would be changing the resolution to 1080p, which companies are already experimenting on. To gain better graphics more storage capacity, more CPU performance and more graphical power is needed.

Another point that should be considered is that the user is fixed on one particular point in space when using virtual reality. An astronaut needs to move around the space station. Also what is important is feedback that should be given to the astronaut, which requires a powerful computing power. All systems strive for more MIPS and megabytes.

To make virtual reality more realistic not only for astronauts but for more applications is to give enough and sufficient feedback. When action is taken for an object the user cannot feel the sensation, so other feedback is required, for instance sounds or visual feedback. When this is not synchronic the experience will suffer because of it.

To gain the ultimate virtual reality experience, senses should be added to the system, like sounds, voice recognition, but also smell and taste. For astronaut this part would not be very useful but to unlock the ultimate virtual reality world all these senses are important.[17]

Oculus rift has proven to be a possible solution for gaining real life experience in the virtual reality world which astronauts need instead of going into space with not enough experience. Although it is still a new concept but the possibilities are better than other HDM or virtual reality devices.

[17] *Immersive training systems: Virtual reality and education and training. JOSEPH PSOTKA.U. S. Army Research Institute, ATTN: PERI-IIC, 5001 Eisenhower Avenue, Alexandria, VA 22333-5600, U.S.A. Instructional Science 23:405-431.1995*

8. Conclusion

The implementation of virtual reality improve the training of astronauts. This because a trip to space to train is very expensive and might not go as planned. Therefore finding a solutions for astronauts to just train on the ground and receiving the experience of being in space, makes a difference. Although virtual reality is still not yet optimized in a way that full real life experience is gained it still provides an efficient method for training the astronaut. Possible risks that might occur and also solving complicated tasks can be done by using the virtual co-location and using the HDM. Experts can give instructions to the astronaut while not being physically there.

The new project on virtual reality is called oculus rift. This has proven to be a sufficient tool for gaining the experience astronauts need, but also getting the appropriate feedback can be given by using the HDM. It is not yet used by astronauts, but experiments are being made for making the device possible for astronauts. The source code is made available, which means every person can change the code to his advantage.

One setback is the graphics which are not very realistic, this gives the feeling of being in an artificial world instead of the real world. But besides this negative point oculus rift gives the user a realistic experience, for instance one of the tests of oculus rift is the rollercoaster. The users vision is completely covered by the 7-inch screen. This provides a solution to distractions which are not visible anymore only the screen and the virtual world are seen by the user. The user gets a ride in the rollercoaster and receive the same emotions, as if the person is sitting in a real rollercoaster.

Gaining real emotions is very important for training an astronaut. He or she might get in a situation where stress is becoming a factor. Seeing through the oculus rift which actions needs to be performed and how to handle in the stressful situations might learn the astronaut how to deal with the situation. Learning such scenarios can also avoid disaster.

The initial target of oculus rift was for the gaming industry. They provided a solutions to have virtual reality with a low budget. It obtain the best experience in contract to other virtual reality devices and comes also with a low budget, which makes it interesting for other companies. It is proven that oculus rift is effective for many applications, not only gaming but also in the medical field or education, but also for astronauts.

Thus, virtual reality makes a huge difference when it comes to training astronauts and will only become better in the future. Oculus rift has proven to be a powerful tool and when being optimized with 1080p resolution and more intuitive into it, it will become a great asset for several parties.

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10. Annotated bibliography

The articles mentioned here are considered the most important articles of this research paper. The are the most important because the information was relevant and give a better insight of the particular subject than other articles.

The first articles is from **Katchhi, Shrutik, and Pritish Sachdeva and is called "A Review Paper on Oculus Rift." (2014). (See appendix).** This article give insight in the technical perspective of the oculus rift. The software that is required for using the HDM is explained in the oculus rift software development kit, but also the technical parts it contains are described in the oculus rift development kit. One major part are the lenses which have a 640x800 pixel resolution the glasses are close to the eyes which makes distractions not possible. For instance someone standing in front of the screen is not a problem anymore since the screen of oculus rift is around the users eyes, so there is only vision of the screen.

The next article is from **Tomasz Mazuryk and Michael Gervautz. Institute of Computer Graphics. Vienna University of Technology, Austria and is called Virtual Reality History, Applications, Technology and Future (See appendix)**. Here several definitions are given of the term virtual reality. Many definitions are explained which makes this article better than other articles about definition of virtual reality. It describes that virtual reality is actually interaction with the virtual environment in such a way the user has the experience of being in the real world.

The last article is from **Reiners, T. and Wood, L. and Gregory, S. and Baestians, T. 2014. and is called Experimental study on consumer-technology supported authentic immersion in virtual worlds for education and vocational training. Perth, WA, Curtin University of Technology.(See appendix).** This article explains how oculus rift can be used by astronauts to solve complicated tasks and how they can interact with experts not physically at the same location as the astronaut. This aspect is called virtual co-location. The article is important to this research paper because it explains the steps of having oculus rift as a training method.