Diploma Project

A VIRTUAL REALITY 360 INTERACTIVE VIDEO FOR EDUCATIONAL PURPOSES

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ABSTRACT

This dissertation focuses on developing an interactive 360 video in which the user can interact with various elements present within the virtual environment they observe.

Virtual Reality video is a new type of video that is constantly under research and development by many technology giants. Virtual reality has a plethora of applications in education and entertainment alike as one can be extremely immersed by viewing a VR video with VR Goggles. Due to the capabilities of virtual reality, its use has yet to be completely defined and thus, many researchers along with big tech companies constantly strive to release better VR products and videos to figure out its best possible uses.

Viewing a Virtual Reality video is as simple as wearing a VR Headset and using a mobile phone as the means of playing the 360 video. The interactivity of a 360 video also depends on the hardware used to view the 360 video since, it can range from devices as simple as mobile phones to completely ready, setup rigs for VR experiences such as an Oculus Rift which comes with a complete set of motion controllers. An individual can be completely immersed into the virtual environment they are viewing and they can imitate real movements such as walking, jumping, moving their hands and also interacting with virtual elements present on the screen with the use of the aforementioned motion controllers.

This dissertation focuses on creating the most interactive 360 video possible by using a 360 camera and leveraging the VR integration of Unity and then using that 360 video to observe how it can be used for educational purposes. The 360 video that was developed during this dissertation consists of a virtual reality tutorial regarding the operation of a Lathe Machine in the laboratory of the Technical School of Avgorou to help students understand the entire procedure without the need of their precense.

CONTENTS

LIST OF ABBREVIATIONS

VR	Virtual Reality
AR	Augmented Reality
XR	Mixed Reality
HUD	Heads Up Display
UI	User Interface
SFX	Sound Effects
IVE	Immersive Virtual World
VE	Virtual Environment
FOV	Field-Of-View
UCY	University Of Cyprus
RISE	Research Centre on Interactive Media and Emerging Technologies
CPU	Central Processing Unit
GPU	Graphical Processing Unit
RAM	Random Access Memory
CAD	Computer Aided Design
HD	High Definition
SSD	Solid State Drive
TB	Terabyte
8K	8000
Mbps	Megabits Per Second
3D	Three Dimensional

LIST OF FIGURES

Chapter 1

Introduction

Introduction

The last 5 years, virtual reality (VR) is considered to be one of the most researched topics in the computer graphics sector[1] and its functional uses have been widely leveraged in a plethora of fields. Due to its initial complex configuration and availability, VR was solely restricted to large corporations, research universities and military applications. Nonetheless, as technology gradually progressed in developing more efficient and affordable hardware and software alike, the aforementioned limitations had been dealt with and thus VR is now more widely available and useful to the general public.[2]

In essence, the technology of virtual reality relies on computer graphics that create a realistic word which responds to the user's input. Thus, in virtual reality the user experiences an utmost immersive and responsive virtual world, which ultimately allows the user to feel they are part of the action that takes place within that world. In parallel with that, the VR environment is instantly connected to how users can immerse

1 G. Nalbant and B. Bostan, "Interaction in virtual reality," in 4th International Symposium of Interactive Medial Design (ISIMD), 2006

2 E. Hodgson, E. Bachmann, D. Waller, A. Bair, and A. Oberlin, "Virtual reality in the wild: A self-contained and wearable simulation system," in Virtual Reality Workshops (VR), 2012 IEEE. IEEE, 2012, pp. 157–158.

themselves and instantly feel part of the virtual world which in turn corresponds to the capabilities of interaction within that environment in meaningful ways[1]. In a nutshell, the most crucial features of virtual reality according to the above definitions are:

- Virtual World
- Immersion
- Sensory Feedback
- Interaction

The first three features ultimately depend upon the last one being able to be executed properly. Hence, interaction in a virtual environment is considered to be one of the most, if not, crucial features in VR. It contributes to helping users feel truly and authentically involved within the Immersive Virtual Environments (IVE).[3]

When asking about Interaction in VR, interaction is usually defined as the ability of the user to move and interact with the objects inside the virtual world[1]. Therefore, interaction in IVEs is broken down into three basic elements:

- Speed
- Range
- Mapping

In his article, Steuer (1992)[4], defined **speed** as the system's ability to respond quickly to actions performed by users in the virtual environment such as, object selection, manipulation and navigation in the IVE. Thus, delayed responses to the user's action ultimately affect the interactivity in the 3D virtual environment. On top of that, he defined **range** as interactions that allowed the manipulation of objects in the virtual environment. This specific element enhances and increases the interactivity level within the IVE when the user is able to manipulate a vast amount of objects. Last, but not least, he defined **mapping** as the connecting bridge between the user and the actions that are executed in the IVE, which would ultimately lead to producing natural results based on the user's interactions.

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3 W. R. Sherman and A. B. Craig, "Understanding virtual reality interface, application, and design," Presence: Teleoperators and Virtual Environments, vol. 12, no. 4, pp. 441–442, 2003.

4 J. Steuer, "Defining virtual reality: Dimensions determining telepresence," Journal of communication, vol. 42, no. 4, pp. 73–93, 1992.

According to previous definitions of interaction, it can be considered that the accomplishment of tasks in IVEs most of the time depends on the success of the interaction device[5]. In order to properly measure the success of the device used for interaction within the IVE we must take into consideration of the immersion and sense of presence[1]. Through various research and trial & error, developers have discovered that users feel more immersed into the experience when the device used for interaction is easy, plain and interesting. Therefore, this means that interaction with inadequate interaction devices could diminish the immersion and sense of presence[6]. Thus, the level of the user-controls compared to interactivity of virtual objects with the current state-of-the-art devices such as keyboard, mouse and joysticks varies from one device to another[1].

In this research, the issue is present in interaction with objects in virtual environments using traditional input devices (a joystick or keyboard for example) which is often difficult or inaccessible. Therefore, the aforementioned difficulty could completely eliminate the immersion and sense of presence in immersive virtual environment tasks. Hence, a significant contribution to the immersion of virtual environments has been evident by the use of mobile devices as interaction devices. This research will present different approaches for interacting with IVEs by using mainly mobile devices for manipulation and object selections as the project that has been developed is aimed to students who only have access to mobile phones.

As a result, we assume that using mobile devices for gaze-based interaction will facilitate simple tasks such as manipulation, object selection and navigation within the immersive virtual environment of the 360 video tutorial that is to be developed. Additionally, we hypothesize that with the use of mobile devices as an interaction device, the immersion will ultimately increase and the sense of presence will be enhanced within the IVE. In parallel with that, we propose that using the gyroscope of the mobile device and a small reticle within the field of view of the user in the mobile device would significantly reduce the amount of time required by users to learn how to deal with the virtual world they are presented. For this to be accomplished, we did not

5 J.-S. Kim, D. Gracanin, K. Matkovic, and F. Quek, “iphone/ipod touch as input devices for navigation in immersive virtual environments,” in Virtual Reality Conference, 2009. VR 2009. IEEE. IEEE, 2009, pp. 261–262.

6 D. A. Bowman, E. Kruij↵, J. J. LaViola Jr, and I. Poupyrev, 3D user interfaces: theory and practice. Addison-Wesley, 2004.

include any kind of button interactions on the mobile devices or touch-based interaction to encourage the use of the reticle that is located at the center of the field of view of the user. The reticle acts as the “gaze” of the viewer with which the viewer can point to and interact with objects as shown in Figure 1.0.

Figure 1.0 – Red Reticle in VR Goggle View on Mobile Devices

1.1 Problem Definition

1. Interaction with objects in virtual worlds using traditional input such as a joystick or mouse is often difficult and could diminish the immersion and sense of presence for the user in 3D immersive virtual environment tasks.

2. Most of the times, traditional input uses indirect manipulation techniques to manipulate objects using buttons

3. State of the art equipment such as Oculus Rift or HTC Vive requires expensive hardware to work properly and offer a smooth VR experience

4. It is more likely for students in schools to possess a mobile device rather than a VR-Ready Goggle such as the Oculus Go.

1.2 Research Objectives – Goals of the study

1. To enable the use of mobile devices as a gaze-based interaction tool which acts as a controller in IVEs

2. To leverage mobile devices' capabilities (i.e. multi-touch screen, monitor screen, sensors, accelerometer, magnetometer, gyroscope and finger gestures), which provide new possibilities for interaction techniques on mobile devices within an immersive virtual environment.

3. To effectively increase and enhance the immersion and sense of presence when using mobile devices in IVEs.

4. To allow multiple students to interact with the virtual environment from the comfort of their home by the use of a VR-capable mobile device.

5. To offer an alternative way of learning specific courses or classes in the form of VR video

6. To eliminate any risk of danger when it comes to demonstrating operations to students that require supervision by an instructor.

1.3 Prior work and motivation

The use of 3D imaging has been widely popular in movie theatres, gaming, education and in military applications and thus, researchers have been increasingly showing interest in making the 3D virtual world more effective and immersive through time. As mentioned above, interaction is one, if not, the most crucial feature in VR as it helps in effectively enhancing the virtual experience of the user. VR interaction tasks are heavily based on the interaction techniques and interaction devices used to execute these techniques. Researchers have striven to use these two components in conjunction with each other to produce more natural interactions within the IVE that are more intuitive and easy to learn.

Interactions make use of a vast variety of input devices, such as joysticks, motion controllers, data gloves and instrumented objects. Depending on the interaction device that is used the level of interactivity is directly tied to the capabilities of said device when it comes to manipulating 3D objects or executing manipulative tasks in IVEs. Thus one can conclude that there is a strong bond between the interaction techniques and the interaction device to produce high-level interaction within a virtual environment[7].

A variety of issues exist that directly relate to interaction in virtual reality. One of these issues, is object manipulation[7]. As previously mentioned, manipulation is certainly one of the most fundamental tasks in both real and immersive virtual environments. Manipulation consists of two types of interaction techniques, direct manipulation and indirect manipulation. When speaking about indirect manipulation, we often refer to devices such as the Nintendo Wiimote for example, which uses indirect ways to interact within a virtual environment, such as buttons to select and manipulate the virtual objects present on-screen. Direct Manipulation on the other hand, such as direct-hand manipulation, consists of a natural technique that is intuitive for humans due to the fact that it consists of using hands to select and manipulate the virtual objects. Nonetheless, using direct manipulation is not always possible with all the interaction devices that exist[8]. In the scenario that the user cannot manipulate the virtual objects effectively, then the user might not manage to accomplish other tasks in the immersive virtual environment.

In order to overcome this limitation we propose using hand-held devices including mobile phones and tablets. Hand-held devices are widely spread across the world and many people rely on them daily to accomplish daily tasks. Rapid developments on smartphones with respect to both software and hardware offer a huge potential for using mobile devices as VR Controllers (Figure 1.2). Due to their vast amount of capabilities

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7 D. A. Bowman, E. Kruij, J. J. LaViola Jr, and I. Poupyrev, 3D user interfaces: theory and practice. Addison-Wesley, 2004.

8 J. H. Chuah and B. Lok, “Experiences in using a smartphone as a virtual reality interaction device,” in Workshop on The-Shelf Virtual Reality, Orange County, CA, 2012.

they offer such as multi-touch screens, monitor screens, sensors, accelerometers, magnetometers, gyroscopes and finger gestures new possibilities for interaction techniques within IVEs are presented. This scenario opens an interesting area for VR applications.

In this work, our prime goals are to effectively utilize and leverage the advantages of the forthcoming developments in mobile devices, including monitor screens, gyroscopes and high processing power through the new CPUs they use to use mobile devices as both input and output devices. We consider the mobile device as an input device by using the gyroscope in conjunction with the movement of the red reticle within the VR video to provide a direct means of interaction through direct movement of the user's head to allow the user to manipulate various objects in the immersive virtual environment. In parallel with that, we consider the mobile device as an output device by using a mobile device with built-in high quality display to allow the user to view the virtual environment on the display screen. This provides the user with the flexibility to move and explore the environment freely without the need of any additional VR hardware. Finally, by using mobile devices within the IVE, multiple users (students in this project) are able to use their own device to interact with the virtual world rather than restricting the interaction with the virtual world to only one user due to hardware limitations. By using a mobile device as an interaction device with the IVE, we strongly believe that a new opportunity will be presented to developers when considering to use mobile devices as VR controllers to interact with the virtual world in their Virtual Reality Applications. In retrospect, this encourages the use of mobile devices to further enhance the user experience and inspire academic institutions and schools alike to contribute to developing new VR applications for courses and classes in schools.

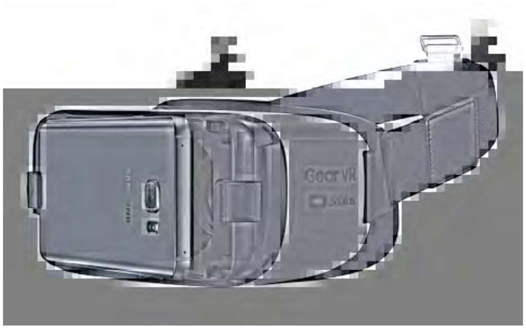

Figure 1.1 – Mobile device used as motion controller and screen - Samsung Gear VR

1.4 Metholodgy

The following diagram presents the abstract Metholodgy of this study.

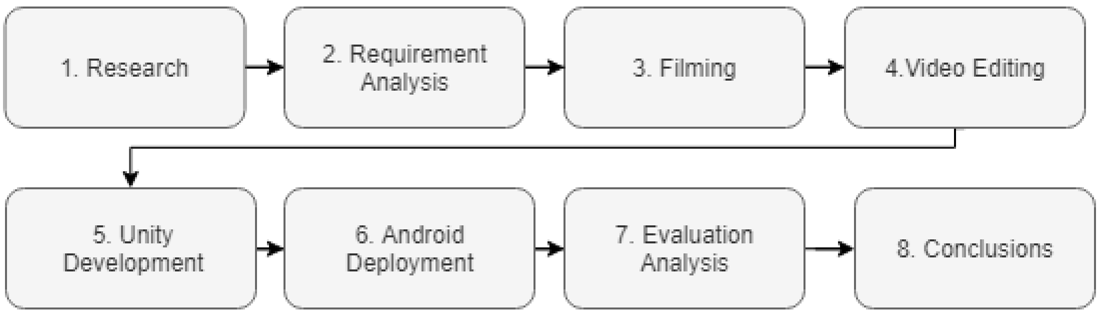

Figure 1.2 – Abstract Diagram of the Metholodgy Used in this study

Research: The initial research that was conducted in terms of virtual reality and how a virtual reality experience can be as interactive as possible. The elements that directly affect the level of interactivity in an immersive virtual environment are thoroughly discussed in Chapter 2: Literature Review.

Requirement Analysis: The requirement analysis that was conducted prior to initiating the development of this project in regards to what will be needed in terms of hardware, editing software, filming, unity development and android deployment based on the user's standards as described by the client. The requirements of each aforementioned section is thoroughly detailed in Chapter 3: Requirement Analysis.

Filming: The break down of the filming process from start to finish and the techniques and methods that were used to achieve the most interactivity possible. All the required steps in order to film with a 360 camera are described and explained thoroughly in Chapter 4: Filming.

Video Editing: The video editing that took place in order to produce the final scenes of the 360 tutorial that were edited in Adobe Premiere Pro. Every aspect of video editing a 360 video along with all the required configurations and project settings is thoroughly described in Chapter 5: Editing

Unity Development: The final development of the 360 tutorial in Unity. This section is one of the most crucial parts of this project since all the interaction was implemented into the project by using Unity's great integration with VR in conjunction with the use of virtual objects that could be triggered by the user's gaze by the use of Unity's utilities. The process behind implementing the interactive objects within the 360 videos through Unity is described in Chapter 6: Unity Development

Android Deployment: Since the project had to be used by students on their mobile devices, Android was the choice of platform for development since it is more widely spread across the world. The deployment to said platform required some specific configuration with Unity in order to work properly and smoothly on the majority of

Android devices currently available. More information regarding the Android Deployment is found in Chapter 6.7: Android Development

Evaluation Analysis: After completing the initial draft of the project, the project was given to both random participants and the client to measure the interactivity levels of the 360 tutorial. Various comments were taken into consideration by the participants for further improvement of the tutorial's interactivity and user experience to produce the best results possible. The findings and analysis of the results by the participant's demos are discussed in Chapter 7: Evaluation Analysis.

Conclusions: After evaluating and finalizing the product, further development possibilities are discussed in terms of educational purposes and VR applications of this magnitude.

1.5 Contributions

This study offers several contributions to both the developer community and the academical institutions. First of all it allows any novice to rapidly pick up and understand the basic implementation of VR videos in Unity since information regarding VR videos development specifically is scarce. In addition, a variety of techniques used to overcome various technical obstacles in filming, editing and unity development of this project are presented to thoroughly help future developments by using this thesis for future reference.

The findings of this study also help to further understand how successful VR applications are in teaching and learning specific aspects of classes and courses since the product developed is directly targeted to lyceum students. Thus, more opportunities could be opened for future development in terms of VR applications that not only help students understand a course's material better but make the process of learning very enjoyable at the same time. Simultaneously, teachers and academic staff could benefit from the use of VR as many demonstrations of specific procedures could have a high risk of danger due to the use of machines that require advanced knowledge, as they would only need to demonstrate on camera the entire procedure once and the student could view it as many times as they please without risking to harm themselves.

Finally, the evaluation and analysis of this 360 interactive tutorial could help understand better how the interactivity level could be improved by examining the behavior of the participants that took place into the testing of this tutorial. It is a crucial part of this project since the entirety of the user experience and immersion of the 360 tutorial solely depends on how easily the user can both navigate and interact within the IVE. In parallel with that, the conclusions extracted from these evaluations and demonstrations to participants and more importantly to the client of this project contribute heavily to the developer community, since they can be used to further consider better implementations of interactivity in future VR applications in regards to education.

1.6 Document Organization

The following table contains a brief summary of what is covered in each chapter.

Chapter 2	This chapter includes the initial research that was conducted regarding what makes a 360 video interactive along with previous researches that were conducted in regards to educational applications of Virtual Reality.
Chapter 3	In this chapter, the requirement analysis is thoroughly discussed in terms of filming, editing, hardware, unity requirements and android development based on the user's requirements as described by the client of this project.
Chapter 4	This chapter includes the entire filming process from the beginning to the end. All the methods and techniques used in terms of filming to achieve the highest interactivity level possible is thoroughly discussed and demonstrated step by step in this chapter to help any novice quickly come up to speed and use this guide for future reference.
Chapter 5	In this chapter, the entire post production process is thoroughly detailed and all the phases are demonstrated step by step. The postproduction process includes the editing of the 360 video along with the sound design that took place and the HUD elements that were added on top of the video to help with Unity's interactive object implementation.
Chapter 6	This chapter includes the Unity development of the project, in which all the various steps into designing the final product are explained step by step. This chapter includes the required 360 video configurations that were used in unity along with how to manipulate 3D objects in a 360 environment in unity.
Chapter 7	This chapter includes the evaluation analysis that was conducted after giving the initial draft of the project to participants to test. The findings and improvements that were taken into consideration are discussed in this chapter.
Chapter 8	In this chapter, the overall conclusions of the study are included. In addition, it discusses future work that could be done based on a hypothesis that could lead to the creation of much beneficial and intuitive models.

Chapter 2

Literature Review

2. Literature Review

Research work related to the use of VR as a tool for education has been of great interest to many researchers and academic staff since the early 1990s. With the use of virtual reality spreading across the globe, computer scientists introduced various approaches to overcome interaction limitations within virtual environments and improved the usability of said VR devices to enable students interact easily within a virtual world. This was highly effective when using mobile devices as an interaction device. By using VR, it is easier for students to understand the material of their course while simultaneously expanding their way of thinking to include other processes. More specifically, they can relate their natural style with another style. For instance, they can see a film with text and relate the style they know to the foreign object that appears in the virtual world.

By conducting a literature search regarding the combination of learning style and computers leads to articles advocating computer usage and more specifically, Virtual Reality Device usage, as a positive method of matching learning styles to the students if used correctly. In other words, the articles suggest that the features of computers and VR devices are more likely to relate to a wide range of learning styles. However, there is no guarantee that how the computers and virtual devices are actually programmed will actually be beneficial to many different people.

For instance, even though computers can be designed to have overwhelming graphics and interesting interactivity, more often than not, the only programs that are actually used most of the time by students are those assigned to them to accomplish certain tasks in class which leads to boredom or not excitement at all. Therefore, generally speaking, a better implementation of VR in classes and in education could potentially benefit learning at a higher level than ever achieved before.

2.1 Virtual Reality

The definition "Virtual Reality" is used to describe virtual worlds in which an individual can explore from within, navigate through, interact with objects and other users. Additionally, users have the ability to exchange information via text, audio, still images, animation and video (Kluge and Riley, 2008). A digital 3D object that is used to represent the user, often called "avatar" imitates the user's presence as a means of navigating and interacting in the virtual world in a form of a human. This visual representation is chosen by the user who may choose if their virtual identity has any real-world resemblance (Miah and Jones, 2011).

The year in which VR has seen the most exponential growth was year 2016 which was seen as the year in which virtual reality could reach households through consumers' electronic devices like smartphones (Cellan-Jones 2016; Sag, 2016). This would indicate the implementation of VR technologies in educational environments by providing different learning styles and ease of teaching.

In his report, Mr. Christian Reimsbach-Kounatze (OECD, 2011) of the OECD Directorate for Science, Technology and Industry (STI), he suggested that the most promising application of VR technologies and 3D Virtual Worlds was the educational and training section. As of today, over 150 universities have joined the Second Life virtual world or other similar virtual worlds. This exponential adoption of virtual reality by universities and various other educational institutions is strongly related to numerous factors that highlight the advantages of using virtual reality (OECD, 2011).

Such factors are voice communication, examination of abstract and complex models through 3D Visualization, face-to-face and group interaction both between students and educators from all over the globe and projections of visual information in various parts of the virtual world.

Moreover, a virtual world is capable of delivering a highly realistic and yet interactive role-playing simulation for training situations, such as pilot-training simulators. Hence, reaping the benefits of virtual reality and its applications is what made this major type of technology the biggest point of interest in teaching, learning, research and collaboration. Virtual reality is gradually becoming a big part of an increasingly bigger online space for learning, edutainment, work and collaborations.

2.2 The educational potential of 3D Virtual Worlds

Nowadays, 3D Virtual Worlds have become a big trend as learning platforms for learning. They provide new learning delivery methods through which many training organizations can offer experiential or simulated learning and group activities in a shared space. A virtual world in which many individuals can freely interact with each other, is the perfect example of a multi-dimensional environment in which one can benefit from the use of tools in regards to informal learning, coaching, brainstorming sessions in real time collaboration and also recording and capturing the ongoing activities.

Thus, the existing 3D virtual worlds offer immersive learning delivery platforms that can be easily adapted to different training scenarios (3D Learning and Virtual Worlds):

- Simulated learning by modelling a process or interaction that closely resembles the real world in terms of fidelity and outcomes
- Reinforcement learning by offering a knowledge repository and tools associated with 3D objects
- Discovery learning by clicking on objects with associated information
- Traditional instructor-led learning through remote distances

- Collaborative workspaces, such as 3D classrooms and informal sites for discussion, encouraging school-style study and research

The significant advantages of 3D virtual environments over other traditional training approaches are increasingly beneficial and more efficient (Ross McKerlich 2007):

- The learner can learn by doing
- The experience can be much more engaging than a typical page-turning course
- Expensive video conferencing is not required for real-time online activity
- A User's learning experience can be designed to fit specific task needs with a flexibility and immediacy that is impossible in real life
- Exploration and discovery are encouraged
- Fantasy and imagination can be greatly unleashed
- Virtual 3D Spaces often allow full recording of any activity, interaction or exchange, enabling past events to be re-experienced, re-used or examined for further personal improvement.

On top of all the aforementioned advantages, the ability to inhabit any type of body and to customize an individual's own look gives many people the opportunity to express themselves as they truly feel and not as society forces them to be.

2.3 Related Work

Virtual Reality has a plethora of unique benefits when it is properly used in education. For starters, by implementing VR Technologies in educational institutions, modern education can be enhanced by offering a new tool for academic staff with the added benefit of reaching out to even more students[9]. The main goal of virtual reality in education is to motivate, stimulate and enhance students of specific events[10] while simultaneously allowing students to be part of an almost realistic hands-on learning

9 J. T. Bell and H. S. Fogler, "The application of virtual reality to chemical engineering education," VR, vol. 4, pp. 217–218, 2004.

10 M. Bricken, "Virtual reality learning environments: potentials and challenges," ACM SIGGRAPH Computer Graphics, vol. 25, no. 3, pp. 178–184, 1991.

experience[11]. In parallel with that, the experience in virtual reality worlds can help stimulate and allow students to practice procedures without the risk involved. This can be highly effective when applied in experiments that have proven to be difficult to be carried out in traditional instructional environments, teaching students regarding safety procedures and in medical education without involving the safety of a real patient[12].

Nonetheless, various concerns regarding the usefulness, practicality and acceptance arise with the emergence of any kind of new technology. Such is the case with virtual reality being incorporated in education which has been thoroughly discussed between academical institutions and researchers. Having that said, Bricken indicated three challenges by comparing Virtual Reality to pedagogical practice and theories: cost, usability and fear of technology[10]. An additional factor which plays a very important role in incorporating VR in education is the learner's attitude towards VR; this factor is correlated to the individual's perception of the technology of Virtual Reality and the willingness to incorporate it in their learning[12].

Regarding technical education, by using VR devices, a special feeling is provided that will further help persuade students to learn more on the specific subject[9]. For example, in chemical engineering, VR was used to develop virtual chemical plants in an attempt to learn about the technology and how effective virtual reality actually is. The main objective of said project was to re-create virtual lab accidents on purpose to show participants the consequences of not following the safety procedure[9].

Moreover, in the medical area, VR can be highly beneficial as it can be used in surgical educations to help surgeons determine their competence level regarding real life scenarios before operating a surgery on a real patient[13]. 3D Computer applications have been of very high interest for a very long time in medical education and more so in the human anatomy field. To further elaborate on this subject, a study was made to evaluate

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11 K.-C. Shim, J.-S. Park, H.-S. Kim, J.-H. Kim, Y.-C.Park, and H.-I. Ryu, "Application of virtual reality technology in biology education," Journal of Biological Education, vol. 37, no. 2, pp. 71–74, 2003.

12 H.-M. Huang, S.-S. Liaw, and C.-M. Lai, "Exploring learner acceptance of the use of virtual reality in medical education: a case study of desktop and projection based display systems," Interactive Learning Environments, no. ahead-of-print, pp. 1–17, 2013.

13 D. Ota, B. Loftin, T. Saito, R. Lea, and J. Keller, "Virtual reality in surgical education," Computers in Biology and Medicine, vol. 25, no. 2, pp. 127–137, 1995.

the use of 3D models to improve the learning process of human anatomy students, and it was shown that using such technology has a positive impact on the students[14].

Additionally, in regards to engineering education, labs are designed in such a way to improve the practical knowledge of the students and enhance their ability to solve problems on their own[15]. Virtual Reality can become a helping hand to the students that are trying to apply their theoretical knowledge into a real industrial problem, as they can maximize their potential to the best of their abilities by executing various tasks in virtual environments. For example, Autodesk Showcase software allows the students to create 3D models in CAD to later integrate them in a virtual environment. This ultimately reduces the cost of actually building the models and as an added benefit, it encourages the students to unleash their creativity and evaluate the value of their solutions. Next to that, by leveraging the benefits of VR in the engineering field, the risk of using hazardous materials in the teaching process will be reduced along with the impact on climate by eliminating the wasteful materials or any harmful mistakes made by the students[15]. As such, many educational institutions are making use of this technology in their research and educational purposes making it definitely more affordable and effective[15].

Last but not least, in the year of 1993, a virtual physics laboratory was modelled after traditional labs to imitate their form, and it consisted of a large room containing a table as a workspace to allow the students to experiment in Virtual Reality[16]. The main uses of the lab were to measure the period of pendulum for different lengths and magnitudes of gravity, to measure the average rate of energy loss of a ball dropped from different heights and to compare the trajectories of objects projected in two dimensions without atmospheric drag[16]. For the students to interact with the virtual environment, the lab used a helmet-mounted colored display and special gloves to register the gestures of the

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14 D. T. Nicholson, C. Chalk, W. R. J. Funnell, and S. J. Daniel, "Can virtual reality improve anatomy education? a randomised controlled study of a computer generated three-dimensional anatomical ear model," Medical education, vol. 40, no. 11, pp. 1081–1087, 2006.

15 A. Abulrub, A. N. Attridge, and M. A.Williams, "Virtual reality in engineering education: The future of creative learning," in Global Engineering Education Conference (EDUCON), 2011 IEEE. IEEE, 2011, pp. 751–757.

16 R. Bowen Loftin, M. Engleberg, and R. Benedetti, "Applying virtual reality in education: A prototypical virtual physics laboratory," in Virtual Reality, 1993. Proceedings., IEEE 1993 Symposium on Research Frontiers in. IEEE, 1993, pp. 67–74.

hand. The lab was developed using NASA's Solid System Modeller and rendering software[16].

2.4 Project to be developed

Based on the aforementioned findings and with education in mind, the project to be developed is a 360 Virtual Reality tutorial targeted to lyceum students that leverages all the benefits of interactivity within a virtual world and maximizes learning to the best of its ability through an interactive 360 video. Within this 360 video tutorial, students will be able to learn about the lathe machine operation procedure from the beginning till the end with the help of an instructor present within the video who will guide the student throughout the entire process. Students will be given the opportunity to interact with various objects within the virtual world and as the project's ultimate goal, they will learn how to use the lathe machine in an entertaining yet easy to use method. Details regarding the requirements and details of the project are described thoroughly in Chapter 3.

Chapter 3

Requirement Analysis

Requirement Analysis

Since the project was going to be developed based on the user requirements of the client of this project, Mr. Thomas Antoniou, Professor at the Technical School of Avgorou, the following requirements had to first be examined, evaluated and then defined. The project to be developed consists of an Interactive 360 Virtual Reality Tutorial regarding the teaching of the Lathe Machine operation, as part of one of the courses in the Technical School of Avgorou. The requirements defined by the client of this project are separated in 5 parts; Hardware, Filming, Editing, Unity and Android Deployment Requirements which will be thoroughly discussed in this chapter.

3.1 Requirement Extraction Methods

The methods that were used to properly understand the demands and needs of the project's client were:

1. Interviewing the client
2. Conducting further research based on the needs of the client's extracted by the interview

These methods are thoroughly discussed below:

1) **Interviewing the client:**

As previously mentioned the client of the project is Mr. Thomas Antoniou. To better understand the needs of Mr. Antoniou regarding the 360 tutorial which was based towards his students, a face-to-face interview was conducted. Based on Mr. Antoniou's replies given on this specific subject the following were noted:

According to Mr. Antoniou, the requested tutorial had to be recorded in the equirectangular 360 format in the lathe machine laboratory in which the class takes place. For the instructing purposes of the video, an actor would be used as an instructor in the 360 video to guide the viewer from the beginning of the lathe machine process till the end. This would require the separate audio recording of said actor, to offer a crystal clear audio experience through narration when viewing the tutorial. Additionally, the surrounding audio had to be recorded in the ambisonic 360 format to offer 360 audio as well. On top of that, for interactivity purposes, Mr. Antoniou made it clear that certain tools presented in the video played a crucial part in terms of operating a lathe machine and therefore their names and uses had to clearly be visible on-screen by the use of UIs (User Interfaces) and interaction elements for ease of use by the students. Moreover, Mr. Antoniou stated that the 360 video tutorial had to be accessible by the school's students and he insisted on making the tutorial as remotely accessible and cheap as possible since the possession of expensive VR equipment or funding by the school was not possible by the students. Therefore, Mr. Antoniou agreed upon the development of an Android app (delivered in the form of an APK file) which would be installed on the students' devices which would then enable students to view the 360 tutorial with a pair of cheap VR Goggles and headphones. The main selling-point of this 360 tutorial was that any kind of interaction within the virtual world would be performed by the use of gaze-based interactions by integrating a red reticle (a small dot) in the center of the screen to imitate the gaze of the user and thus no use of external controllers is required.

2) **<u>Research based on the needs of the client:</u>**

Since Mr. Antoniou's requirements and needs were based solely on the interactivity level of the 360 virtual world, various methods of increasing the interactivity level of the video were examined to further determine what would be needed to implement different types of interactivy. The results of the research regarding the interactivity of the developed project can be found at Annex C.

3.2 Functional Requirements

3.2.1 Functional Requirement 1 - Gaze-based interaction

3.2.1.1 Introduction

The most important feature of the VR app is to offer interaction between the user and the objects present in the virtual world with the user's gaze. This enables the user to trigger events by gazing at certain points within their field of view.

3.2.1.2 Inputs

The user will gaze to a certain position in the virtual world by the use of a red reticle at the center of their screen.

3.2.1.3 Processing

By gazing at a specific object, the system acknowledges the interaction between the user and the virtual object since both the object and the user's gaze (reticle) are two interactive items which trigger certain functions such as showing a title. While the user is gazing at an object, a circular loading bar appears around the red reticle which indicates the loading of the specific action to be triggered.

3.2.1.4 Outputs

While the user is gazing at an object, a loading circular bar will appear on screen which indicates the loading of the event to be triggered and as soon as the bar is loaded the corresponding event is executed. (e.g. title appears on top of object)

3.2.2 Functional Requirement 1 – Ambisonic Audio

3.2.2.1 Introduction

This feature describes the ambisonic audio (360 audio) when experiencing the virtual world which changes its direction accordingly based on where the user looks at within the virtual world.

3.2.2.2 Inputs

A new scene is loading or a UI component such as a text title or graphical element appears within the virtual world.

3.2.2.3 Processing

When a new scene loads or a UI component appears on the screen the system starts playing the sound that corresponds to either one of these two elements. When the user changes their direction by moving their heads when wearing a VR goggle, the system adaptively adjusts the audio gain accordingly between the left and right ear to mimic the distance of the sound of the objects surrounding the user.

3.2.2.4 Output

The user will experience 360 ambisonic audio as they move their heads around in the virtual world and they will be able to tell the difference in the direction of the incoming sounds based on the position of the originating objects.

3.2.3 Functional Requirement 3 – Skipping and Changing Scenes

3.2.3.1 Introduction

The user can change or skip to scenes by gazing at specific hotspots designed to trigger the loading of a new scene

3.2.3.2 Inputs

The user gazes at a specific hotspot (a 3D sphere) which changes scenes.

3.2.3.3 Processing

When the user gazes at a specific hotspot, based on the type of the hotspot a new scene will be loaded. Upon gazing on the hotspot, a circular loading bar surrounds the reticle of the user which indicates the time required for the effect to take place. When the circular bar is loaded the system triggers the loading of the new scene.

3.2.3.4 Output

The scene that corresponds to the hotspot the user gazed at loads up and starts playing.

3.2.4 Functional Requirement 4 – Menu Manager

3.2.4.1 Introduction

The user will be presented with a menu manager in the form of virtual gaze-buttons upon launching the VR application from which they can choose a specific part of the tutorial to play instead of starting from the beginning.

3.2.4.2 Inputs

The user will gaze at the part of the tutorial they want to play.

3.2.4.3 Processing

Upon gazing on the specific part the user wants to load, a linear loading bar will start loading to indicate the loading of the event to be triggered. When the loading bar is filled, the system loads the scene that corresponds to the specific button the user gazed at.

3.2.4.4 Output

The new scene that the user chose through the gaze-button is now loaded and starts playing.

3.2.5 Functional Requirements 5 – Interactive Objects

3.2.5.1 Introduction

The virtual world in the 360 tutorial will include various interactive objects which a user can interact with. Such objects are blue circular hotspots located in various spots within a scene which the user can gaze at and trigger events such as titles.

3.2.5.2 Inputs

The user will gaze at a blue hotspot or a 3D sphere

3.2.5.3 Processing

Upon gazing on either a blue hotspot or a 3D sphere, a circular loading bar will appear indicating the loading of the event. When the bar is filled, the system will recognize the event that corresponds to the object the user gazed at and trigger the corresponding event.

3.2.5.4 Output

If the user gazes at a blue hotspot, a title which describes the item they gazed at will appear on top of the corresponding item. If the user gazes at 3D sphere, a new scene that is tied to that 3D sphere will be loaded.

3.2.6 Functional Requirement 6 – Audio Feedback

3.2.6.1 Introduction

When the user gazes on an interactable object within the virtual world of the tutorial a specific audio that corresponds to that object plays to indicate that the object they're looking at can trigger an event.

3.2.6.2 Inputs

The user gazes at a specific object within the scene.

3.2.6.3 Processing

When the user gazes at a specific object within the scene, a specific audio clip that is tied to that object is loaded into the mobile device and played back to the user's headphones.

3.2.6.4 Output

The corresponding audio clip plays.

3.3 Performance Requirements

- Optimal use of the application requires a gaze latency of less than a second upon the time the user gazes at a 3D object within the virtual world.
- The audio has to be completely in sync with the video to provide stable audiovisual feedback of the tutorial
- All the videos included in the application have to be compressed and exported to the appropriate video format supported by the host device for smooth playback
- The application must not crash.

3.3.1 Minimum Device Hardware / Software Requirements

The platform of choice was Android since many students nowadays can afford and possess an Android phone compared to their iOS counterparts. Additionally, the development of an Android application does not require a paid developer subscription and therefore it was the preferred platform for development for the convenience it offers both and the user and developer end.

<u>Android Device Requirements:</u>

1. The host device must have a gyroscope. Older and budget versions of certain smartphones do not have gyroscopes.
2. Phone must have an accelerometer (almost guaranteed for any phone)

3. Android phones need to be on Android 5.0 (Lollipop) or higher.
4. A VR Compatible headset which depends on the size of the smartphone such as the Google Cardboard
5. Magnetometer Sensor (acts as a magnetic compass in the smartphone)
6. At least 2GB of RAM
7. At least 2 Physical Cores @ 2.4GHz
8. The device must support H.264 decoding at least 4096x2048 @ 25fps-30 Mbps
9. The device must have an embedded screen, and its resolution MUST be at least be Full HD (1080p) and STRONGLY RECOMMENDED to be Quad HD (1440p) or higher
10. Quality headphones/earphones for an immersive experience

3.4 Software System Attributes

3.4.1 Reliability

- The stability and smooth operation of the application relies heavily on the specifications of the host device. It is strongly recommended to use a device that meets the minimum device requirements as mentioned above.

- The clarity of the image displayed to the user relies on the VR Goggles that are used to display the VR tutorial as some VR Goggles are manufactured with cheap lens material which may hinder with the device’s screen quality.

- The audio quality of the VR tutorial relies on the use of quality headset by the user as ambisonic audio adaptively changes the audio gain of both the left and right ear. The use of a cheap pair of earphones may not provide the full immersive experience to the user.

3.4.2 Security

- No security measures are required for the operation of the application.

- No user data is stored on the device the app is running on.

3.4.3 Maintainability

The development of the application will be based on C# which is the main coding language in Unity. Thus, if any future requirements arise, the implementation of extra features can easily be achieved.

3.4.4 Portability

- **The app will be developed for the following mobile platforms:**
  a) Android

3.5 Hardware Requirements

For the development purposes of the 360 tutorial in Unity and the editing of the 8K 360 videos a strong workstation was needed to meet the high demands of the editing material. On top of that, since capturing 8K 360 video requires high amount of storage, additional external hard drives capable of reading and writing at high speeds were required. Additionally, an Android mobile device was also required to deploy the VR app onto and test its performance and how the final product looks.

Therefore, for the development and editing purposes of this project a Windows 10 based PC tower was used with the following specifications:

- **CPU**: Intel® Core™ i7-6800K Processor 15M Cache, up to 3.60 GHz
- **Graphics Card:** ROG Strix Geforce GTX 1070 OC Edition 8GB GDDR5
- **RAM:** 32GB
- **Internal Storage:** Samsung NVMe SSD 960 PRO – 500GB
- **Motherboard:** ASUS x99 – Deluxe II

For the storage and backup requirements of the footage filmed with the Insta360 Pro 2 an additional Western Digital 4TB external hard drive was used.

For the testing purposes regarding the Android development of the project the OnePlus 6[17] Android phone was used.

3.6 Filming Requirements

For the filming requirements of the projects various filmmaking equipment was needed to capture the highest quality 360 video possible along with the accompanying spatial audio. In the section below, the equipment used is thoroughly discussed.

Insta360 Pro 2:

For the 360 video requirements of the project we used the Insta360 Pro 2 at various angles to capture the entire process of the lathe machine operation.

Figure 1.3 - Insta360 Pro 2

Insta360 Far Sight Controller with iPhone X:

The Insta360 Pro 2 was controlled remotely with the Insta360 Far Sight Controller via an iPhone X to monitor the performance of the instructor when filming. The Insta360 Far Sight provides ground-to-ground range of up to 300 meters and ground-to-air range

17 OnePlus 6 – Phone Specifications - https://www.gsmarena.com/oneplus_6-9109.php

of up to 1000 meters, with 30 FPS preview through two WiFi Signal antennas as indicated in the picture to the right. The Insta360 Pro 2 was connected to a WiFI signal receiver through an ethernet cable. The WiFi Signal receiver communicates with the Far Sight Remote Controller through the Insta360 Pro App which provides full control of the camera to the user as indicated in Figures 1.4 – 1.5 below.

Figure 1.4 - Insta360 Pro 2 Far Sight Remote Controller

Figure 1.5 - Insta360 Pro 2 Far Sight WiFi Signal Receiver

This was a crucial part of the filming process since we could monitor and guide the instructor from afar if needed. Moreover, we could preview the film live through the Insta360 Pro app in VR/Goggle mode. Therefore, results were immediate and we could adjust the positioning both of our Insta360 Pro 2 as well as the instructor's to achieve the best performance and viewing pleasure possible.

Sony A7s Mark II:

Due to the lathe machine's delicate operation we were advised by the client to highlight specific and also important parts of the process through numerous UI windows to the viewer. These parts would also contribute to the whole "interactivity" of the 360 Tutorial as these crucial steps of the machine's operation will pop up automatically but also on-demand to the viewer when gazing to a specific hotspot within the video.

Such close up shots which were not possible to capture by the Insta360 Pro 2 were shot on the Sony A7s Mark II with a 35mm and a 50mm lens. We chose lenses depending on how tight or wide the available space was between the action that took place and the camera.

Figure 1.6 – Sony A7s Mark II

Figure 1.7 – 35mm Samyang E-Mount Lens

Figure 1.8 – Canon 50mm L Series Lens

Zoom H1N Recorder:

The Insta360 Pro 2 offers Spatial "Ambisonic" Audio through 4 built-in Mono microphones. To extend the capabilities of the ambisonic sound of the 360 video tutorial we used a dedicated Zoom H1N Audio Recorder on top of the Insta360 Pro 2 to enhance the audio experience of the viewer and make the entire experience feel as real as possible by providing sound from all possible directions.

Figure 1.9 – Zoom h1n Recorder on top of the Insta360 Pro 2

Figure 2.0 - Zoom H1N Recorder on top of the Insta360 Pro 2 next to the Lathe Machine

Zoom H2n Recorder:

After the initial shooting of the tutorial was done some noise crackling was apparent in the footage's audio due to the inability of the built-in microphones of the Insta360 Pro 2 to capture crystal clear audio. Therefore, it was recommended by the Insta360 Pro Support team to use the Zoom H2n recorder instead which supports true ambisonic audio to be used in conjunction with the Insta360 Pro 2. The H2n was attached on top of the camera shown in Figure 2.1:

Figure 2.1 – Placement of Zoom H2n Recorder on top of the Insta360 Pro 2

<u>Tripod:</u>

The Insta360 Pro 2 was attached to a Manfrotto Tripod at a fixed position within the filming area and it was moved accordingly to distinct spots through the filming process to cover all the steps of the operating procedure. The placement of the tripod is shown in Figure 2.2 below:

Figure 2.2 – Placement of Insta360 Pro 2 next to the lathe machine on top of the Manfrotto tripod

3.7 Editing Requirements

For the editing purposes of the tutorial, Adobe Premiere Pro 2019 v13.0.2 was the choice of editing software due to its vast capabilities and features in editing VR videos.

<u>As specified in Adobe's Premiere Pro release notes[18], Premiere Pro 2019 v13.0.2 includes:</u>

- Hardware Decoding Improvements for H.264 and HEVC
- Smoother HEVC playback on windows with new 10-bit hardware decoding
- Better VR integration and bug fixes regarding specific VR tools and effects
- Improved audio and sound effects manipulation within the timeline
- Graphical and text enhancement in conjunction with the Graphic Essentials panel
- Ability to export to Apple's ProRes

These improvements were of utmost importance since the video to be edited is in a 360 format and the best performance software and hardware wise is needed. Especially, since the videos that were shot were shot in 8K which would then need to be transcoded to 2K using proxies.

Additionally, the introduction and enhancement of the Graphic's Essentials tab is essential as various UI elements will be added into the final video to demonstrate the names of multiple tools within the introductory scene of the tutorial. The integration of such an easy way of adding graphical elements instead of round-tripping to After Effects to export and re-import such graphical elements makes editing 360 videos in Premiere Pro as fast and smooth as possible whilst ultimately reducing your editing workflow time.

Moreover, the audio manipulation improvements are a great addition to this version of Premiere Pro as it offers more flexibility in post production in terms of managing ambisonic audio in the sound panel within Premiere Pro.

3.8 Unity Requirements

For the development purposes of this application Unity 2018.3.6f1 was required since it offers a ton of integration with VR utilities and audio spatialization and fixes an important issue regarding the VideoPlayer component. Additionally, the fast

18 Feature Summary | Premiere Pro (April 2019 release) - https://helpx.adobe.com/cy_en/premiere-pro/using/whats-new/2019-1.html

deployment method Unity offers for building and testing an android app on an android device is unconventionally fast and helped speed up the debugging workflow immensely.

Chapter 4

Filming Procedure

4.1 Filming Setup

The first step of the filming process was choosing the best spot for the camera that would provide all the required information to the viewer around the area and also the least amount of distance that the instructor would need to walk to use the various machines needed for the entire procedure. In VR it is strongly advised to place the camera at a fixed spot at which the user can observe their surroundings without the need to "walk" within the video. Since the industrial room offered many lathe machines we chose the one closest to the tool station located at the bottom right of Figure 2.3 indicated below as the tool station offered the opportunity of interaction by the viewer.

Figure 2.3 - Industrial Room with numerous Lathe Machines

Figure 2.4 - Tool Station

Figure 2.5 - Insta360 Pro 2 Placement

Figure 2.6 - What the Insta360 Pro 2 captures

The next step was to place the most important tools of the procedure right in front of the viewer so that both the instructor and the viewer could have immediate contact with the tools while observing the lathe machine in process. The tools were placed on the green table as indicated in Figure 2.7 below:

Figure 2.7 - Tools that are needed to operate the lathe machine

The reason the tools were placed between the viewer and the instructor is due to the fact that during each step of the lathe machine procedure, the instructor would raise up each one of these tools right in front of the camera (right in front of the viewer's face) and he would explain what kind of tool it was and what use it has. These types of interactions between the subject within the video and the viewer in VR contributes to making the experience feel as real as possible while also providing small windows of time within the video (while the tool is raised in front of the viewer) to implement discrete UI elements on top of each tool to enhance the information of the viewer whilst the instructor explains each tool. The way these UI elements are added will be later explained in the post-production (Chapter 5) phase of this document.

Figure 2.8 - The instructor is holding a tool right in front of the camera as if the viewer is right

4.2 Guiding the Instructor to achieve the most interactivity possible:

As the entire tutorial was based on how to operate the lathe machine to an individual we had to adjust the instructor's performance to make it feel as if the viewer was there and had the entire process explained to them. Therefore, we advised the instructor to watch towards the camera at all times when he was explaining each step of the procedure and whenever he had to explain a tool that he used he would raise it up straight to the camera. By doing so, when the video is viewed later through VR goggles the user will feel as if they are there being told what to do.

We also made it very clear to the instructor that he had to be very precise and clear with his choice of words as well as explaining everything he did to the maximum detail possible to eliminate any knowledge gaps in-between different steps of the lathe machine operation. Moreover, every move, every step and every action the instructor took, had to be explained by him loudly and clearly in order to make sure that his voice was captured precisely by both the built in microphones and the Zoom H1N Recorder.

Additionally, the instructor was also told to hold each tool he explained for a long duration of time (around 15-20 seconds) while rotating the tool in front of the camera. This was crucial for our post-production phase as we need enough on screen time for every tool to make every UI element added readable and noticeable by the user that watches the VR video.

Prior to the filming day the instructor was told to rehearse the lines he would say on camera regarding the entire process in order to have a specific script to follow on the day of the shoot. Before filming each part we told the instructor to rehearse his speech right in front of us while previewing the video and audio live through the Insta360 monitoring app to check whether there were any missing parts in his speech that would lead to lack of information regarding the procedure of the lathe machine. As soon as each rehearsed part was validated and checked by another professor on the spot, we moved on to filming that specific part.

<u>For every scene we filmed we followed these steps:</u>

1. Start recording audio from the Zoom H1N Recorder
2. Start recording the 360 Video through the Insta360 Remote App
3. Indicate the name and sequence of the scene by speaking to the camera's microphone (this was done to help separate the scenes in post-production)
4. Clap twice as loud as possible to cause peaks in the sound waves of both the Insta360 Pro 2 microphone and the Zoom H1N Recorder's to help syncing the sound later in post-production
5. Move outside the room with the Insta360 Far Sight Controller
6. Signaling the instructor to start performing
7. Monitoring the performance through the Insta360 Far Sight Controller

4.3 The filming of each segment of the lathe machine tutorial

At first, the instructor was filmed from the initial angle shown in the picture above in which the instructor welcomed the viewer to the room and gave them directional and verbal cues to watch their surroundings. More specifically, the instructor was told to guide the viewer to see at their back (where the tool station was located) to force the viewer turn their head to the back when viewing the video through VR Goggles. Then, the instructor was told to explain a couple of important tools on the tool station in order to add UI elements on top of each segment of the tool station that the instructor would explain. These UI elements present information regarding the tools specified to the viewer, such as the name of the tool and its uses.

Figure 2.9 – Tool station separated in segments which will be explained by the instructor in the final video

Afterwards, in order to add interaction within the video the instructor would raise up each tool located on the green table (which consisted of the most important tools) right in front of the camera lens and he would explain the use of every tool in the exact same way as he did at the tool station.

Figure 3.0 – Instructor explaining various tools to the viewer

The second part of the shoot required the instructor to walk up to the sharpening machine which was located 5 meters apart from the Lathe Machine. Thus, the instructor told the viewer that the sharpening of the tool would follow through and he walked up to the sharpening machine from the initial position of the camera (Lathe Machine Position). Then, we placed the camera near the sharpening machine and we told the instructor to do the exact same thing starting from the lathe machine again but this time the camera would face the front side of the actor.

The instructor walked from the initial position (Figure 3.2) towards the sharpening machine (Figure 3.1)

Figure 3.2 - Position of camera at the lathe machine

When the instructor reached the sharpening machine he explained to the viewer (directly to the camera) what would follow and proceeded to take the protective glasses off the wall. Several parts of this process were filmed with the Sony A7s II so that specific actions would later be popped up as UI windows in the final 360 video as shown in Figures 3.3-3.4.

Figure 3.3 - Protective glasses

Figure 3.4 - Sharpening the tool

Figure 3.5 – What the Insta360 Pro 2 captures at the Sharpening Machine and how the secondary video from the Sony a7s II appears

As soon as the sharpening of the tool was done, the instructor had to move to the lathe machine to proceed with the operation of the lathe machine and the adjustment of the rotations of the spinner wheel. For this reason, we placed the camera next to the rotation controller of the spinner wheel so that the viewer could get a better view of the controller as the instructor adjusted the levers. Thus, as the instructor would have to walk up to the lathe machine again, we filmed him walking from the sharpening machine towards the lathe machine in the same fashion as before to connect the two scenes together.

Figure 3.6- Position of Camera at Rotation Controller

Figure 3.7 - Rotation Controller

Figure 3.8 - What the Insta360 Pro 2 captures at the Rotation Controller

At this stage of the filming process (last step of lathe machine operation) the instructor started operating the lathe machine to shape a metal object. Since the procedure required specific actions to be visible both from the right and left hand side of the lathe machine, we recorded the entire procedure from the Rotation Controller (Figure 4.0) and from within the inside of the lathe machine (Figure 3.9 & Figure 4.1).

Figure 3.9 - Position of Camera inside Lathe Machine

Figure 4.0 - Position of Camera at Rotation

Figure 4.1 - View of Camera inside Lathe Machine

This was due to the fact that we could not be sure which side would work best in post-production when combined with the added UI elements; therefore for safety matters both sides were recorded. The issue we stumbled upon during filming the procedure was, that, while the instructor adjusted the various levers and the lathe machine's parts, he explained to the viewer every action he made. We had to figure out a way that would give us an opening to cut in-between scenes if needed, to transition from one side to the other. Thus, we told the instructor to not speak for 10 seconds after giving the explanation of the rotation wheel while continuing his actions on lathe machine. This was done from both sides of lathe machine in which the instructor gave the exact same performance. The 10 second window is enough for the two scenes to transition from one side to the other without losing the continuity of the film and without missing out lines of the instructor's script since he was quiet for 10 seconds.

At last, when the instructor finished operating the lathe machine, he showed on camera the resulted product of the lathe machine. To end the interaction between the viewer and himself, the instructor declared in front of the camera that this was the end of the Lathe Machine operation and that signaled the end of the 360 tutorial as well.

4.4 Challenges – Issues Faced during the filming process

The issues that were faced regarding the filming process can be found in Appendix D. The solutions that were used to face those issues are listed here.

1.Sun flares hitting the camera's lens:

Therefore, we came up with the idea of covering the window with a black bin bag with white tape to block the light of the sun as indicated in the Figures 4.2 - 4.4 below:

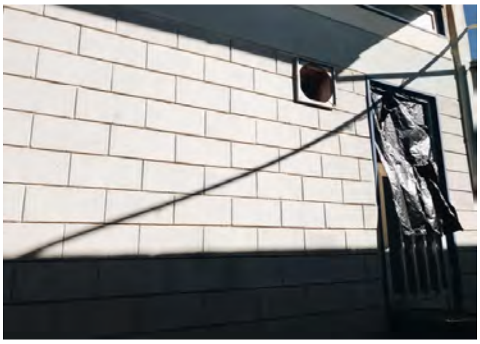

Figure 4.2 - Black Bin Bag attached to the window

Figure 4.3 – Black Bin Bag attached to the window with tape – closer inspection

Figure 4.4 – Black Bin Bag attached to the window with tape

<u>Final Result:</u>

Thus, the light is blocked from the top left window and the final stitched image is seamless.

Figure 4.5 – Filming area after attaching the black bin bag to the window

<u>2. Lens angle adjustment when tools were raised</u>

To avoid any type of blending artifacts we advised the instructor to hold up the tool directly right it in front of one of the camera's 6 lenses in a straight line in order to place the object between that specific lens' field of view without causing any distortion. Even though the Insta360 Pro Stitcher software correctly stitches all the images with barely any artifacts we did not want to risk any type of blending issue since we could use the solution described above.

Figure 4.6 demonstrates an example of 3 lenses with the middle being the current one and their field of views:

Figure 4.6 - Top View of the Insta360 Pro 2 and the field of view of each lens

3. Moving between different spots – Scene Transitions:

To solve this issue the following solution was used:

We filmed the instructor walking towards the sharpening machine from the camera's initial position as indicated above (therefore showing the instructor's back) and then we filmed the instructor walking towards the camera from the new position of the camera (next to the sharpening machine as indicated in the picture above) in the exact same way he did in the previous scene. The combination of similar movement would preserve the film's continuity to the viewer as the two scenes transitioned from one another[1] . However, since we are working in VR, based on previous research it is strongly advised to fade out from one scene and fade in to another scene to avoid any symptoms of nausea by the viewer[2]. Therefore, in the post production phase a fade in/fade out transition will be added by using Premiere Pro's VR plugins between scene transitions.

4. Instructor forgetting his lines:

During the filming process sometimes the instructor would forget his lines or misinterpret words when the procedure of the lathe machine was explained. Since in 360 video you have to shoot everything in one go, cutting actor lines in post-production was not an option. Thus, we had to get everything right from the start till the end without any mistakes. As the instructor would need a couple of attempts to get all the lines right we had to re-film each scene 3 times. The instructor would also be corrected by the professor who monitored the entire filming process as he knew the subject in hand. Additionally, since some parts that the instructor said wouldn't add up on the filming day, the professor modified the script of the instructor to match the placement of the tools in the scene (since it required guidance by the instructor to the viewer) as well as the lathe machine operation steps.

1 . HUMBOLDT UNIVERSITÄT ZU BERLIN Film-Analysis: A Review of American Film History and Seminal Texts of Film Theory - How continuity editing is achieved through match cuts / Section 2.1 Screen Direction, Framing and Action Match

2. Movement in VR (Unity) - https://unity3d.com/learn/tutorials/topics/virtual-reality/movement-vr

5. Audio Crackling from built-in microphones:

The solution regarding this issue is listed below:

Thus, the entire lathe machine process had to be filmed again from the start with the use of a Zoom H2n recorder. The Zoom H2n recorder was bought from a local store that specializes in sound equipment called TechnoSound. The process that was followed to film the entire lathe machine tutorial with the Zoom H2n is explained in the chapter "Filming Part 2: Re-filming the Lathe Machine 360 Tutorial with the Zoom H2n".

To ensure that the audio would be recorded correctly in the ambisonic format a forum thread regarding the best configuration setup was posted in the Insta360 Support Forum[19] as shown in the Insta360 Support forum reply figure attached at Annex A.

4.5 Filming Part 2: Re-filming the Lathe Machine 360 Tutorial with the Zoom H2n

Prior to beginning the filming process for the second time a research regarding the capabilities of the Zoom H2n and spatial audio was conducted to ensure the best configuration during the filming process. More specifically, through the research, it was discovered that it is possible to use a lavalier microphone attached on the speaker of the video clip and convert the mono channel sound of the lavalier microphone into spatial audio[20] to offer a clearer narrative when viewing the 360 video along with the spatial audio coming from the Zoom H2n. This feature was a must for the purpose of this project as it had to do with an instructional video where the user would be given directions on how to use a certain machine.

The entire lathe machine tutorial was then filmed the exact same way as it was filmed the first time with the following key differences:

19 Best setup and configuration for Insta360 Pro 2 and Zoom H2n? - https://forum.insta360.com/topic/712/best-setup-and-configuration-for-insta360-pro-2-and-zoom-h2n

20 Converting Mono Audio from Lavalier Mic to Spatial - https://www.youtube.com/watch?v=pLk53pXNrHg&list=PLAyCpxLR2TxvmPShqIURryF44gDIF1zTY&index=3

1) A lavalier microphone was attached to the speaker of the video at the side of his coat as shown in Figures 4.7 – 4.9. Additionally, the lavalier microphone was then connected to the Zoom H1n to save the recorded sound onto the Zoom H1's MiniSD card. To prevent the Zoom H1n from showing up on camera it was hidden in the speaker's shirt's side pocket at the front.

Figure 4.7 – Lavalier Microphone attached to the speaker's coat

Figure 4.8 – Lavalier Microphone connected to the Zoom H1n

Figure 4.9 – Zoom H1n hidden in the speaker's front side pocket under the coat

2) The Zoom H2n sound recorder was attached on top of the Insta360 Pro 2 as specified by the Insta360 Pro 2's manual regarding the specific direction[21] the sound recorder should be facing at. The configuration of the Zoom H2n is indicated in the Figures 4.8-4.9 below:

Figure 5.0 - Zoom H2n attached on top of the Insta360 Pro 2

Figure 5.1 - Zoom H2n attached on top of the Insta360 Pro 2 with the Zoom H2n's interface

21 Insta360 Pro 2 Manual – 3.1.4 [Advanced] Recording Equipment - http://onlinemanual.insta360.com/pro2/en-us/video/prepare/4

It is important to note that the Zoom H2n's direction when positioned on top of the camera is very specific as that positions the Zoom H2n's microphones in such a way to correspond to the same direction the sound is recorded by the Insta360 Pro 2. The Zoom H2n is connected through a USB cable to the Insta360 Pro 2 to embed the audio directly to the clips.

Additionally, the Zoom H2n has to be setup properly for 360 spatial audio with the following settings:

- Select 4ch mode at the scrolling wheel located on top of the Zoom h2n
- Adjust audio settings accordingly:

1.MENU->REC->REC FORMAT->WAV48kHz/24bit;

2.MENU->REC->Spatial Audio->ON, to open spatial audio

4.6 Filming Part 3: Re-filming the introductory scene and extra close up scenes

After editing the footage that was filmed from the second time the tutorial was shot, the first scene of the video tutorial appeared to be way too close to the toolbox located within the lathe machine room. This led to symptoms of nausea and dizziness to the participants who tested the first draft of the film. Therefore, the intro scene in which the instructor greets the viewer to the room had to be re-shot at a further distance to allocate enough room between the viewer and the toolbox. The recommended distance between the main subject of your video and your 360 camera should be at least 1 – 1.5 meters to make sure the viewer does not get dizzy by objects that are close to their field of view when wearing the VR Goggles[22] .

Prior to shooting for the 3rd time the Insta360 Pro 2 was setup on the tripod with the Zoom H2n in a different way compared to previous shoots. This time the tripod's legs were placed in between the blind spots of the Insta360 Pro 2 where the stitching areas of the lenses are, thus instantly removing the tripod from the shots. This helps a ton later in post production as there is no need of removing the tripod by creating a mask for every scene. However, there were some scenes which needed the tripod to be positioned in such a way that wouldn't allow us to hide the legs in between the blind spots. An

22 360 Video Production Tactics: What We've Learned So Far, Ch. "Framing The Shot" - https://wistia.com/learn/production/360-video-shooting-techniques

example of how the tripod was setup to hide the legs in preview mode is shown in Figures 5.2-5.3 below:

Figure 5.2 - Insta360 Pro 2 setup on a tripod to hide legs between blind spots

Figure 5.3 - Preview of what Insta360 Pro 2 captures when tripod legs are hidden in between blind spots

During the filming process of the intro scene the instructor was told to speak clearer and slower when explaining the various categories of tools included in the toolbox to allow more screen time for the on-screen UI elements that would later be added in post production on top of the tools included in the toolbox category. Another important part that was pointed out to the instructor was to remove the long gaps where he would think what to say and have a more streamlined version of his script ready to make the flow of the film smoother.

Moving on to filming the first scene of the tutorial again, the Insta360 Pro 2 was setup 1.5 meters away from the toolbox to provide enough space for the viewer to familiarize with the environment. Additionally, this would provide more flexibility for stitching errors in MistikaVR, as previous attempts to fix the warping caused by Insta360 Pro Stitcher in MistikaVR, would not completely remove the warping that was caused by objects that move between the stitching areas of 2 lenses. On top of that, the additional distance would further help in motion tracking the objects that the instructor presents to the viewer in the tutorial with Mocha Pro as that would give more room for Mocha Pro's algorithm to track the moving object properly without it moving out of screen. The setup of the Insta360 Pro 2 and its preview are shown in Figures 5.4-5.5 below:

Figure 5.4 - Placement of Insta360 Pro 2 in front of toolbox

Figure 5.5 - What the Insta360 Pro 2 captures

Moreover, after implementing additional UI elements on the first draft of the film within Premiere Pro such as text boxes on top of tools and popup windows which show certain parts of the lathe machine process in close up angles, participants recommended adding the option to switch to alternative angles of certain scenes to observe what the instructor does at a closer view. These alternative angles would be presented to the viewer as small 360 bubbles at certain spots on top of the film which would be triggered by gazing at them for a certain amount of time. Once triggered, the scene would switch to the desired angle and the film would follow on from there and once finished the initial scene would return back. By implementing this utility in Unity, the film becomes even more interactive since the user can alter the story of the film on their own instead of it following a plain sequence of scenes. Therefore, to achieve this, the sharpening process was filmed again in 3 different angles to provide different perspectives to the viewer. The angles are shown in Figures 5.6-5.8 below:

Figure 5.6 - Sharpening Process – Angle 1 (Left View)

Figure 5.7 - Sharpening Process – Angle 2 (Right View)

Figure 5.8 - Sharpening Process – Angle 3
Bottom / Close Up View

Chapter 5

Post Production – Editing & Sound Effects

5.1 Organizing and importing the footage:

The Insta360 Pro 2 includes 6 Mini SD Card slots as well as a regular SD Card slot. The Mini SD cards store the original footage of the 6 origin lens separately. The SD Card stores the required preview files of the recorded footage and photos to provide easy preview playback when reviewing your scenes through the Insta360 Pro App.

To import the footage the supplied USB Hub and Card Readers were used. In each card reader one of the 6 labelled Mini SD Cards was inserted as well as the main SD Card as shown in Figure 5.9 below:

Figure 5.9 - The provided USB Hub and SD Card readers

5.2 Importing Footage through the Insta360 Stitcher:

To import the footage from the Insta360 Pro 2 through the Stitcher you have to choose one of the two methods the software offers. The first method is importing the footage through the official USB Card Readers and the second method is importing the footage directly through the camera. The first method was used and the footage was loaded into the software by selecting one of the 7 cards in the software's file dialog box. The software automatically recognizes the 6 remaining cards and loads the footage into the project panel as shown in Figure 6.0 Below.

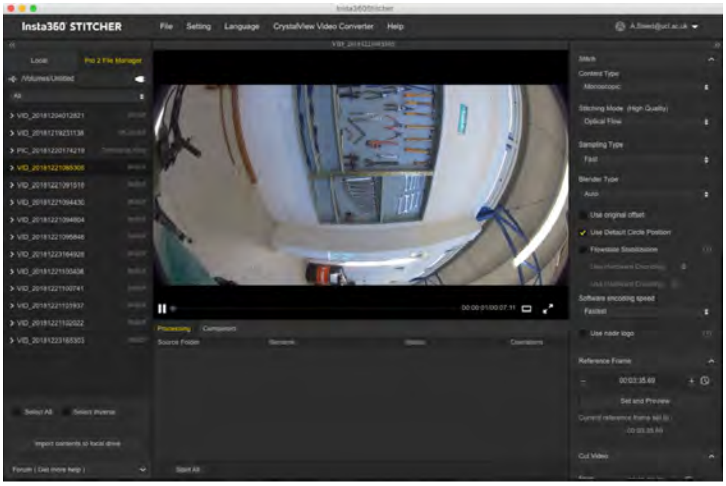

Figure 6.0 – Insta360 Stitcher where clips have been imported as indicated at the left

At the left there is a list that consists of all the footage that was shot on the camera and at the right, there is a configuration panel where you can adjust the export settings of the final stitched video.

<u>As the original files are large in size we had to make the following adjustments to the export settings:</u>

<u>Resolution</u>: 8K
<u>Output Format</u>: MOV(ProRes/H.264/H.265)
<u>Codec Type</u>: H264 Codec
<u>Bitrate</u>: 288 Mbps
<u>Frame Rate</u>: 59.94 (Original Frame Rate from Camera)
<u>Audio Type</u>: Spatial

The Apple ProRes codec was tested as well which resulted in an ultra-smooth playback of the resulting 8K stitched video. However, as the Apple ProRes codec exports an uncompressed file, the size of the resulting video was 400GB for an 8 minute 360 video. Thus, the H264 codec was preferred.

Every clip was labelled after its respective scene during the filming process.

Lastly, when every setting was adjusted for all the footage, everything was sent as a Batch List to be rendered.

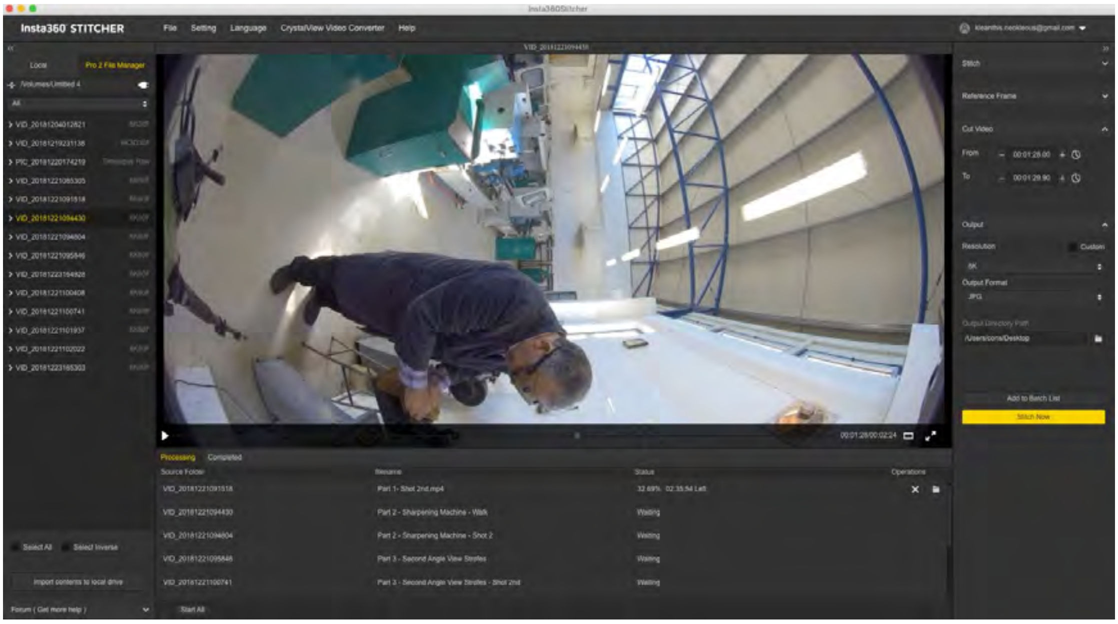

Figure 6.1 – Insta360 Stitcher where the footage has been stitched and exported

5.3 Re-stitching certain scenes with MistikaVR to fix stitching errors:

When the scenes were imported to Premiere Pro and played back, most of them showed signs of warping at the spots where the Insta360 Pro 2's lenses would be stitched together. As a result, if an object within a scene moved from one area of a lens to that of an adjacent lens, the object would warp as a result of the stitching done in between the two lenses by Insta360 Stitcher. This is mainly caused due to Insta360 Stitcher's New Optical Flow stitching algorithm which does not handle stitching very well. Therefore, MistikaVR is recommended for more advanced stitching since you can adjust the specific points of stitching per lens individually and also apply feathering[23].

With every purchase of the Insta360 Pro 2 a code for a 3-month trial of MistikaVR is also included. The 3 month activation code was used to download and activate MistikaVR.

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23 PERFECTLY stitch Insta360 Pro 2 with Mistika VR in 360°- https://www.youtube.com/watch?v=Ku7jPzpOEv0

Upon opening MistikaVR the introductory scene was imported. To import any kind of Insta360 Pro 2 footage into MistikaVR, all 6 clips originated from the 6 lenses of the camera have to be imported in reverse order. Thus, the clips were imported starting from origin6 down to origin1. Additionally, the grid mode was enabled to show each one of the 6 individual clips on their own as shown in Figure 6.2:

Figure 6.2 – Importing clips in reverse order in MistikaVR with Grid Mode enabled

MistikaVR needs to know how Insta360 Pro 2 footage is stitched and thus a stitching profile had to be generated through Insta360 Pro Stitcher and then imported to MistikaVR so that all 6 clips were stitched properly. To achieve that, the introductory scene was also imported into Insta360 Pro Stitcher and then a reference frame was set in the middle of the video. Zenith optimization was enabled to improve possible stitching errors and then the changes were applied and saved. By doing so, a stitching profile is generated by Insta360 Pro Stitcher at the insta360 folder located in the Documents folder of the computer which was used. The stitching profile is always located at the following path:

C:\Users\<username>\Documents\insta360\insta360stitcher\log

The stitching profile was then imported into MistikaVR and all 6 clips were stitched perfectly with each other. Upon stitching all clips together a feather amount of 45 was applied to remove the hard lines which appeared after the stitching in between the scenes and optical flow stitching was disabled. Then, the video was played back to inspect where the warping was caused. Usually, the warping is caused when an object moves from one lens to an adjacent lens. This was easy indicate as the moving hand of the instructor clearly caused a significant amount of warping. To see how much area of the frame each lens covers stitching preview was enabled. Every lens, has a small circle at their center and every center is named after its corresponding lens ranging from C1 to C6. To fix the warping of the hand which moves as the instructor presents the tools an edge point was added to C5. By adding an edge point you are able to enlarge the lens' area of coverage and thus "pushing" the stitching line further away. To achieve the best stitching possible the video was played frame by frame to locate the exact moment the warping was caused as the hand moved. At that specific time in the video the extra edge point P5 was moved to the right to make more space for the hand to move. This fixed the issue immediately and the video was played forward to ensure that all warping was gone. Similar warping issues were fixed in the same way by adding edge points to other lenses at specific parts of the video. The final adjustments of the edge points is shown in Figure 6.3:

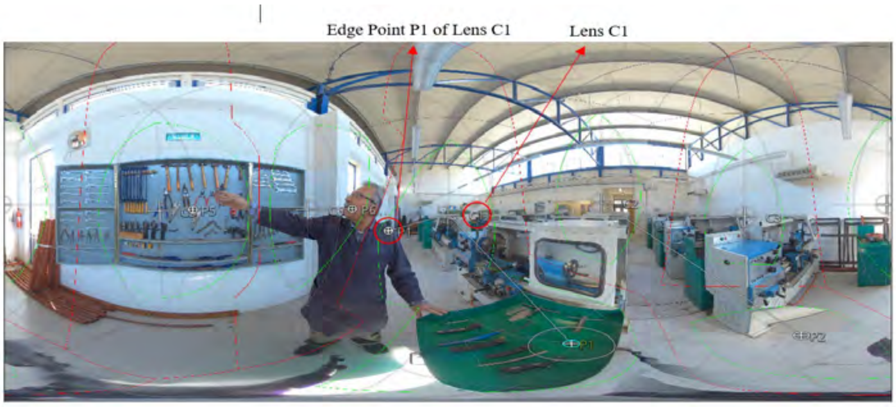

Figure 6.3 – MistikaVR in Stitching Mode presenting the Stitching Points

The video was also previewed in VR mode to check the final result as shown in Figure 6.4:

Figure 6.4 – MistikaVR - VR mode

Finally, the clip was then exported to Apple ProRes HQ which is an intermediate editing codec for smooth editing in Premiere Pro.

5.4 Video Editing Codecs

After importing all the clips into Premiere Pro 2018 v12.02 we noticed that the playback of the clips on Premiere Pro's timeline was considerably slow and it was almost impossible to preview the clips. This is due to how the H.264 codec works since it is a Long GOP codec. In the text that follows we will introduce some basic terms regarding codecs and finally breaking down as to why H.264 was not suitable for editing the 360 video files and what solution was used instead.

In basic terms a codec is used to create smaller video files while retaining the video's quality to the maximum level possible. There is a huge variety of codecs available and they all cater to different needs, whether those be editing, online streaming or previewing. A codec creates smaller video files through the compression of the original source file by applying specific techniques to remove information from the video that is not visible to the human eye. The removal of information is done by processing frames which are similar to each other and thus similar block of pixels are used through-out the adjacent frames to reproduce every sequential frame. This saves a significant amount of storage space. However, every codec is different and it all comes down to what we need the video for.

Some of the most popular techniques codecs use to compress videos are listed below[24]:

1) Chroma subsampling
2) Macro-Blocking
3) Temporal Compression

24 How to Choose The Right Codec for Every Project, David Kong, https://blog.frame.io/2017/02/15/choose-the-right-codec/#codec-edit

Breakdown of techniques:

Chroma Subsampling: As mentioned earlier since the human eye cannot distinguish color difference accurately between adjacent pixels it is easier for codecs to get away with removing color information. Therefore, chrome subsampling is the technique in which the codec removes color data from the original source file to create another video file which requires less storage space (since less information is needed to store the file).

The amount of color removal or chroma subsampling is separated in 3 categories, each indicating the level of removal:

4:2:0 **–** High amount of color removal / chroma subsampling
4:2:2 **–** Partial amount of color removal / chroma subsampling
4:4:4 **–** No color removal / chroma subsampling

Macro-Blocking: Macro-blocking is the method in which similar blocks of pixels of the same color are found within the frame and then converted into one color closest to the colors of the pixels analyzed. Since the amount of pixels for every color is different every block that is created is different in size than any other block of another color. As one color is used to represent for example, 100 pixels of different shades of red, less storage space is needed to store that information.
Temporal Compression: This is the process in which, one particular frame is calculated, by analyzing the difference between the proceeding and preceding frames of the current frame and then calculating the difference between them in order to form the specified frame. This is highly inefficient for video editing software as scrubbing around the timeline requires a high amount of CPU/GPU power as for every frame selected a calculation has to be performed to produce the frame.

5.4.1 Lossless Codecs:

There are codecs that instead of compressing the video’s file size to a smaller file size they instead, retain the original video file’s data and quality. The amount of data retained by the codec is not explicitly visible to the human eye but it is of critical importance when working with Virtual Effects (VFX) where processing is done on the pixel level. A simple way to understand whether a codec is lossless is to observe how similar the exported video file or image is to the original file. If both results are close or very similar to each other then, that means the codec used was lossless. A codec that removes information and does not retain the original quality of the source file is called a lossy codec. The "lossyness" of a codec is determined by the technique used to compress the video file in conjunction with the codec's bitrate.

To understand the difference between a lossless and lossy codec we will examine the pictures as indicated below in Figures 6.5 – 7.2 *(Courtesy of David Kong in the article "How to Choose The Right Codec for Every Project", www.blog.frame.io)*:

This is an image that was captured in raw, which means the picture was saved in its original state before being processed by the camera's processor and thus "baking in" information.

Figure 6.5 – Raw Image

This is the exact same image as in Figure 6.5 but compressed with the H.264 codec (with the recommended settings from YouTube[25])

Figure 6.6 – H.264 Compressed File

As mentioned above, once again this is the exact image but compressed with the DNxHD codec.

Figure 6.7 – DNxHD Compressed File

25 Recommended upload encoding Settings (YouTube: https://support.google.com/youtube/answer/1722171?hl=en)

At first glance all 3 files in Figures 6.5 – 6.7 look visually exactly the same. However, the H.264 compressed file indicated in Figure 5.1 consists of a significant smaller file size compared to the file size of the DNxHD compressed file indicated in Figure 6.7. Hence, making the H.264 file a more convenient option for uploading and streaming video files online since it requires less storage space.

However, if you want to manipulate the two files in any type of way (e.g. Color Correction) you will notice a significant difference into how the two files correspond to changes made to attributes such as exposure or contrast. An example is shown in Figures 6.8 – 6.9 below:

This is the DNxHD file with its exposure setting increased:

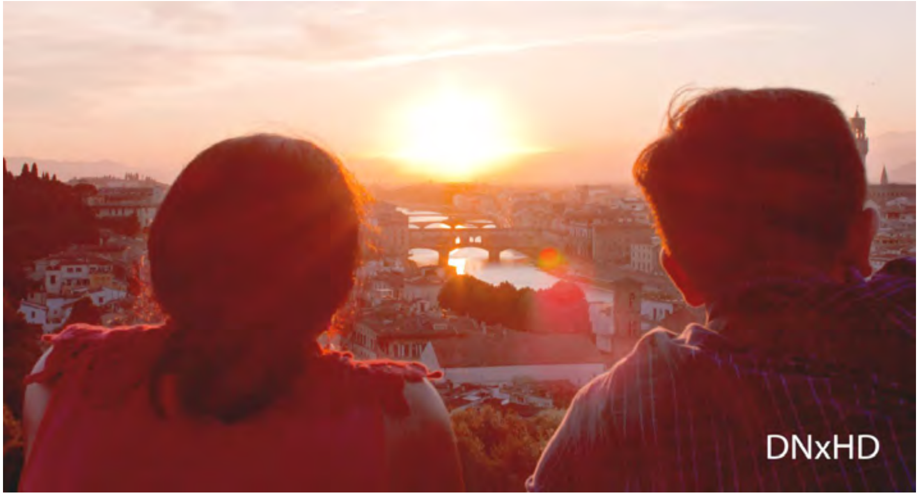

Figure 6.8 – DNxHD File – Exposure Increased

This is the H.264 file with its exposure setting increased:

Figure 6.9 – H.264 File – Exposure Increased

By observing Figures 6.8 and 6.9 we can see that the H.264 compressed file shows extreme artifacts at several spots of the image by having the exposure increased whereas the DNxHD file preserves the quality of the image. We can also see the various pixel blocks that were the result of the macro-blocking used by the H.264 codec in Figure 6.9. If you take a closer look, you will notice that the woman's hair and shirt look extremely bad and populated by artefacts caused by the codec's inability to correspond to changes to the image's exposure.

A closer look to the image in Figures 7.0 – 7.3 shows us how bad the H.264 codec handles the changes to the pictures compared to DNxHD:

Figure 7.0 – DNxHD File Zoomed In

Figure 7.1 – H.264 File Zoomed In

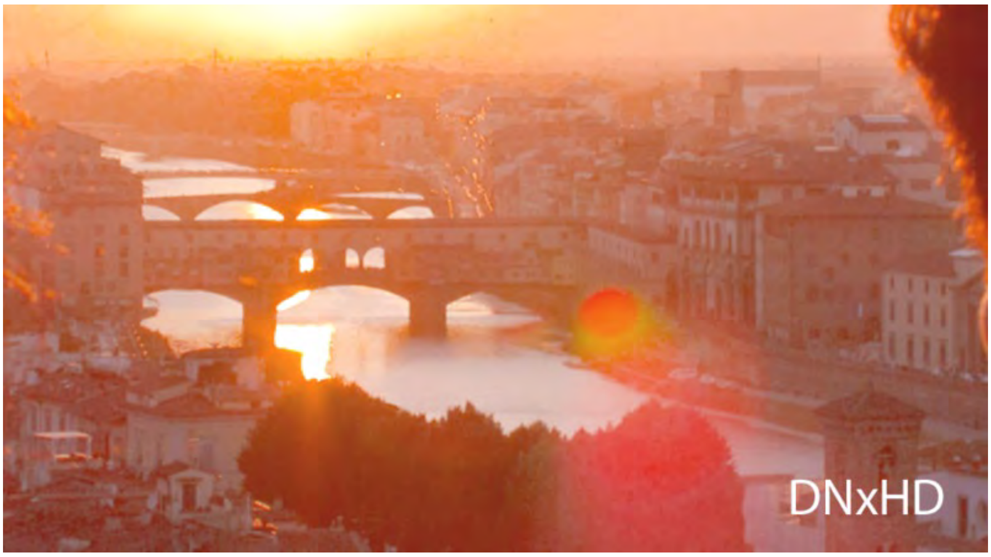

Figure 7.2 – DNxHD File

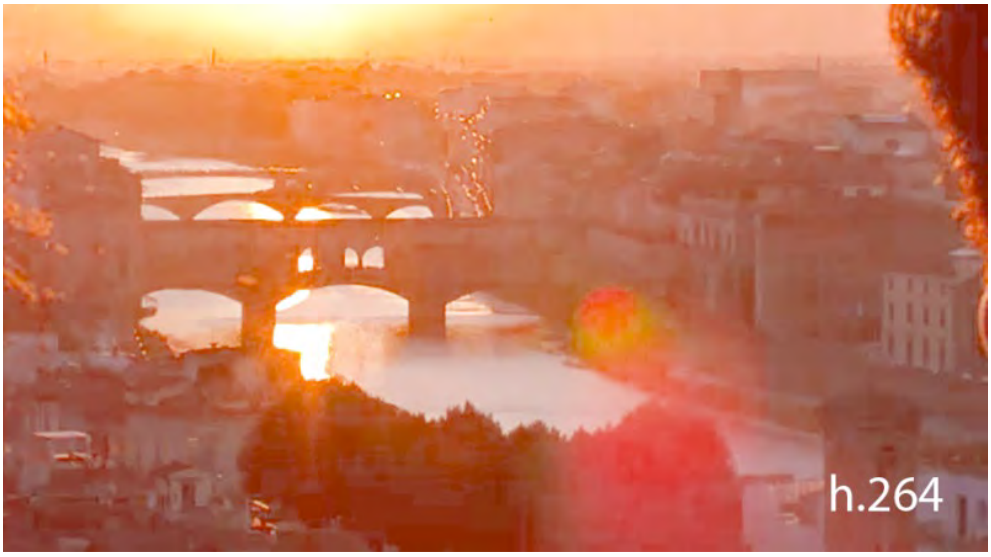

Figure 7.3 – H.264 File

Thus, as seen in Figures 7.0 – 7.3 a highly compressed file does not allow for huge changes in color and contrast without breaking down. Therefore, the best option is to shoot with the highest quality codec your camera provides to capture as much information as possible, regardless of whether you will use it or not. This is a crucial step in the filming and post-production process as you will not know how you will process your footage and in what way later on.

Most files that come out of camera are not readily suitable for editing as that capture codecs are not optimized for editing. This is why the footage was shot in 8K 60 FPS during the filming process. As specified, in Insta360 Pro 2's specification page[26] the camera originally shoots in the H.264 codec but offers a variety of codecs during the stitching process. Since the H.264 is a highly compressed codec as explained above, by shooting at the highest quality possible in-camera (8K) we made sure to preserve as much information as possible to retain the video's quality when the 6 lens videos would be stitched and exported to a different codec that would be suitable for editing the 360 video.

When choosing a codec that will suit your editing needs you need to consider two things, the compression type and the bit rate of your codec.

5.4.2 How Compression Type affects the performance of your editing system:

Most consumer cameras in the lower to mid range category use capture codecs that make use of Temporal Compression which is also known as long GOP(Group Of Pictures) compression. Temporal Compression means we are compressing frames over time which also refers to Inter-Frame compression (moving in-between frames). For example, consider that we have one frame (Frame A – Figure 7.4) of a scene where two people are located towards the right of the frame and in the next frame (Frame B – Figure 7.5) (which would be the next 1/30th of a second) the two individual move a tiny bit forward. The entire background of the frame is exactly the same between Frame A and Frame B. Therefore, the only difference between Frame A and Frame B is the individuals' position. In this instance, what the Long GOP compression does is, it stores the entire information of Frame A and then it calculates the difference between Frame A and Frame B and only stores the pixels that are different between the two frames. The difference may only be the center of the frame (where the man is positioned). Therefore, if Frame A needs 2MB to be stored then, based on the difference calculation, Frame B may only need 0.2MB to be stored. This is done sequentially for every frame that follows after Frame A and B and thus gradually reducing the storage space needed to store each following frame and the video in its entirety which makes the codec very efficient[27].

26 Insta360 Pro 2 – Specs Page, https://www.insta360.com/product/insta360-pro2/

27 How Codecs Work – Tutorial – 19:00 Minute Mark - https://vimeo.com/104554788#t=1135

Figure 7.4 – Frame A -Two People Walking

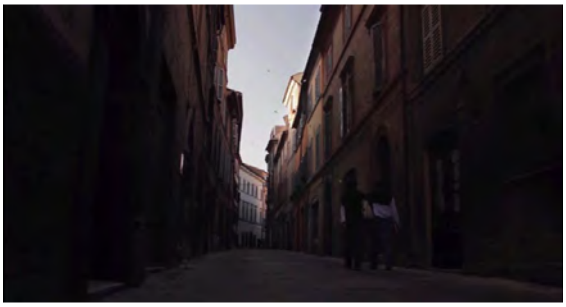

Figure 7.5 – Frame B - Two People Walking – Position Further Away

<u>Another example which shows the difference in pixels between the first and next frame[28]:</u>

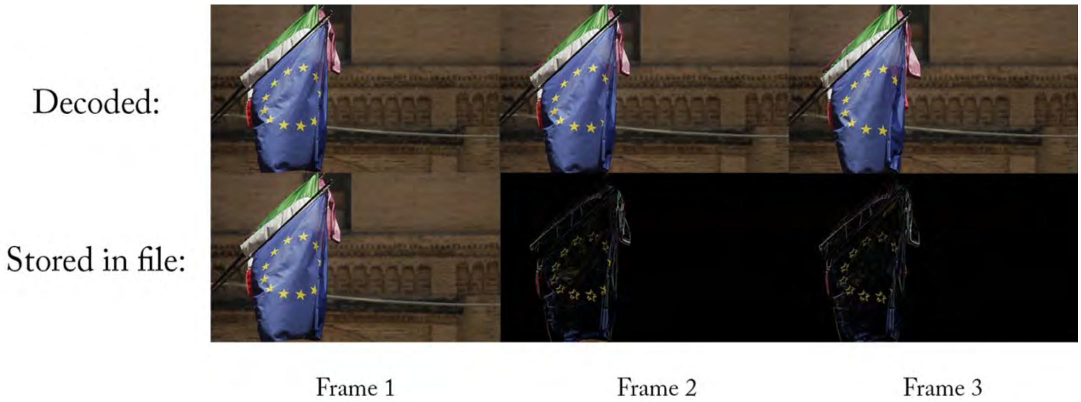

Figure 7.6 – Differences between Capture Footage and Long GOP Compressed Footage

Since this is done for a long group of pictures (long GOP) within the video, every time we've been trying to calculate the difference between the frames and copying them over from one frame to the next. In a video editor, if we try to display Frame 30 in the timeline (frames following Frame 1,2,3 from Figure 7.6) the only information we have regarding Frame 30 is the difference calculated between Frame 29 and Frame 30. It is impossible to display Frame 30 in its entirety with only just the difference (if its 0.1MB for example). To display Frame 30 we have to look back at the difference of Frame 29 and then the difference between Frame 29 and Frame 28, and continually tracing back the difference between frames till we reach Frame 1 which stores the background

28 How to Choose The Right Codec for Every Project, Ch. "Highly-Compressed codecs can Slow Down your Editing", David Kong, https://blog.frame.io/2017/02/15/choose-the-right-codec/#codec-edit

information. As the background didn't change from frame to frame none of the following frames except Frame 1 stored the background information. As a result this becomes extremely inefficient when editing and it could cause extreme slowdowns on your editing system as you jump from one frame to another within the timeline as your computer has to process 30 frames in order to show you one. This is why playing the video forward is not a problem and does not require high processing power which makes the codec greatly suitable for low-end devices and online streaming services. Whereas, going backwards is the real downside of this codec which is especially bad when editing because you are often playing a clip backwards or scrubbing backwards on your timeline. Skimming through footage like this on a low to mid range computer may cause lag and stutter.

As such, non long-GOP codecs are very edit-friendly and easily be played forward and backwards very smoothly even on the slowest of systems.

However, the H.264 codec falls under the Long-GOP codec category.

5.4.3 How Bit Rate affects the performance of your editing system:

Another factor that is of great importance regarding the performance on your editing system is the bitrate of the codec your footage was encoded with. The higher the bitrate required by your footage the harder it gets for an average system to handle demanding tasks in editing software.

If your computer's hard drive speed is not at least as high as your video's bitrate it will not be able to read the data from your hard drive at a bitrate that is at least as high as your videos bitrate, thus creating a bottleneck between your hard drive and your editing system.

For example, if your video has a bitrate of 100Mb/s and your hard drive can read at a bitrate of 70Mb/s it is expected to experience slow downs and stutter when playing your footage in your editor's timeline. As a result, an editor has to be prepared in advance and build a system that is capable of meeting the demands of the video codec they're working with. In the following list the common data storage speeds are listed for reference[29]:

- Standard spinning drive: 100-120MB/s
- Professional spinning drive: 150-200MB/s
- Standard SSD: 400-500 MB/s
- Low-end RAID: 200-300 MB/s
- High-end RAID: 1000-2000 MB/s

5.5 Alternative way of working with high demanding video files – Using Proxies

In basic terms, proxy footage is the use of a lower resolution version (encoded in an intermediate codec) of the original source file for video editing[30]. The advantage of using a lower resolution version of the original source file is that a smaller file size is required to store the footage and thus a lower bitrate is needed for the video to playback. The editor can use the lower resolution files to finish their project and then the proxy footage is relinked to its original source files at the exact timecode the proxy footage was used. The relinking of the proxy footage with its original variant happens before the final project will be exported for delivery. Proxy editing is used for projects that consist of large video files that either the editor's system cannot handle or when the source footage's video format does not offer smooth playback (such as H.264/H.265). When proxy editing, it is strongly advised to use codecs that do not use temporal compression for the reason explained in chapter "How Compression Type affects the performance of your editing system". The most popular and convenient proxy codecs are DNxHD and Apple's ProRes which will be explained in detail in a bit.

<u>There are two types of proxy workflows:</u>

- Intermediate
- Direct Intermediate

29 How to Choose The Right Codec for Every Project, Ch. "Highly-Compressed codecs can Slow Down your Editing", David Kong, https://blog.frame.io/2017/02/15/choose-the-right-codec/#codec-edit

30 Getting to Know Offline Editing, Chris "Ace" Gates, https://www.videomaker.com/article/c3/17050-getting-to-know-offline-editing

The difference between the two workflows is that when using the Intermediate workflow, you transcode your original footage into an intermediate codec to accommodate your editing needs and then export the final video into another codec. The reason it is called intermediate it is because it intervenes between the capture codec and the delivery codec. Whereas, in the Direct Intermediate workflow you transcode your original footage to an intermediate codec such as DNxHD or Apple ProRes which retains the quality of your footage at the maximum level possible while offering you flexibility in your editing software. Since the quality is retained in the direct intermediate codec, any kind of color correction or VFX work is **directly** done on the direct intermediate codec without the need to relink back to the original source files. This also means you save time and trouble relinking back to the original media as this can get cumbersome when roundtripping between different editing software. Since, the process requires you to just transcode your original footage to another codec and **directly** export to the final deliverable this workflow was called Direct Intermediate workflow by David Kong of frame.io[31].

As mentioned earlier, the most popular codecs are DNxHD and Apple ProRes. Both provide seamless editing in editing software and they've been widely used for years. The most important difference between the two is that you can transcode videos to Apple ProRes solely on Apple Computers whereas transcoding to DNxHD is easily done on Windows systems by many software suites available online. Both Apple and Windows computers can edit natively in Apple's ProRes and DNxHD formats. Since the Insta360 Pro Stitcher offers the option to stitch and export the 360 videos to Apple ProRes 422 HQ this was not an issue for us.

Thus, for our purposes we chose to work with the Direct Workflow to save time and trouble. In order to work with the Direct Workflow you need to make sure you choose the right type of direct-intermediate codec based on your original footage to preserve all the information from the capture codec. By choosing the wrong intermediate codec for your footage you risk making it worse. The Insta360 Pro 2 captures 8K 60FPS video

31 How to Choose The Right Codec for Every Project, Ch. "Direct Intermediate", David Kong, https://blog.frame.io/2017/02/15/choose-the-right-codec/#codec-edit

with a bitrate of 120Mbps[32] per lens. The camera consists of 6 lenses, making the final stitched video's bitrate 720Mbps (6 x 120Mbps). That being said, we had to choose a codec that would at least meet the specifications of the original footage.

As the project would be edited on a Hackintosh we used Apple's ProRes codec with this list as reference[33]:

- 145Mb/s ProRes 422 Proxy
- 328Mb/s ProRes 422 LT
- 471Mb/s ProRes 422
- 707Mb/s ProRes 422 HQ

By checking the list of available bitrates for every version of ProRes we chose to export to Apple ProRes 422 HQ which is the closest codec that meets the demands of the original footage of the camera. Even though the camera's final output file consists of 720MBps, the slight difference in Apple ProRes' codec bitrate which is 707Mbps wouldn't make a noticeable difference in the final product and it preserves the highest quality possible.

At first the footage was exported into 8K 60 FPS using the Apple ProRes 422 HQ codec offered by Insta360 Pro Stitcher but due to the codec's format which creates an uncompressed version of the original file (The codec does not let the user control the bitrate of the final output), the file size of every VR clip was approximately 200~300GB for 4 minutes of footage. Therefore, we decided to test the file size of the video files when exported to 4K 60 FPS (half the quality of 8K) and check if the quality was preserved. The decision to export to 4k 60FPS in Apple ProRes was made after watching the following video[34].

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32 Insta360 Pro 2 – Specs Page, https://www.insta360.com/product/insta360-pro2/

33 How to Choose The Right Codec for Every Project, Ch. "Direct Intermediate", David Kong, https://blog.frame.io/2017/02/15/choose-the-right-codec/#codec-edit

34 CreatorUp – Compression Type for 360 video -

https://www.youtube.com/watch?v=rSQUUHsDePY&feature=youtu.be&t=2088&fbclid=IwAR3cDupvrxHQQk3zzrH3LrM3OwckgxndHnkeI3_MrTGFQLg-b20BvuUGlH0

At the 35:00 minute mark the author (CreatorUp) states that, to achieve the smoothest playback on Apple computers and generally just any editing software the most flexible codec to use is Apple ProRes. Additionally, by exporting to 4k 60FPS instead of 8K 60FPS the final output's file size is cut in half and therefore less storage space is needed to save the files.

The stitched files were significantly lower in file size and required 584GB worth of storage space to store. The files were moved to a Samsung NVME 960 Pro 1TB drive which supports a Sequential Read speed of 3500 MB/s[35]; a more than adequate reading speeding for the video files which require 88MB/s (707Mbps / 8 bytes = 88.375 MB/s)

Additionally, we updated Premiere Pro to 2019 v13.0.2 which supports better integration of VR video and a lot of useful features regarding VR video editing. Then, we imported the 360 footage to Premiere Pro to test both the quality and the editing performance of the video. It turned out that the video files retained the quality at an extremely high level since the video was down sampled from 8K to 4K, therefore it didn't remove information but rather combined it to achieve a better looking 4K video. As the final project in Premiere Pro will be also exported using the H.264 codec to accommodate Unity's VideoPlayer specifications, the video will be compressed even more and thus the 4K resolution of the files is as good as they can get.

5.6 Premiere Pro – Editing

Prior to importing the videos into Unity, they had to be edited separately in Premiere Pro in order to add UI elements as well as performing colour corrections and grading. Since the tutorial is divided into many scenes from different angles, it was a good idea to cut up each scene individually instead of exporting an entire 7 minute video for the whole tutorial. This makes things a whole lot easier since each scene in Unity would consist of only one video of a specific segment of the tutorial. Moreover, there are functions that are easier performed in Premiere Pro rather than Unity such as cutting scenes, fading scenes, adding UI elements and also manipulating ambisonic audio.

35 Samsung SSD Comparison, https://www.anandtech.com/show/10698/samsung-announces-960-pro-and-960-evo-m2-pcie-ssds

5.6.1 Importing the clips to Premiere Pro & Sequence Setup

Firstly, upon launching Premiere Pro, the videos 360 footage of the Insta360 Pro 2 and the Zoom H1n audio recording were imported into the Project Panel by dragging the clips to the project panel from the window explorer. Due to some of the clips being exported using MistikaVR, their metadata regarding their VR information was lost and thus Premiere Pro could not instantly recognize them as equirectangular 360 videos. Therefore, they had to be interpreted as 360 footage. To do so, each MistikaVR exported video was selected and then by right clicking and navigating to Modify->Interprete Footage… in the VR Properties panel located at the bottom of the window that pops up, their values were changed to:

- Projection: Equirectangular
- Layout: Monoscopic
- Horizontal Captured View: 360
- Vertical: 180
-

As shown in Figure 7.7:

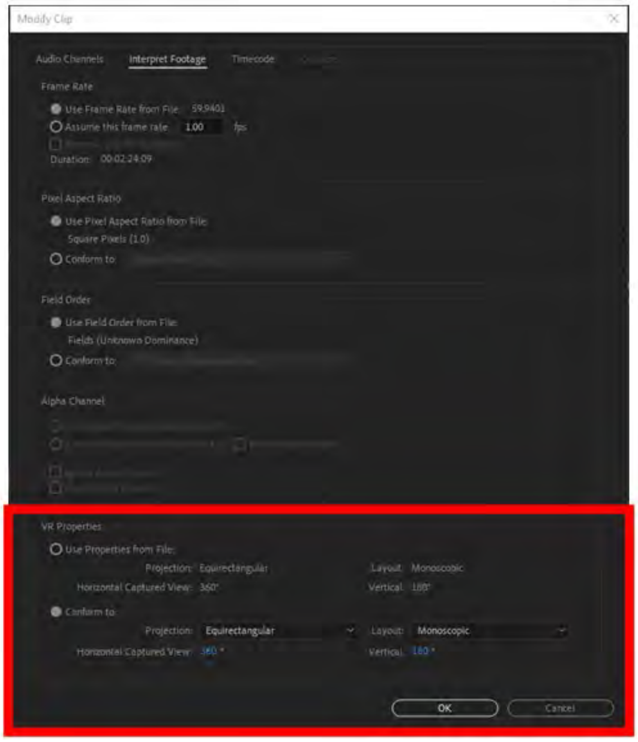

Figure 7.7 – Premiere Pro – 360 Video Conform

After interpreting all the required clips a new sequence had to be created in the timeline. Since Premiere Pro has its own VR sequences with proper ambisonic settings, the best practice to follow is to choose any of the following premade VR sequences that include ambisonic audio presets as shown in Figure 7.8.

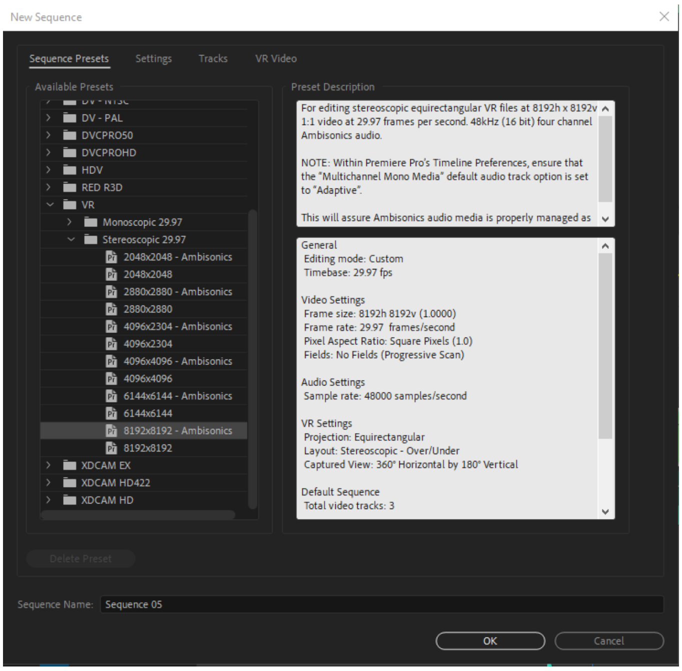

Figure 7.8 – Premiere Pro – Creating a new 360 Sequence

This ensures that the proper settings are set for the 360 video timeline in terms of both audio and video. Upon, creating the sequence, all the footage was dragged into the timeline. Since the footage had a slight difference in terms of video properties compared to the selected sequence's properties, a dialogue box asking whether to adjust the sequence settings to the footage added pops up. It is advised to **always** click on "Change Sequence Settings" as that ensures that the sequence is properly adjusted up to the footage's needs[36].

Then, the 3 main shots consisting of the 3 main scenes of the tutorial were added into the same sequence called "Main Sequence. The additional shots corresponding to the extra angles the user could switch to for each one of the 3 main shots were added to two separated sequences called Part 2 – Sharpening Angles and Part 4 – Tornos Process –

36 Record & Edit Ambisonic Spatial Audio for VR180 in Premiere for Oculus Go, Facebook, YouTube – https://youtu.be/pLk53pXNrHg?list=PLAyCpxLR2TxvmPShqIURryF44gDIF1zTY&t=500

Angles. This helped into organizing the footage better since the main film could be laid out in one huge sequence where the footage could be easily cut and divided into the segments that made up the final tutorial as shown in Figure 7.9 below:

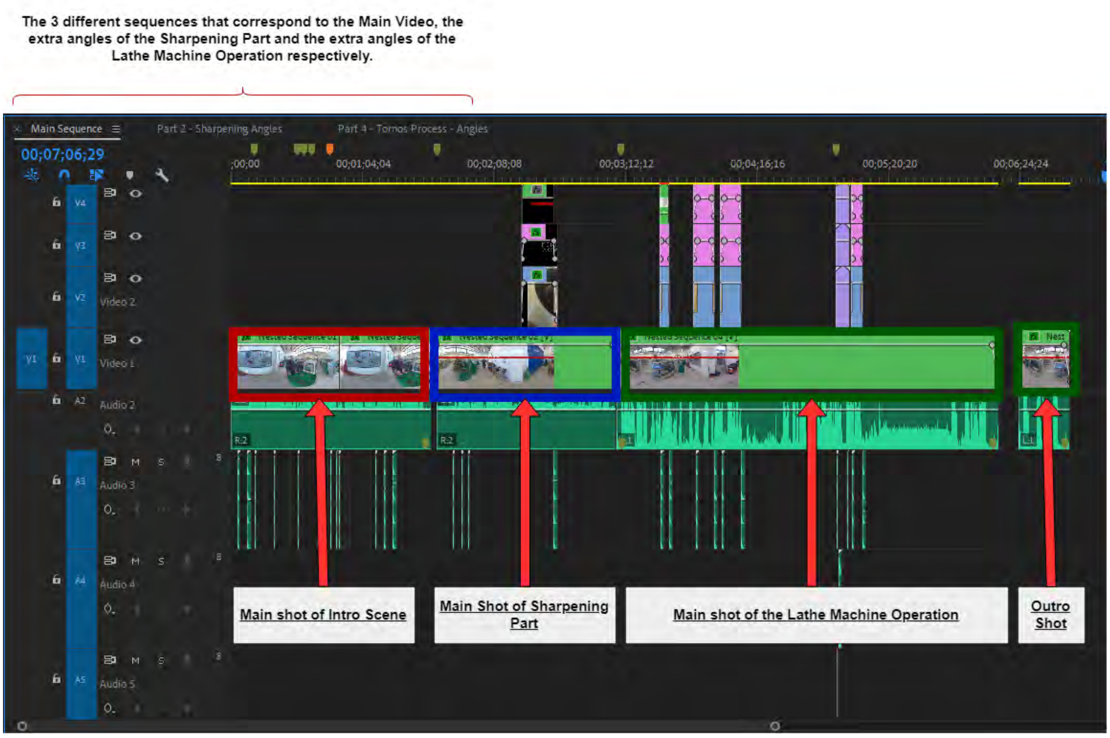

Figure 7.9 – Premiere Pro – Main Videos laid out in main

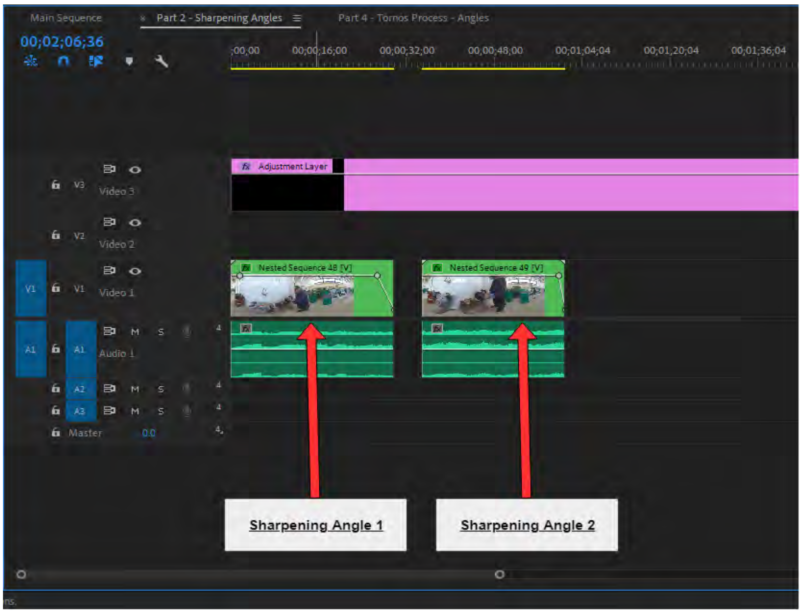

Figure 8.0 – Premiere Pro – Sharpening Scene Extra Angles

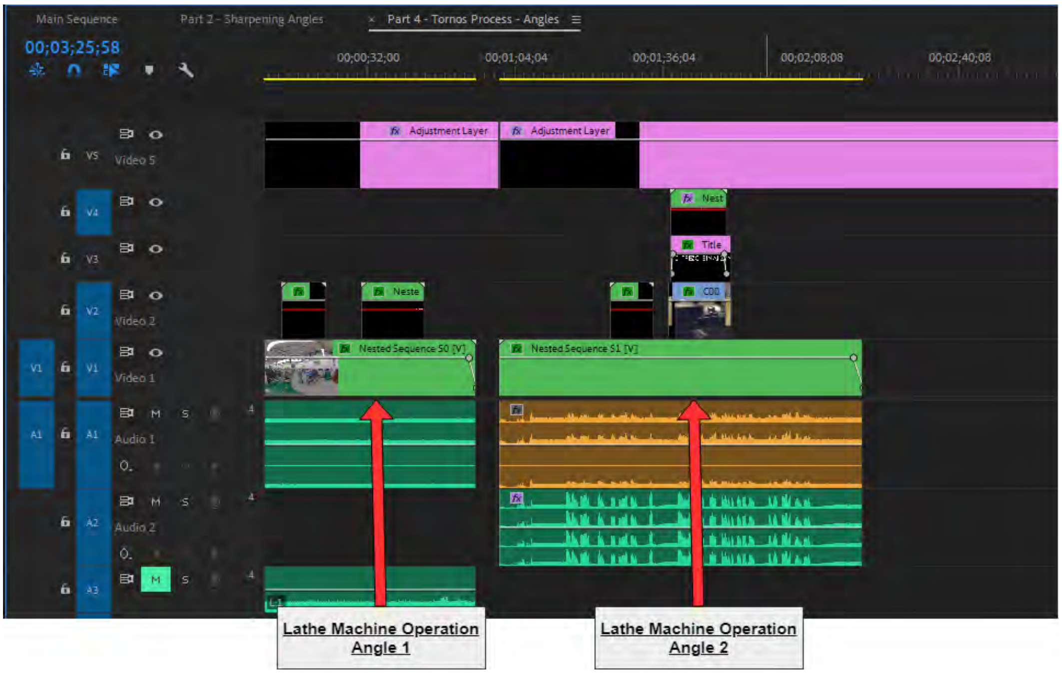

Figure 8.1 – Premiere Pro – Lathe Machine Operation Scene Extra Angles

When all the different clips had been laid out to their respective sequences the sequence's audio settings had to be changed in order to make Premiere Pro recognize all 4 four audio channels of the audio embedded on the video. This is achieved by changing the mono soundtracks of the sequence into an adaptive soundtrack which ultimately leads to a 4 channel soundtrack by the recognized audio in the videos. This was done by going into Premiere Pro's tool bar and navigating through Edit-> Preferences -> Timeline and changing the Multichannel Mono Media from "Stereo" to "Adaptive" as shown in Figure 8.2 below:

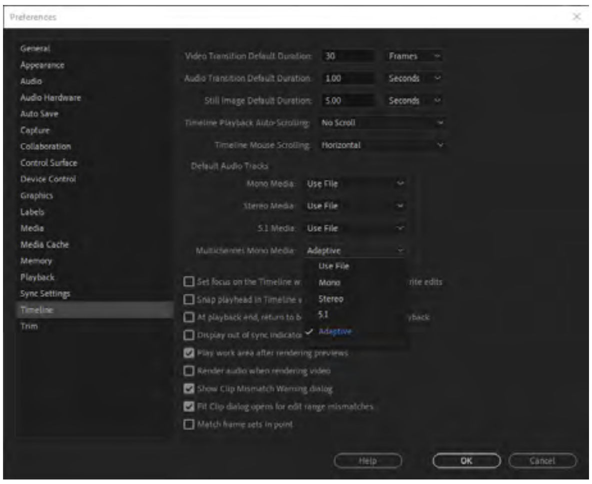

Figure 8.2 – Premiere Pro – Adaptive Audio Settings

5.6.2 Creating Proxies

Prior to working on the videos, proxy videos were created to make the editing process easier since the source videos were in 8K resolution which require high processing power to even play smoothly at ½ of their initial resolution. Even though the computer that was used for the videos to be edited on was powerful enough to handle traditional 6K footage editing, proxies had to be made to downsample the 8K videos to 2K as more UI elements would be added on additional video tracks in Premiere Pro and thus requiring lots of processing power to playback all these elements together.

<u>To create proxies of all the footage that was imported these steps were followed:</u>

1) Select the original 360 videos located in the Project Panel
2) Right click and navigate to Proxy->Create Proxies… (Figure 8.3)
3) At the new window that appears choose Format: QuickTime and Preset: 2K ProRes Mono 360 Proxy (the proxy preset was provided by CreatorUp in his 360 proxy workflow tutorial[37]) (Figure 8.4)
4) Choose the Destination you wish to save the proxy files (next to original media is the recommended option)
5) Press OK and Adobe Media Encoder will automatically open by itself and start encoding the original 360 video files to the preset that was chosen.

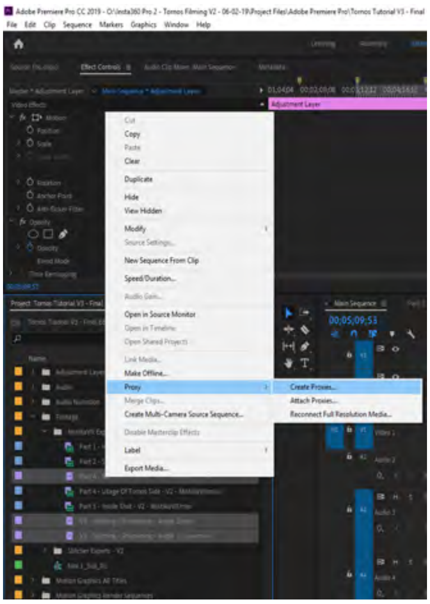

Figure 8.3 – Premiere Pro – Choosing footage to create proxies

37 CreatorUp - 360° VR Proxy workflow with Adobe Premiere & Media Encoder in-depth - https://www.youtube.com/watch?reload=9&v=5YQRF_O_Dzg&t=535s

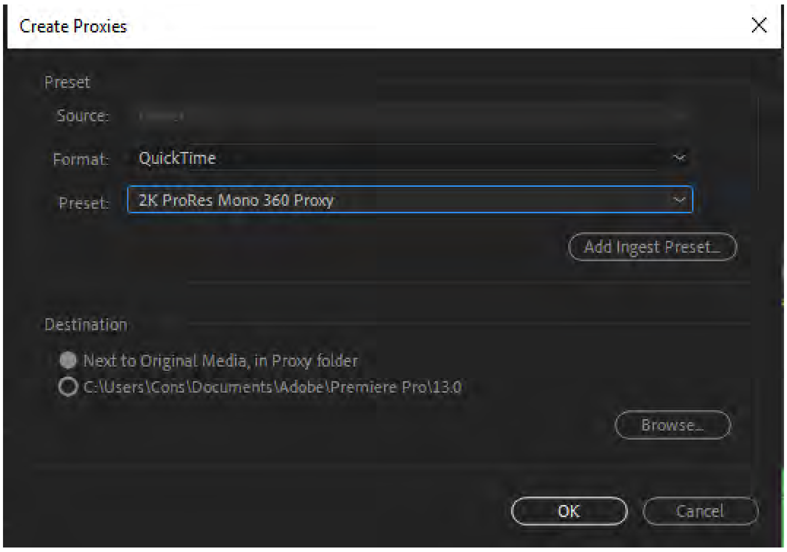

Figure 8.4 – Premiere Pro – Choosing proxy preset

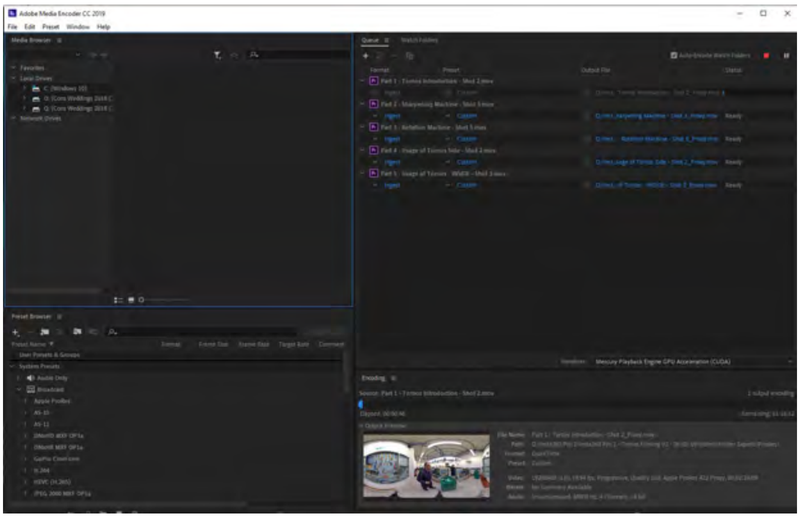

Figure 8.5– Media Encoder – Footage was sent into Media Encoder's que to create the proxies

To switch between proxies and original footage when working in Premiere Pro the Switch Proxy button was used which is located in the Program Monitor as shown in Figure 8.6.

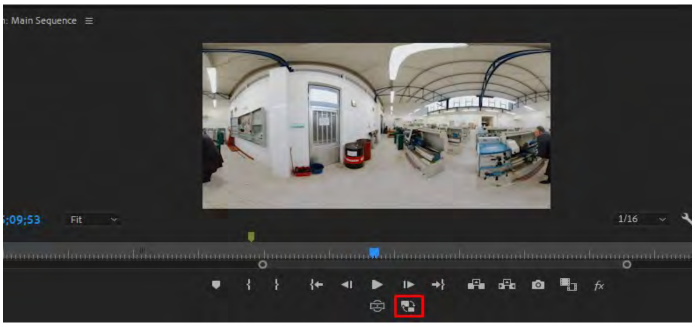

Figure 8.6 – Premiere Pro – Switch proxy button

5.6.3 Audio Synchronization with Zoom H1n & Zoom H2n

Then, the audio recorded by the audio Zoom H1n recorder had to be synced up with the embedded audio recorded with the Zoom H2n of the footage. Prior to syncing up the two audio tracks however, the Zoom H1n audio had to be interpreted as Mono instead of its default setting as Stereo. This was done by right clicking the audio file in the Projects Panel, right clicking and navigating to Modify -> Audio Channels and changing the Clip Channel Format from Stereo to Mono as shown in Figure 8.7.

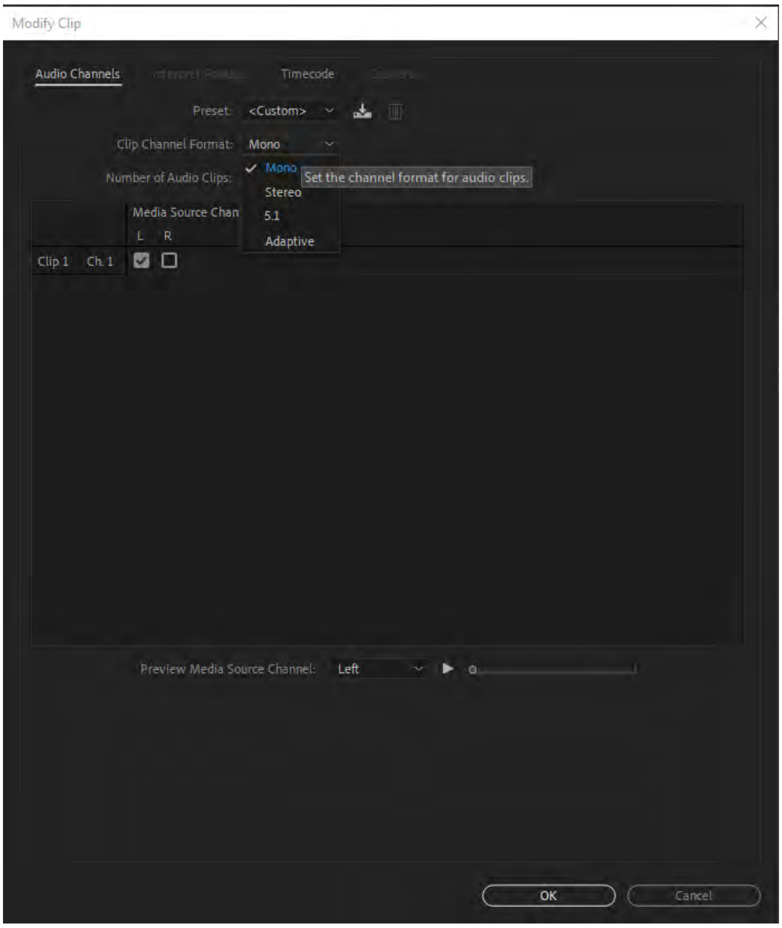

Figure 8.7 – Premiere Pro – Changing Zoom H1n Audio From Stereo to Mono

Afterwards, the Zoom H1n audio recording was dragged into the timeline of the main videos called “Main Sequence” and the audio was synced up between the videos with the following steps:

1) Each audio track of every video was placed on a separate soundtrack in the timeline. Since we had 3 different videos we created 3 additional soundtracks by right clicking on one of the soundtracks in the timeline and

right clicking and navigating to "Add Track".

2) The audio of the Zoom H1n was placed beneath all the audio tracks of the 3 videos
3) The 3 audio tracks of the main videos along with the Zoom H1n Lavalier Microphone audio track were selected and then synced up. This was done by right clicking on one of the audio tracks and navigating to "Synchronize" and clicking the OK button to sync based on Audio. The procedure followed is shown in Figures 8.8-9.0.

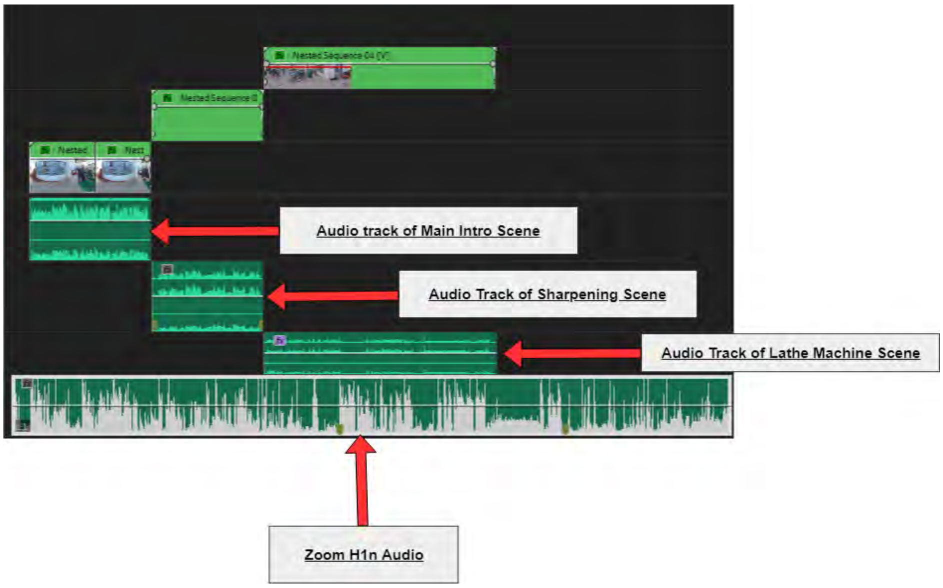

Figure 8.8 – Premiere Pro – Laying out the audio tracks for synchronization

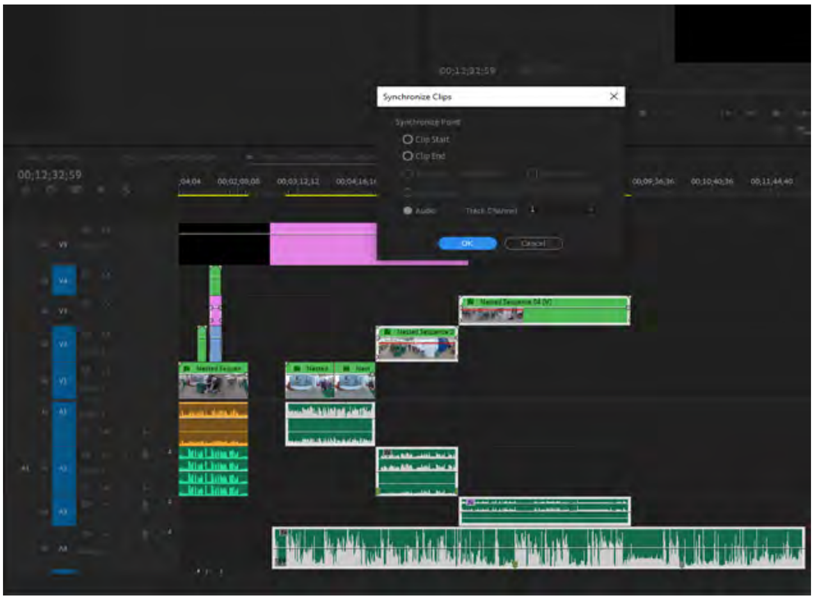

Figure 8.9 – Premiere Pro – Confirming the synchronization by audio

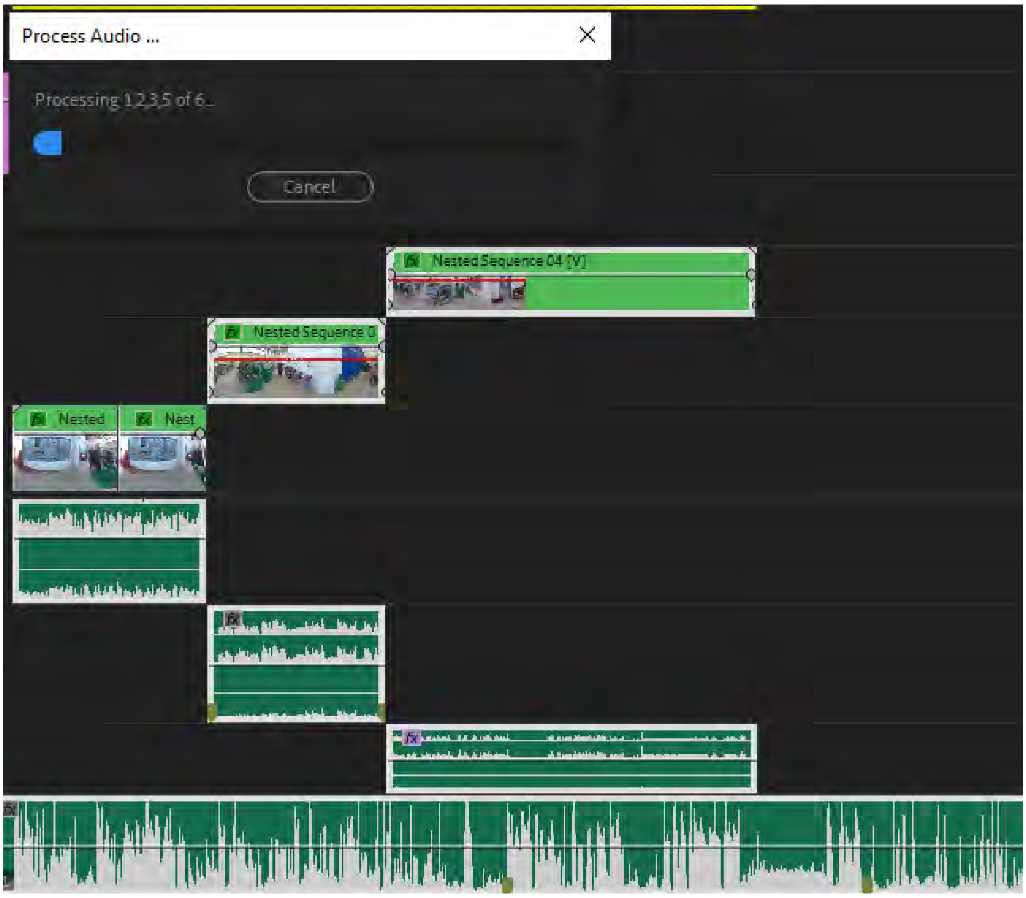

Figure 9.0 – Premiere Pro – Synchronization Processing

As soon as the synchronization was done all the clips were automatically moved to the segments where both the video and the Zoom H1n's audio tracks matched. The same procedure was followed for the remaining two sequences consisting of the Sharpening Part and the Lathe machine operation part extra angles.

5.6.4 Enabling VR Mode and Ambisonic Audio Monitoring in Premiere Pro

Prior to performing any kind of editing on the 360 videos, Premiere Pro had to be first be configured to properly view 360 video and monitor 360 audio. This is easily done by clicking the little wrench icon located at the Program Window and navigating to VR Video -> Enable & VR Video -> Show Controls & enabling "Monitor Ambisonics" as shown in Figure 9.1-9.2. By enabling these two settings, Premiere Pro's Program window changes into VR video viewing along with a little rotating wheel which helps you navigating inside the 360 video. Additionally, the view of the 360 video can be rotated and changed by clicking on the video in the program monitor and dragging the video's view whilst holding the left click on the mouse. At first glance, it was noticed that the Program Monitor was previewing the video in a square outline instead of a 16:9 outline which was expected. The outline could be changed by clicking the wrench icon located at the program monitor and navigating to VR-> Video->Settings… and changing the Monitor View Horizontal parameter to 180 degrees.

Figure 9.1 – Premiere Pro – Wrench Icon at Program Window

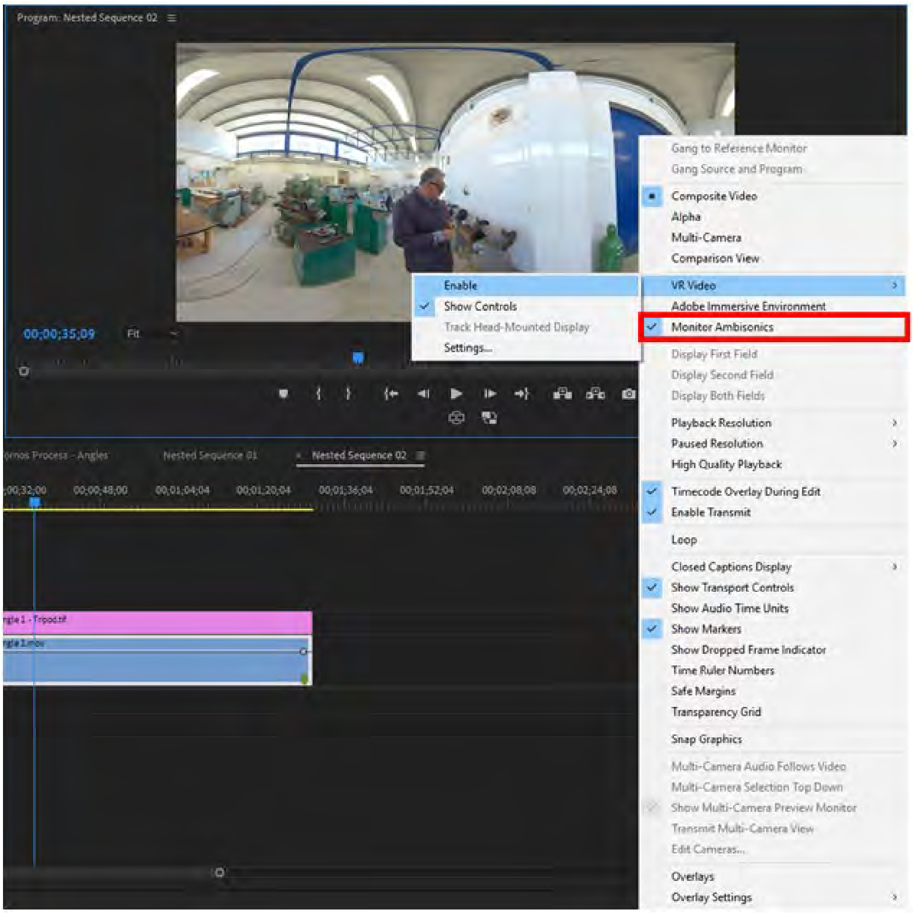

Figure 9.2 – Premiere Pro – Configuring Program Window to VR Mode and Ambisonic Audio Monitoring

5.6.5 Initial Field of View Adjustment for every Scene

Since every scene had to start at a specific field of view to instantly direct the viewer to the action as soon as the video starts playing, the field of view of every video had to be adjusted. This was achieved by applying the effect “VR Rotate Sphere” which is built-in in Premiere Pro to all the clips by highlighting them and dragging the effect on top of them. Then for each corresponding video the initial field of view was adjusted to properly accommodate the instant direction of the user’s view. For example, in the introductory scene where the professor greets the user (Intro Main Scene – Part 1), the camera’s field of view was rotated in such a way that the professor was directly facing the camera and thus the “viewer”. Then, when changing to the following scene which is The Sharpening Part, as the professor moves towards the sharpening machine from the introductory scene the sharpening scene fades in with the field of view adjusted to face the professor from the sharpening machine’s angle and thus maintain the film’s continuity. The procedure followed is shown in Figures 9.3-9.4.

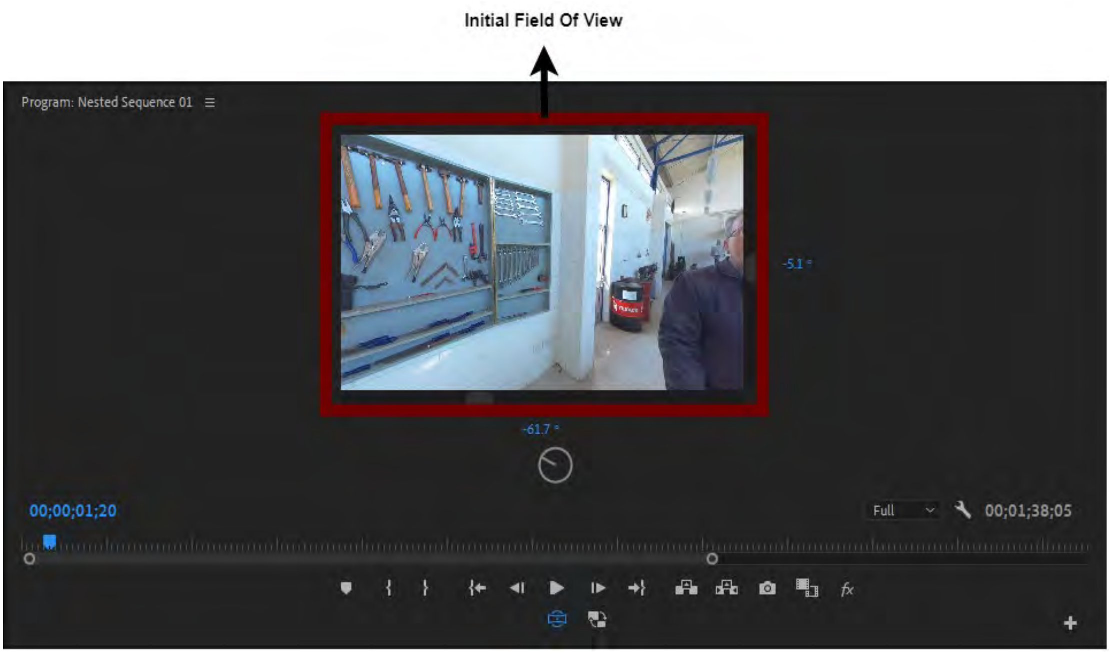

Figure 9.3 – Premiere Pro – Initial Field Of View

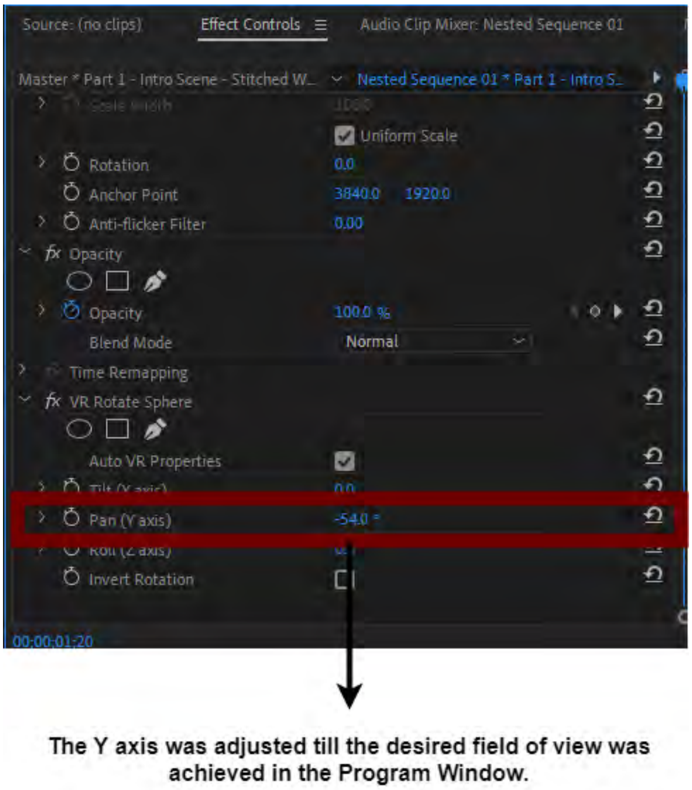

Figure 9.4 – Premiere Pro – Adjusting the Y Axis of VR Rotate Sphere in the Effects Panel

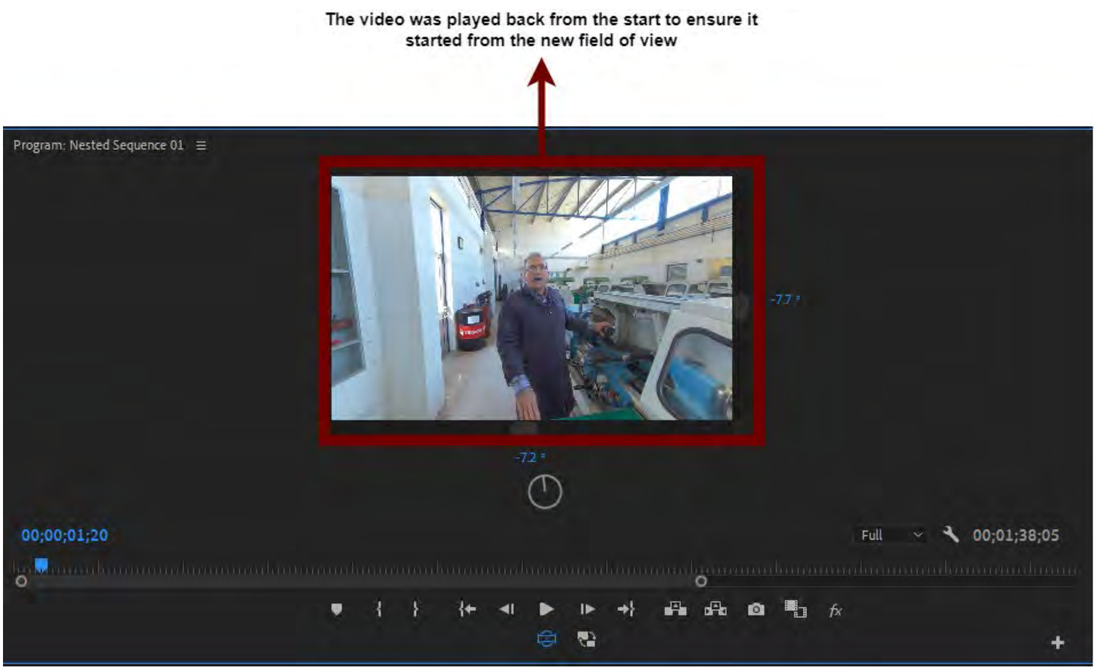

Figure 9.5 – Premiere Pro – Video playback to ensure the field of view is properly adjusted

5.6.6 Removing the tripod from every scene

To make the experience more immersive when viewing the tutorial, the tripod had to be removed from every scene so that the individual who watches the tutorial could feel being there as much as possible. By removing every hint of video equipment within the scene you prevent the viewer from believing a video was being filmed. Thus, a particular order of steps was followed to remove the tripod and it was applied to every scene:

1) Every video was imported into After Effects
2) The video was then dragged into the New Composition Creation button located in the Project Panel and a new composition containing the video was created
3) The video indicator was then placed somewhere between the middle of the video (Figure 9.6)
4) A frame of the video was sent to the render que navigating to Composition -> Save Frame As -> File… (Figure 9.7)
5) Steps 2-4 were repeated for every video until all the corresponding frames were added to the Render Que.
6) All the frames were then exported as .PSD files in a separate folder called by hitting the Render Button in the Render Que settings.
7) All the frames were then imported into Photoshop one by one.
8) To remove the tripod from every frame the Clone Stamp tool was used by carefully copying similar areas around the tripod to remove it evenly without its absence being noticeable. (Figure 9.8)
9) Upon removing all the tripods from every frame, all the frames were exported as .TIFF files within Photoshop and saved to a separate folder called “Tripod Fixed” and each frame was named after its corresponding video’s name to further help with organization in Premiere Pro.
10) Then, all the frames were imported into Premiere Pro.
11) A separate video track was created on top of the main videos and each frame was placed on top of its corresponding video clip and its duration was adjusted based on its corresponding video’s duration. (Figure 9.9)
12) By selecting a specific frame and navigating to the effects panel and clicking on the pen tool a new mask was created that cut out the portion of the video which

included the tripod. To make this process easier, prior to clicking the Pen tool the video track containing the .PSD file was disabled by clicking the eye icon in the video track so that masking out the tripod was more convenient as the tripod was visible in the main video. To create a mask the VR view has to be disabled from the Program Monitor. (Figure 10.0)

13) Some amount of feather was added to smoothen out the edges of the mask
14) Then to avoid the individual fading of the mask and the video, both the .PSD file and the video were nested together and then the nested clip's opacity keyframes were adjusted at the start and end of the video clip. To nest the video and the frame together, first the video and audio had to be unlinked and then nested. Thus, achieving simultaneous fading of both the mask and the video without artifacts. (Figure 10.1-10.2)

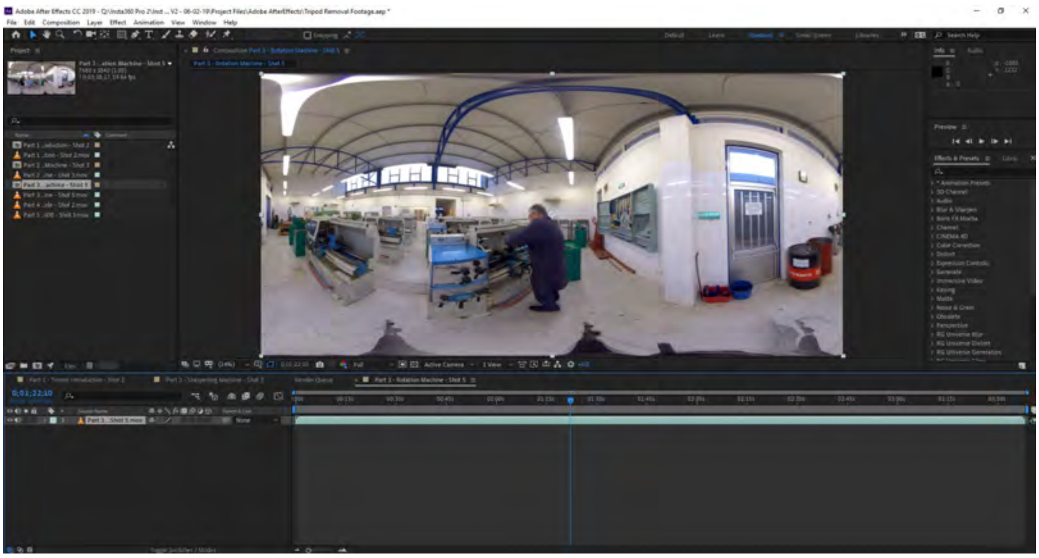

Figure 9.6 – After Effects – Placing the video indicator between the middle of the video

Figure 9.7 – After Effects – Sending the frame to the render que

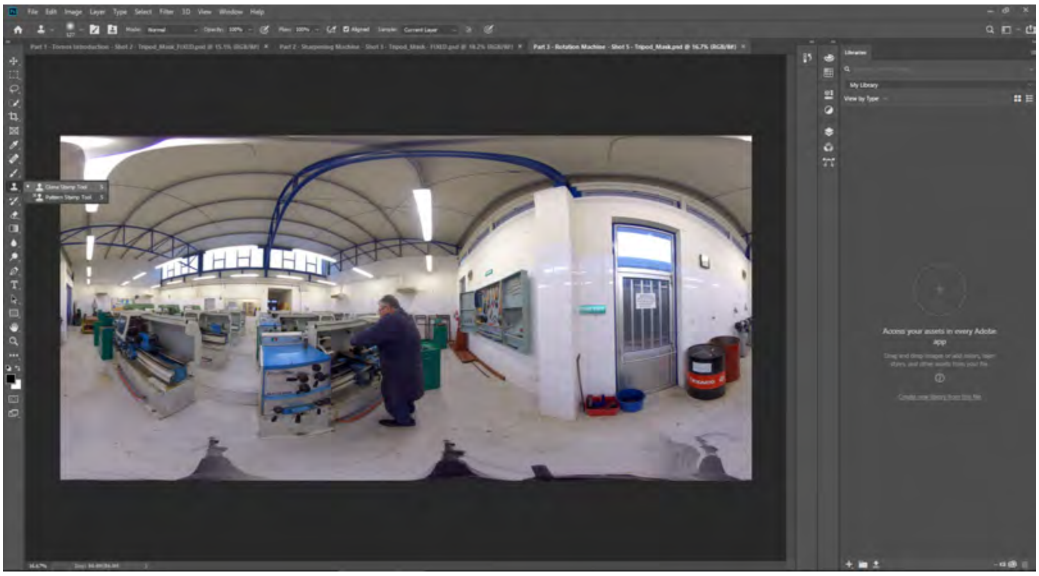

Figure 9.8 – Photoshop – Choosing the Clone Stamp Tool to remove the tripod

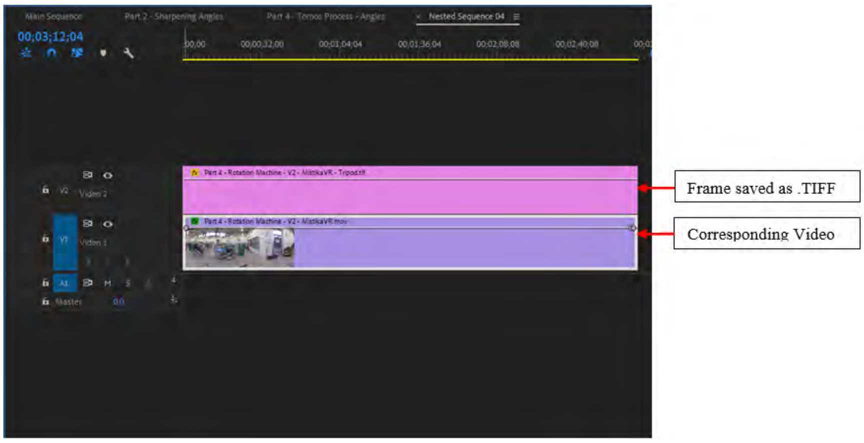

Figure 9.9 – Premiere Pro – Placing the edited frame on top of the video to mask it

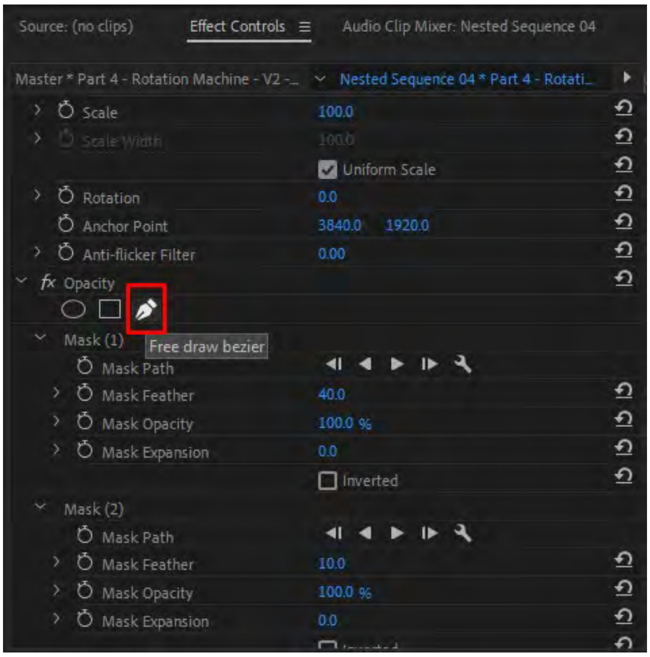

Figure 10.0 – Premiere Pro – Pen Tool in the Effects Panel

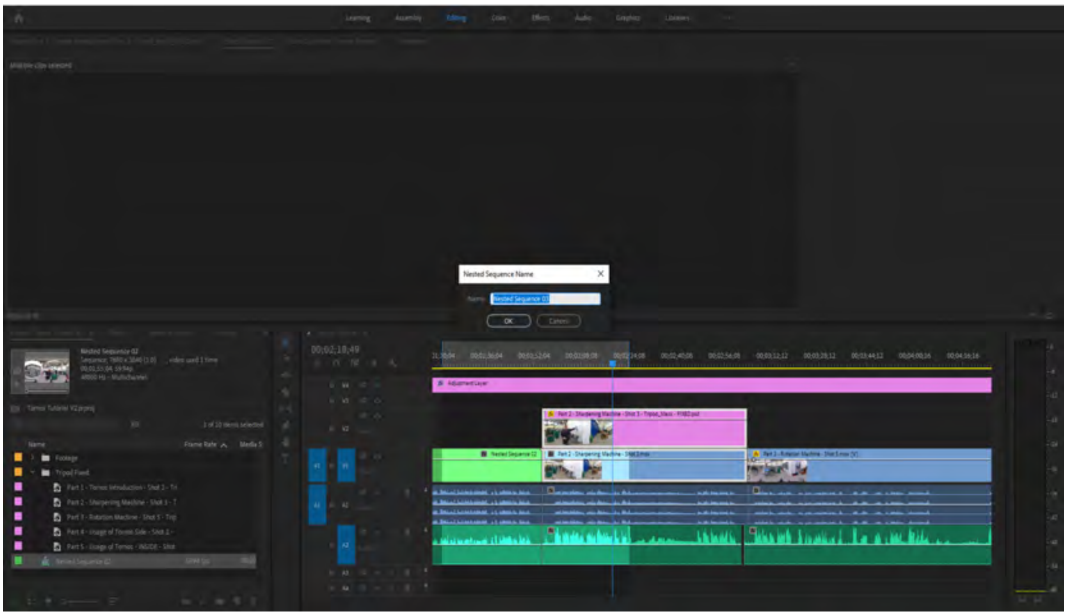

Figure 10.1 – Premiere Pro – Nested the video and the frame

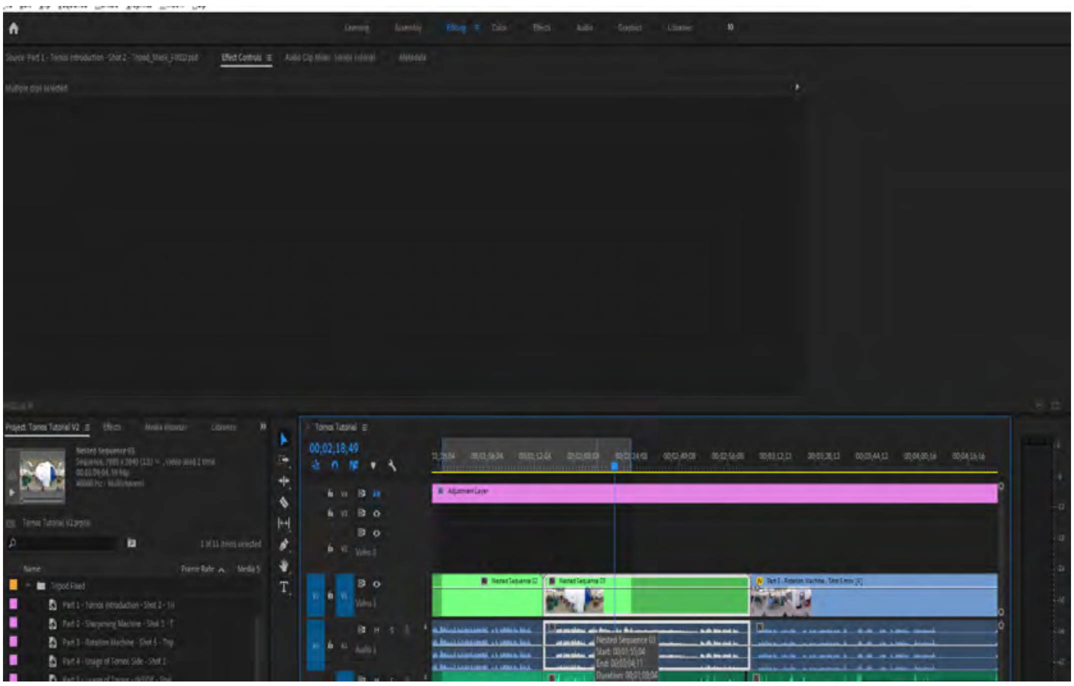

Figure 10.2 – Premiere Pro – Regrouping the nested clip with the Zoom H2n's audio

5.6.7 Adding text on top of the VR videos

Some scenes in the tutorial required titles that specified what was going on during the lathe machine process that had to be placed on top of the flat videos that would pop up during the lathe machine operation demonstration. Thus, titles were added at several parts of the video by firstly creating the different titles that were needed (Figure 10.3). Then, the titles were placed into the timeline at the specific spot they should appear with a fade in and fade out effect. Firstly, to ensure the titles retained their resolution in the VR video they were scaled up to 300 – 500 times accordingly by modifying the "Scale" parameter in the Video Effects panel. The next step was to convert the titles from 2D (since they are a 2D element) into VR so that they could be properly read inside a VR headset. This was done by adding the VR Plane To Sphere effect through the Effects Panel on each individual title in the timeline. Lastly, each title was then moved accordingly, to its position within the 360 video by manipulating the Position parameter in the Video Effects panel (Figure 10.4). At first glance, it was noticed that the white titles were prone to visibility issues due to the white colour of the wall within the lathe machine laboratory and therefore each title layer was duplicated 2 times (Figure 10.5) and a drop shadow effect was added as well to make it completely indistinguishable and visible. (Figure 10.6)

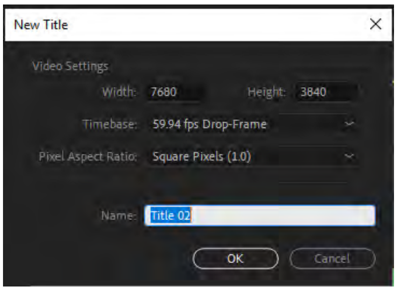

Figure 10.3 – Premiere Pro – Creating a new title

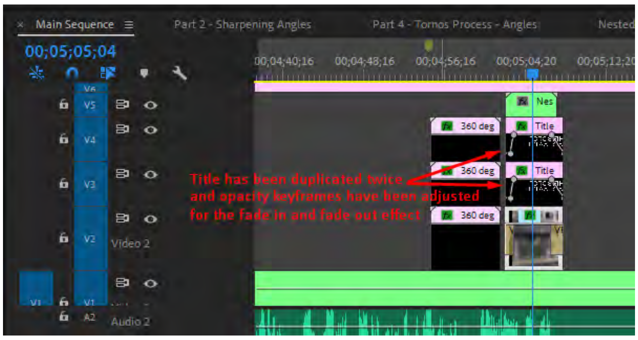

Figure 10.4 – Premiere Pro – Duplicating title layer

Figure 10.5 – Premiere Pro – Effects Panel – VR Plane to Sphere & Position Adjustment

Figure 10.6 – Premiere Pro – Final Title Form and Positioning

5.6.8 Adding flat videos within a VR video

Just like the aforementioned in titles in Chapter 5.6.5, flat videos had to be added at specific parts of the lathe machine demonstration as well. The process followed was similar to that of the titles with a slight difference. The videos that were shot on the Sony a7s II were imported into Premiere Pro. The desired shots which consisted of closeups of specific actions during the tutorial were dragged into the timeline at the specific spot they should appear within the tutorial. Then the effect "VR Plane To Sphere" was added on all the Sony a7s II footage within the timeline and the position of the clips was adjusted accordingly beneath their corresponding title by adjusting both the VR Plane to Sphere and Position parameters in the Video Effects panel. Specifically, to rotate the Sony A7s Mark II's videos within the 360 video sphere of the tutorial the Projection Tilt (X Axis) and Projection Pan (Y Axis) were modified (Figure 10.7). Then, the "Position" parameter was modified accordingly to properly adjust the position of the video at that specific spot that was set by modifying the aforementioned parameters in the VR Plane To Sphere effects. Moreover, to gradually and smoothly fade in the closeup shots of the specific actions of the tutorial, the transition effect VR Mobius Zoom was used to fade in and fade out each video.

Figure 10.7 – Premiere Pro – Adding Flat Videos within VR videos

5.6.9 Adding Motion Graphics

The main goal of this project is to make an as interactive video as possible. As mentioned in Chapter 2, Diegetic and Non – Diegetic Cues play an important part in making a 360 video interactive. Thus, motion graphic titles were added on top of the tools that were placed within the toolbox at the first scene where the instructor of the tutorial explains their use along with motion tracking when the instructor would hold up a specific tool in front of the camera. Additionally, visual hotspots were added on top of the tools within the toolbox to indicate to the user that these hotspots can be gazed upon to trigger a specific event. Moreover, various animations such as rotating circles and video frames were added to further enhance the user experience and make the tutorial more enjoyable and on point.

5.6.9.1 Call Out Titles

The first type of motion graphics that was added into the 360 tutorial was call out titles. Call out titles are basically small text boxes which are attached to a straight line pointing to a specific object within the video and thus "calling out" its name. These titles were very useful for presenting the titles of every object in the introductory scene when the professor would explain the tools within the toolbox to the user. A free template of call out titles was downloaded and installed by following the tutorial from Orange83[38] on YouTube. All the steps required to install the template into Premiere Pro's Graphics panel are demonstrated within the attached video reference on this page.

Firstly, all the required titles provided by Orange83 were added into video timeline in separate video tracks at the specific moment they should appear by dragging the Orange83 title in the Essential Graphics panel to the timeline. The moment each title appears within the video tutorial is synchronized exactly when the professor says the name of the tool in the video so that the call out title starts animating and gradually folds out to reveal the tool's name as the professor is speaking about it. After placing all the call out titles in the timeline at the moment where the professor speaks about the tools located within the toolbox, each title had its text parameter modified to match the specific tool's name it was indicating. The tool names were provided by the school's professor who was supervising the filming process via email to further help with the naming of the call out titles. As the template includes 6 free titles, the best type of title was considered to be "Title 5" as it offered 2 lines of text which were needed for the tool's name and its category. Upon modifying the text of each title, a VR Plane to Sphere effect was added to every title in the timeline to make it moveable within the VR video of the tutorial. The scale of the titles was set to 60 in the VR Plane to Sphere parameters and the positioning of each title was adjusted by modifying the Projection Pan (Y Axis) as well. When all the titles had been properly positioned and scaled, duplicated copies of each title were made in order to freeze their roll out animation at the moment the animation had finished to hold them long enough on the screen. At the moment the instructor of the video tutorial finishes speaking about the toolbox the title layers were reversed and played backwards in order to make them titles disappear with their built-in animation.

38 6 FREE Call Out Titles - MOGRT Preset pack for adobe Premiere Pro - https://www.youtube.com/watch?v=BRAJmzsYu14

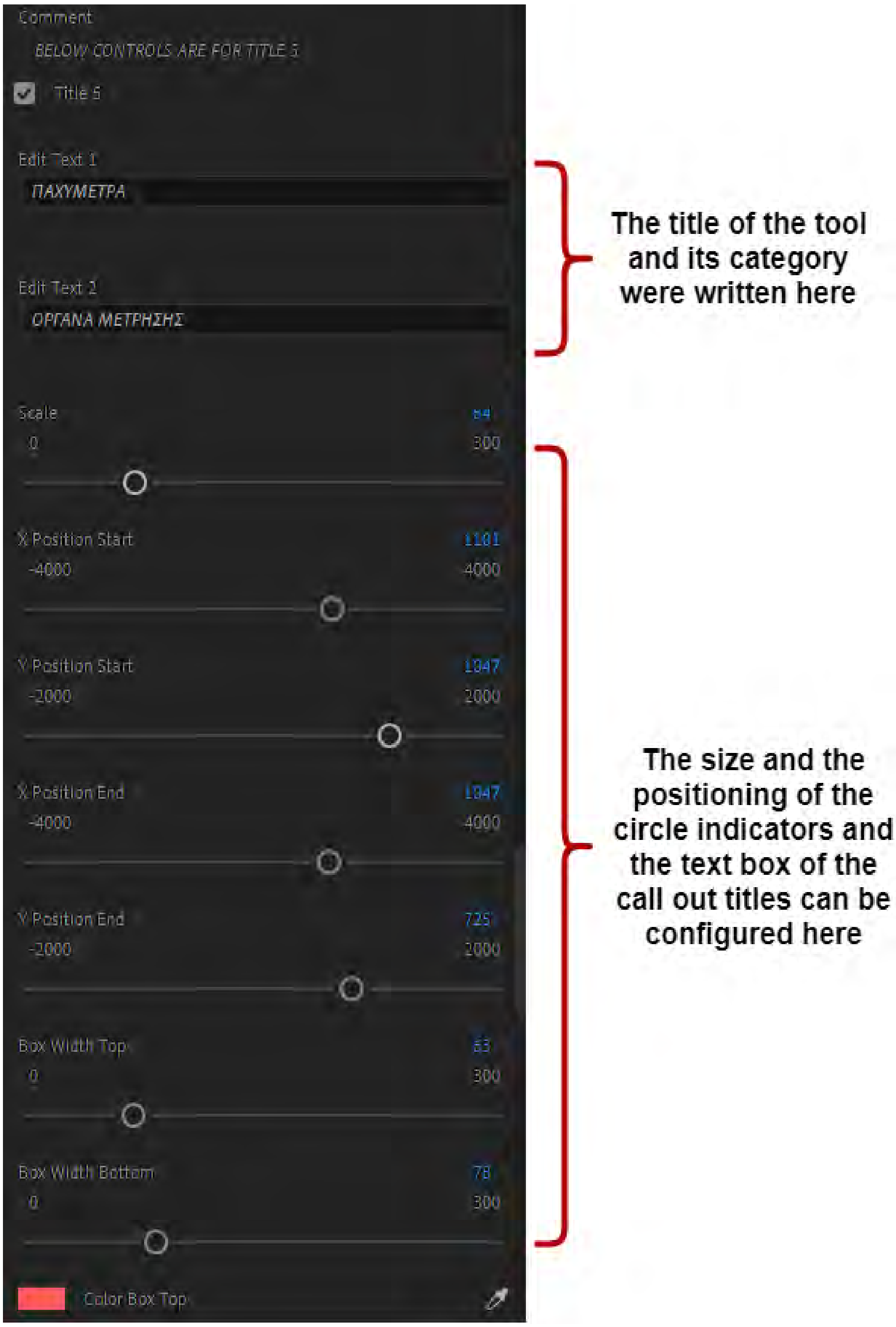

Figure 10.8 – Premiere Pro – Call Out Title Configuration

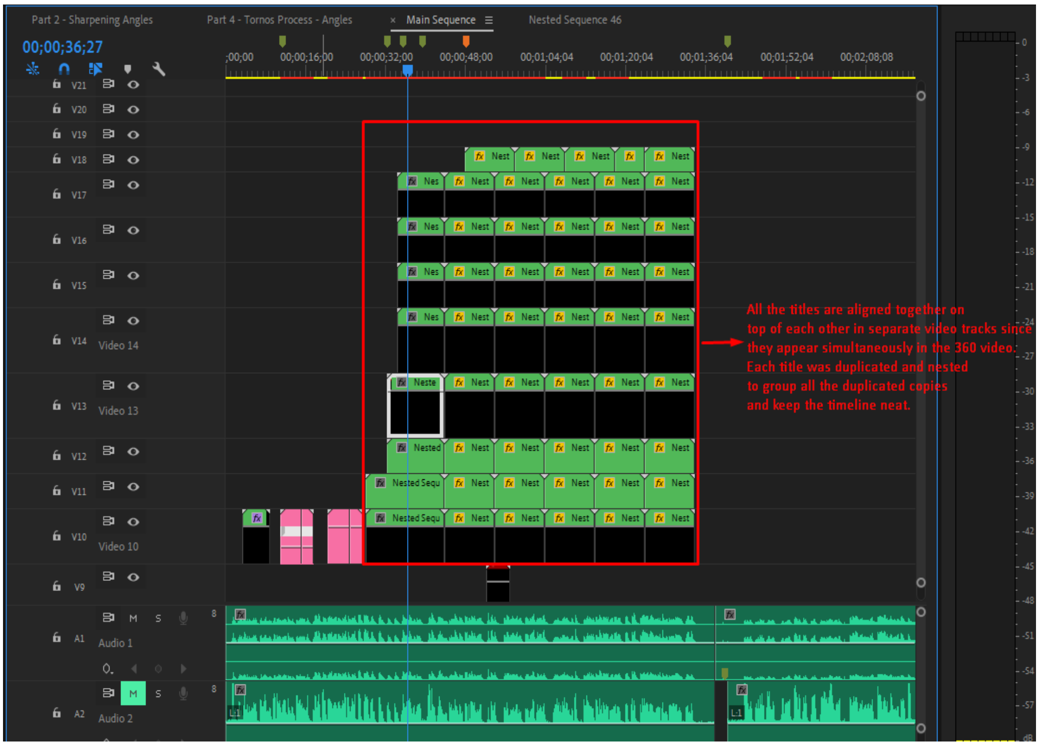

Figure 10.9 – Premiere Pro – Laying out all the titles on top of the 360 video

Figure 11.0 – Premiere Pro – The final result of adding call out titles

As mentioned earlier, the call out titles were also used when the instructor in the tutorial would hold up a specific tool in front of the camera. The call out title would follow the movement of the instructor's hand as he grabbed the tool and presented it in front of the camera. This was achieved by manually motion tracking the hand's movements and creating position keyframes of the call out title. Thus, this results in the call out title gradually changing its position relative to the instructor's hand's position within the 360 video. The method of manually motion tracking in Premiere Pro is perfectly explained by the YouTube user "S C" in comments section of one of tutvid's videos[39] as shown in Figure 13.9 in Annex A.

Prior to keyframing the position of the call out title it was first duplicated enough times to last the entire duration the instructor would hold up the tool on the screen and then all the duplicated copies were nested together so that their position could be keyframed. The result of manually tracking the position of the title and the video result is shown in Figures 11.1-11.2.

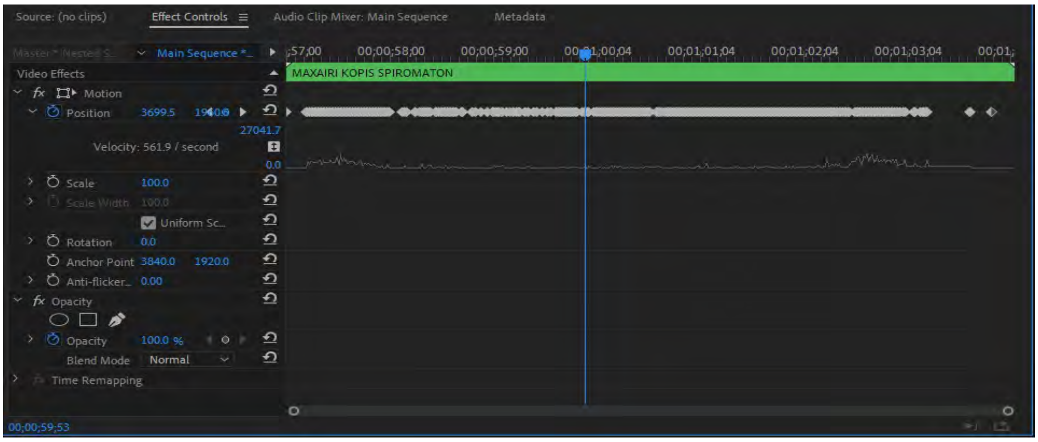

Figure 11.1 – Premiere Pro – Resulting keyframes of manually tracking the position of the call out title relative to the instructor's hand

Figure 11.2 – Premiere Pro – Result of manual motion tracking in 360 video tutorial

39 Auto & Manual Motion Tracking an Object with Premiere Pro - https://www.youtube.com/watch?v=aRI1cjM1UHE&t=29s

5.6.9.2 Rocketstock HUD Interface Video Elements

In addition to the call out titles, to further enhance the user experience of the tutorial and aid into giving hints where a user can gaze at, animated circular blue hotspots were added on top of various spots within the 360 video scenes. Such scenes were the introductory scene where the toolbox is located and the lathe machine operation scene where the use of the rotating wheel machine is explained. Moreover, sci-fi UI video frames were added around the flat videos that pop up and reveal close up shots of certain actions to stylize the whole look of VR tutorial better and give it a more sci-fi look. All these graphical elements were provided by the Rocketstock HUD Interface Video Elements[40] pack which includes a plethora of sci-fi UI elements which perfectly match with the 360 tutorial's theme. The pack includes an After Effects project file which has numerous templates of UI elements. The elements that were chosen to be rendered from the project file were Frame_03_in, Frame_03_loop, Frame_03_out, Tiny_04 and Circle_Cuts_10. The UI element Frame_03 corresponds to the video frame that accompanies all the flat videos that appear in the 360 tutorial. The UI element Tiny_04 corresponds to the blue circular hotspots that blink on specific spots within the video which indicate spots the user can gaze at. The UI Element Circle_Cuts_10 corresponds to the animated circle which reveals the amount of degrees required to configure the rotating wheel machine properly. All of these elements were sent to the Render Que within After Effects and exported using the QuickTime Preset with RGB+Alpha transparency as shown in Figure 11.3.

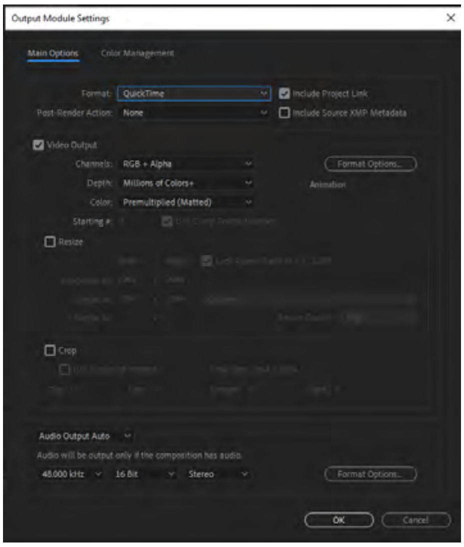

Figure 11.3 – Premiere Pro – Export settings for the Rocketstock UI Elements

40 Rocketstock HUD Interface Video Elements - https://www.rocketstock.com/video-packs/interface-hud-video-elements/

The exported UI elements were then imported into Premiere Pro and each element was added into the timeline at its specific moment in the 360 tutorial.

Placement of UI Elements:

The circular blue hotspots were added in the introductory scene on top of all the tools in the toolbox at the left of the initial position of the video as well as at the bottom green table with all the remaining tools at the bottom of the video as shown in Figure 11.4.

Figure 11.4 – Premiere Pro – Adding the circular blue hotspots on the toolbox

The UI element Frame_03 was added around the flat videos that appeared within the 360 video throughout the tutorial. To properly position them within the 360 video scenes the VR Plane To Sphere effect was added and their position was adjusted so that they surrounded the popped up video. Since the colouring of the frame was light blue, it was not as visible as initially desired and therefore the Frame_03 clip was duplicated 3 times in 3 different video tracks to make it stand out more. The result is shown in Figure 11.5.

Figure 11.5 – Premiere Pro – Frames around the popup videos

The circular UI element that animates and indicates the amount of degrees needed to rotate the lever at the rotating machine was placed on top of the rotating machine in the Lathe Machine Demonstration scene – Part 4. Just like the UI element Frame_03 the effect VR Plane to Sphere had to be applied on the circular UI as well to move it within the 360 video. It was specifically placed and synchronized at the exact moment the instructor in the 360 tutorial emphasizes that the required degrees of rotation for the rotation machine are 360 degrees. Thus, the animated circle gradually appears as the instructor speaks as shown in Figure 11.6.

Figure 11.6 – Premiere Pro – Adding the circular animation that reveals the amount of degrees needed at the rotating machine

5.6.10 Sound Effects & Zoom H1n Audio Configuration

In order to enhance the precense of all the motion graphics that appeared on screen several sound effects were added in the final video. As explained in Chapter 2, directional cues help the viewer guide their attention to specific parts of the video since the viewer turns their head to the direction of the originating sound. Thus, by adding sound effects to the 360 tutorial we could emphasize the spots where the viewer should look while simultaneously making the experience more enjoyable. The sound effects that were used were provided by the free pack by Big5Audio[41] and Free Stock Footage

41 Big5Audio Sound Effects - https://www.toneden.io/big-5-audio/post/ux-and-ui-sound-effects

Archive [42]. Specific sound effects that provided the desired sound for specific animations were chosen from the pack and imported into Premiere Pro. Since the audio effects were in Mono format they had to be converted into ambisonic so that it was possible to choose the direction they would originate from in the video. The conversion from mono to ambisonic was achieved by selecting all the sound effects from the project panel and interpreting (Right click->Modify->Audio Channels) all the desired sound effects as "Adaptive" in a 4 channel format as shown in Figure 11.7.

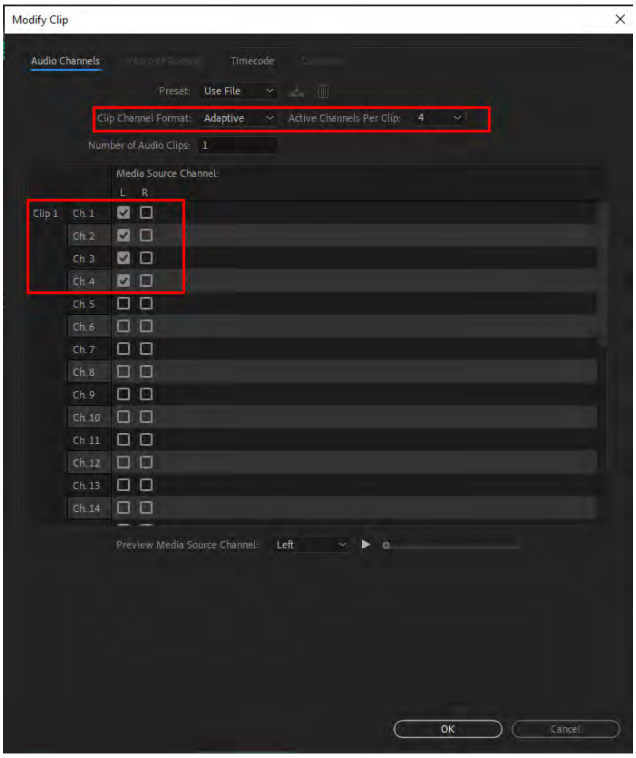

Figure 11.7 – Premiere Pro – Interpreting mono sound effects as adaptive to achieve the ambisonic effect

Afterwards, the sound effects were placed within the timeline at the moments the previously added UI elements appeared in the video. To choose the direction they originated from the Ambisonics Panner was added on every sound effect from the Effects Panel in Premiere Pro. The direction of the sound was adjusted by modifying the Pan parameter in the Ambisonics Panner sound effect until the desired originating direction was achieved as shown in Figure 11.8. It is advised to use a headset to monitor the audio whilst following this procedure for best results.

42 Free Stock Footage Archive sound effects - https://www.youtube.com/watch?v=2YHweysoUjc

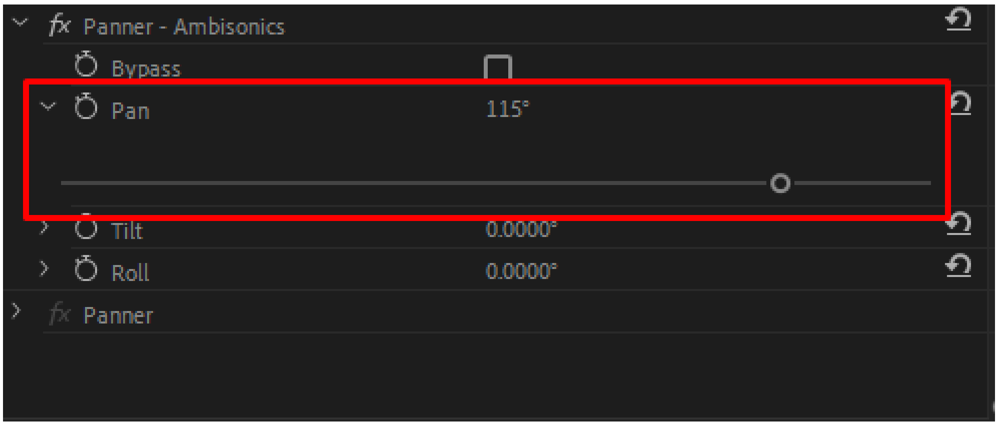

Figure 11.8 – Premiere Pro – Panning the direction of the sound effect

The same procedure was followed for the Zoom H1n sound recording in the Lathe machine Operation scene which shows the operation INSIDE the lathe machine as shown in Figure 11.9. Since the instructor was far away from the camera both the distance and the lathe machine's noise were preventing the instructor from being heard clearly. Thus, the audio of the lavalier microphone had to be layered on top of the zoom h2n audio recording of the video. However, since it was in mono format as well it had to be interpreted as adaptive and its direction had to be adjusted as well.

Figure 11.9 – Premiere Pro – Lathe Machine Operation INSIDE the lathe machine

It is important to note that it is advised to NOT adjust the gain of the Zoom H2n recordings by Premiere Pro’s default audio configuration as it is designed to manipulate 2D and thus removes the spatializing effect of the sound[43]. It is strongly advised to use this[44] instead, if someone wishes to stay within Premiere Pro and edit their spatialized audio.

5.6.11 Export Settings

After all the 360 videos were configured and edited as desired each individual scene was sent to the Adobe Media Encoder render que to be rendered. Due to Unity and Android Hardware’s limitations which will be discussed in Chapter 3 in the Unity segment the following export settings were chosen and saved as a preset:

<u>VIDEO PANEL:</u>

Format: H.264

<u>Basic Video Settings:</u>

- Resolution: 4096 x 2048
- Frame Rate: 29.97
- Field Order: Progressive
- Aspect: Square Pixels

<u>Encoding Settings:</u>

- Performance: Software Encoding
- Profile: Baseline
- Level: 5.1

<u>Bitrate Settings:</u>

- Bitrate Encoding: CBR
- Target Bitrate [Mbps]: 30 Mbps

<u>VR Video:</u>

- Video is VR – Ticked
- Frame Layout: MonoScopic
- Horizonal FOV: 360
- Vertical FOV: 180

43 CreatorUp - Zoom H3-VR Review, Tutorial + complete 3D Audio Post-Production workflow in Adobe Premiere _ https://youtu.be/cy3fqID1dxA?t=966

44 https://www.blueripplesound.com/products/o3a-core

<u>AUDIO PANEL:</u>

<u>Audio Format Settings:</u>

- Audio Format: AAC

<u>Basic Audio Settings:</u>

- Audio Codec: AAC
- Sample Rate: 48000Hz
- Channels: 4.0
- Audio Quality: High

<u>Ambisonics:</u>

- Audio is ambisonics - Ticked

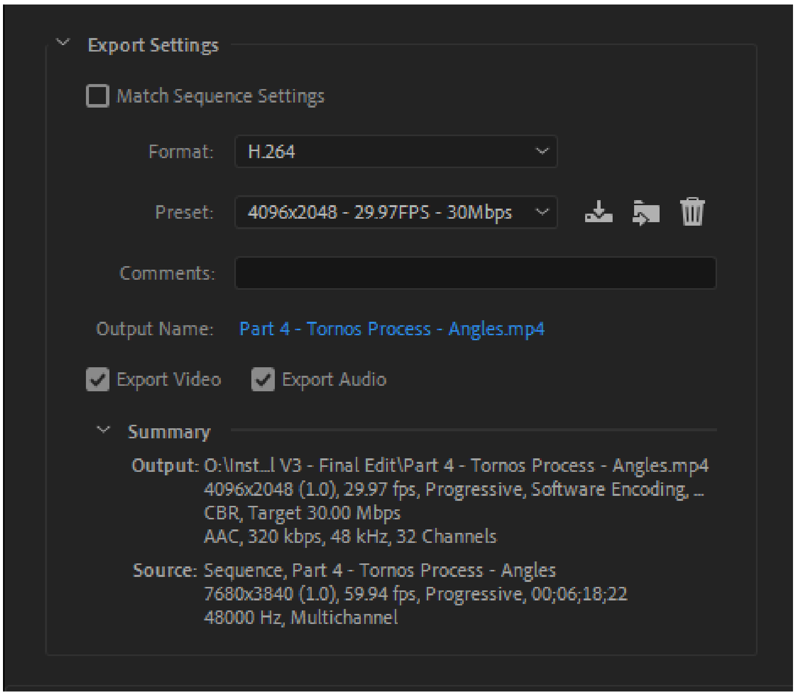

Figure 12.0 – Premiere Pro – Export Settings

Chapter 6

Unity Development

6.1 Project Creation & Asset Import

As explained in Chapter 2 after rigorous trial and error in an attempt to discover what the best way to view VR video in Unity is, it was best considered to create separate scenes that would consist of one single video corresponding to each one of the scenes that were exported through Premiere Pro. These videos will act as a skybox material so that the video occupies the entire screen when viewing the tutorial through VR Goggles for easy navigation with head movement.

Thus, a new 3D project was created in Unity with the help of some assets from Unity's asset store.

The Interactive 360 Sample Project includes some very useful tools for starting up a 360 video project in Unity that helped speed up the development process immensely. More specifically, the sample project includes premade interactive Hotspots that let the user gaze upon to trigger certain functions as well as scripts regarding camera movement & VR. The features of the package that have been used will be thoroughly explained gradually in this section.

6.1.1 Build Settings

To properly setup the Unity environment for Android VR development the Build Settings were changed to Android. This is done by navigating to File->Build Settings… and choosing Android as the desired platform. The settings that were configured regarding the Android development are shown in Figure 9.0.

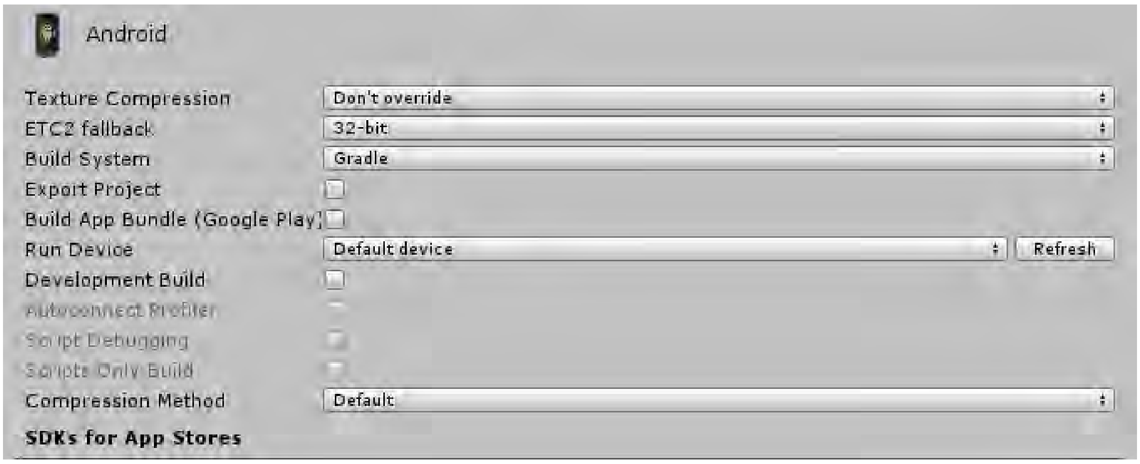

Figure 12.1 – Unity – Android Platform Settings

Then, the project had to be configured for VR development. This is done by Navigating to the Unity toolbar and enabling the VR settings from VR-> Enable VR.

6.1.2 Video Import

Afterwards, all the videos that were originally exported by Adobe Media Encoder for use in Unity were imported into a separate folder called “Videos” in the Unity Asset folder of the project. Upon, importing the videos, Unity automatically transcoded the videos specifically for Android.

6.1.3 Audio Spatializing

In order for spatialized audio to play properly in Unity, the audio spatializer plugin and ambisonic decoder plugin have to be enabled in the projects settings by navigating to Unity’s toolbar and going to Edit -> Project Settings -> Audio. More specifically, in the Spatializer Plugin field, the MS HRTF Spatiliazer was chosen and in the Ambisonic Decoder Plugin, Oculus Spatiliazer was chosen respectively as shown in Figure 12.2. To make both plugins available in your Unity project they have to be separately downloaded as follows:

<u>For the Microsoft Spatializer plugin go to:</u>

- Window -> Package Manager
- Search for “Mixed Reality”
- Install the “Windows Mixed Reality” Package

<u>For the Oculus Spatializer plugin go to:</u>

- Window -> Package Manager
- Search for “Oculus”
- Install the Oculus Package for your target platform

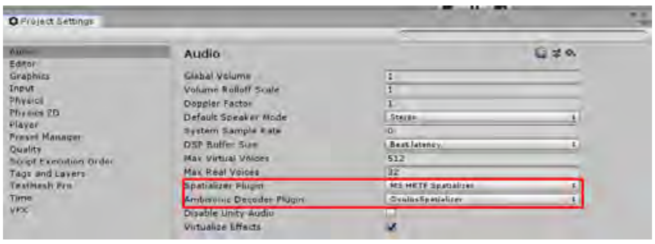

Figure 12.2 – Unity – Audio Settings

6.2 Scene Creation

Since every scene would consist of one video, 9 different new scenes were created and each scene was named after its respective video. These helps immensely since switching between videos would happen by switching separate scenes as it was considered the best way to manipulate several different videos in the project.

6.2.1 Video Setup

For every scene the process below was followed to create a panoramic video skybox[45]:

1) Create a new folder called “RenderTextures” and inside it create a new folder called “4096x2048” which corresponds to the dimensions of the imported videos.
2) Inside the “4096x2048” folder create a new render texture by right clicking into the folder and navigating to Create->Render Texture.
3) Set the size of the render texture equal to the size of the video you want to use it with. In this instance, the video’s dimensions are 4096x2048 and thus the size of the texture will be 4096x2048 as well as shown in Figure 12.3.
4) Duplicate the render texture enough times to be equal with the amount of videos you want to use.
5) Name each render texture after its corresponding video’s name
6) In the editor, open the scene that was just created and drag the video you desire into the project panel. Unity will automatically create a new VideoPlayer with the video that was dragged. Name the VideoPlayer component after the respective video’s name.
7) Click on the VideoPlayer component and in the Inspector window create a new tag named after the respective video of the video player component as shown in Figure 12.4
8) In the Inspector window of the VideoPlayer drag the corresponding render texture that was created into the Target Texture field as shown in Figure 12.5

45 Getting Started with 360 Video – 360 Video Skybox [3/08] Live 2018/03/01 - https://www.youtube.com/watch?v=nf2Jb6tk1GY&t=297s

9) Press the Play button. You'll notice that the video plays without image but the audio can be heard. By playing the video a new frame for the render texture is created. This is evident by clicking on the video's corresponding render texture.
10) In the Assets Folder create a new folder called "Skybox Materials" and create a new folder called "4096x2048" inside it.
11) Create a new material by right clicking inside the folder and navigating to Create -> Material.
12) Click on the material that was created and in the Inspector window through the Shader dropdown list choose "Skybox/Panoramic" and in the Spherical(HDR) field click Select and choose the Render Texture that corresponds to the specific video you're creating the material for and set the following settings as shown in Figure 12.6.
13) Drag and drop the skybox material that was just created into the scene. You will notice that the skybox instantly changes into the respective video's view.
14) Hit Play in the scene editor to ensure that the video is playing and is in the 360 format.
15) Duplicate the material that was created enough times to equal the amount of videos you want to use and repeat steps 12-14 for every scene.

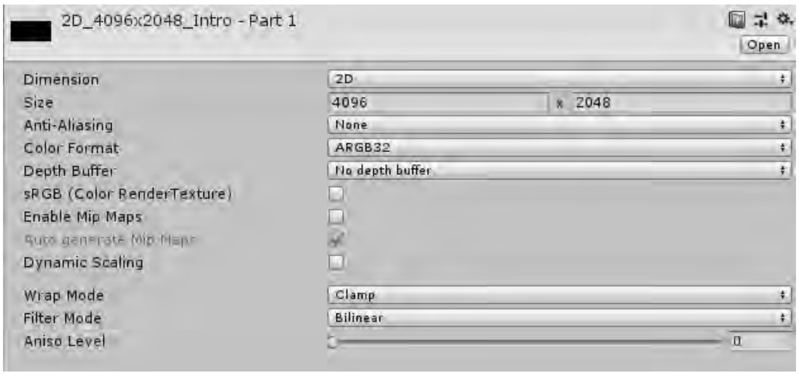

Figure 12.3 – Unity – Render Texture Settings

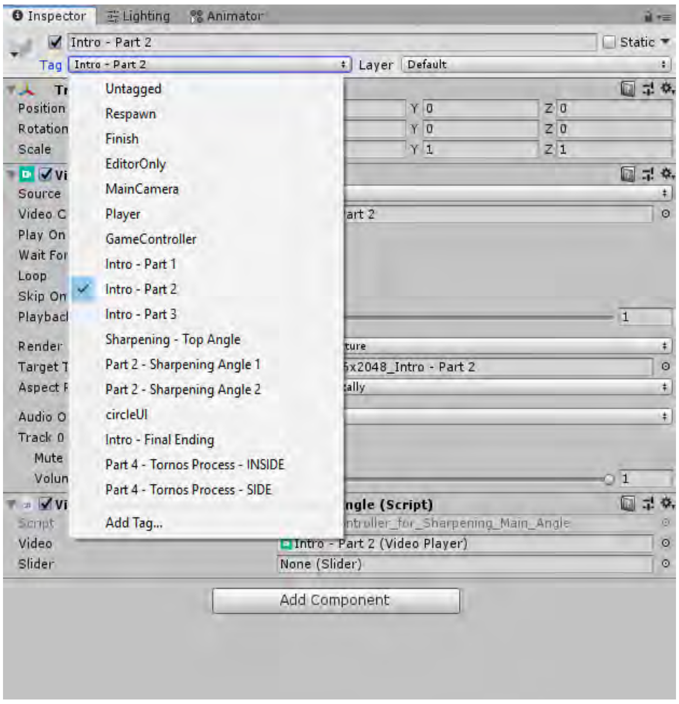

Figure 12.4 – Unity – Creating a new tag for VideoPlayer

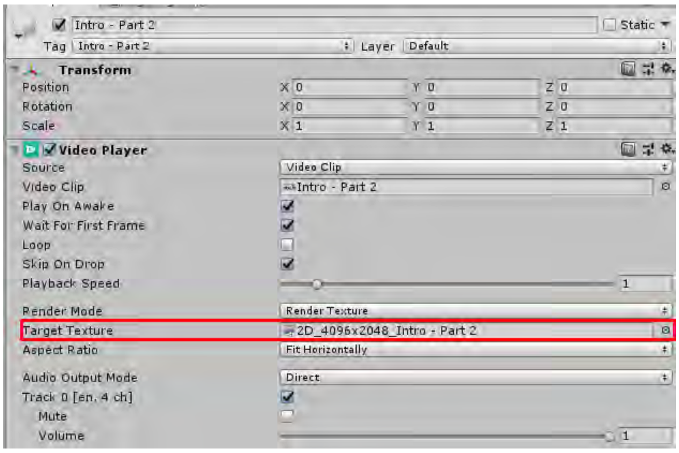

Figure 12.5 – Unity – Placing the render texture on the VideoPlayer component

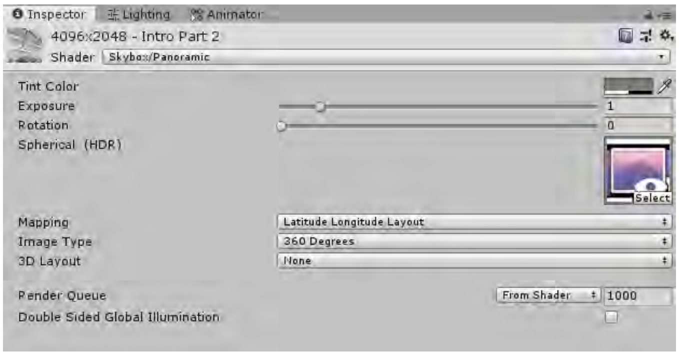

Figure 12.6 – Unity – Skybox Material Settings

6.2.2 Video Preparation

A crucial part in playing videos within a scene in Unity is preparing the video. In basic terms, what preparing the video does is, that all required resources such as the video and audio files are properly loaded into the current Unity scene so that they can be played properly without any stuttering. Thus, on every VideoPlayer component, depending on whether the video is the main video of a scene or an extra angle video (the ones where the user can switch to within the main scene) the following scripts are attached to them respectively:

- VideoController_for_Sharpening_Main_Angle
- VideoController_for_Extra_Angles

In both scripts, the most important part is the video.Prepare() method that is called within Awake() to ensure that upon a scene loads, the video is instantly prepared. As soon as a video is prepared it can be validated whether its prepared or not by other scripts by using the method video.isPrepared() which returns a boolean result regarding the state of the video.

Upon preparing the video, any kind of function included in the VideoPlayer API can be used such as video.Play(), video.frame or video.Pause().

To understand whether a specific alternative angle had finished the method loopPointReached() was used in the scripts of the alternative angles.

More information regarding the two scripts mentioned above can be found in Annex B.

6.3 Creating the main introductory scene

The tutorial has to start off from the introductory scene called "Hotspot_Sharpening_Tornos" which consists of the video "Intro – Part 1" in which the instructor greets the viewer and demonstrates the various tools that are used in the lathe machine operation. Since the user would navigate from one scene into another when using the tutorial, only one camera had to be used that would move in-between scenes without being destroyed. Thus, a main camera was created.

6.3.1 Scene Components

The scene consists of the following components:

- **MainCamera-Gaze:** This is the main camera that was created to navigate through the different scenes of the tutorial. It is also used for gaze-based interaction with various GameObjects included in the scenes. To enable the gaze-based interaction a red reticle UI is attached on top of the MainCamera-Gaze GameObject along with a circular highlighted image which reveals itself as a loading bar when the user gazes upon an interactable object. **It is important to note that the Field Of View was set to 80 in the camera's Inspector Window to offer a bigger field of view to the viewer.** Additionally, the main camera was tagged as "MainCamera" and all other cameras used in the remaining scenes for developing purposes were tagged as "Untagged" so that the main camera always overrides the existing cameras in other scenes.
- **VideoManager:** The VideoManager GameObject is responsible for controlling all the scenes the main scene would switch to. Every additional scene that is used within the project is selected and loaded through the Game Manager Script that is attached on top of the VideoManager GameObject. Additionally, the VideoManager includes a Fade option which basically causes the fade in/out effect when switching between scenes for smoother transitions.
- **FadeOut:** The black image used to imitate the fade in/out effect when switching scenes

- **Loading:** The animated "Loading…" text that appears when transitioning from one scene to another.
- **Hotspots:** This is the hotspot manager that controls all the hotspot GameObjects that are included within a scene. This is a prefab taken from the 360 Interactive 360 Sample Project. Through this prefab, one can create interactable GameObjects (Hotspot1, Hotspot2….) to trigger various functions when gazed upon. The Hotspot Manager is shown in Figure 12.7.

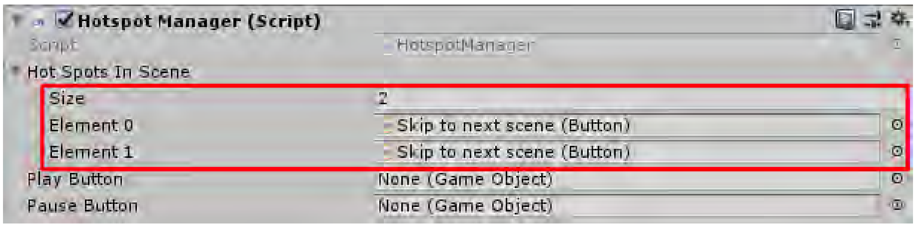

Figure 12.7 – Unity – Hotspot Manager Settings

Since the camera had to be preserved across all the scenes along with the VideoManager and the FadeOut image, all these components had the DontDestroyOnLoad method applied to them.

6.4 Connecting all the scenes together

As mentioned earlier, the VideoManager component is responsible for switching between scenes through the Game Manager script that is attached to it. The switching of the scenes can be triggered by two ways:

- When the video of the current scene finishes
- When the user gazes and triggers a hotspot which skips the current scene and loads the next scene

When either one of these two events happen the method SelectScene is called and the process of changing to the next scene begins. Due to the nature of how differently these two events work, when the video of the current scene finishes, SelectScene is called through the Update method of the GameManager script whereas when the user gazes upon a specific hotspot, SelectScene is called through the

HotspotButtonGaze_SelectScene script attached on that hotspot component. The details about how these specific scripts work are referenced in Annex B.

6.4.1 Switching Scenes and playing videos from a specific part

In scene "Intro – Part 2 – Sharpening Machine" the user is presented with two additional options for different viewing angles of the sharpening process in the form of interactable spheres as shown in Figure 12.8.

Figure 12.8 – Unity – Angle Options in form of Spheres

Upon gazing on one of the two spheres the scene swaps to one of the alternative angles to demonstrate a better view of the sharpening process. When the alternative angle scene finishes, the scene "Intro – Part 2 – Sharpening Machine" is loaded again and its video starts playing from the moment the user had previously chosen to switch scenes. This helps immensely in preserving the continuity of the tutorial, since the user will not have go through the beginning of the Sharpening Machine video and continue from where they left.

This was possible by saving the frames of the video in scene "Intro – Part 2 – Sharpening Machine" into the variable savedFrames in the GameManager script right until the moment the user gazed upon one of the two spheres. Then, when one of the two alternative scenes is done and the GameManager proceeds to loading the previous scene which is "Intro – Part 2 – Sharpening Machine", the scene's video is skipped to the amount of frames saved in variable savedFrames in the VideoController_for_Sharpening_Main_Angle script through the prepareCompleted() method as shown in Annex B. Thus, the video starts playing from the moment the user decided to switch scenes.

6.5 Adding Hotspots to scenes

As previously mentioned, every scene integrates an amount of hotspots which provide various forms of interaction within the scene. These hotspots were customized to the needs of the project and they perform the following:

- Revealing popup messages that inform the user regarding a specific tool
- Skipping to the next scene when viewing the tutorial

<u>These actions were achieved by attaching either one of these two scripts on a Hotspot GameObject within the "Hotspots" manager:</u>

- HotspotButtonGaze_SelectScene
- HotspotButtonGaze_UI_Show

6.5.1 Hotspots that reveal information

For instance, in the scene "Hotspot_Sharpening_Tornos" which is the main introductory scene, a Hotspot GameObject was duplicated numerous times to accommodate the amount of tool segments that needed explanation on the toolbox.

Each Hotspot had a Callout Canvas attached on it along with a Callout Panel which included the desired text that would pop up upon gazing that specific hotspot. By attaching the script HotspotButtonGaze_UI_Show on the Hotspot GameObject and setting the proper reference to its Callout Canvas in the "Canvas" field of the script, the revealing effect could be achieved as shown in Figure 12.9.

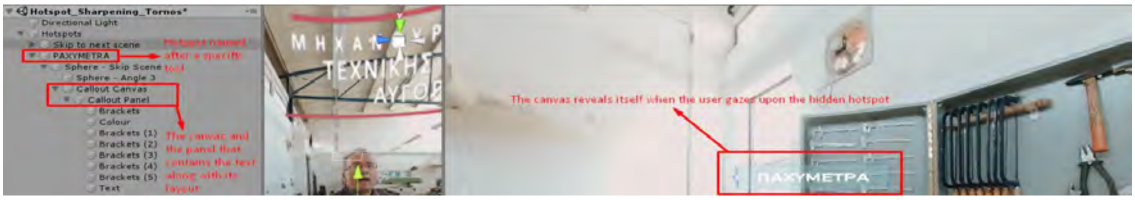

Figure 12.9 – Unity – Text Hotspot Reveal

6.5.2 Hotspots that skip scenes

Moreover, hotspots also have the ability to “skip” scenes by instantly looking at them and changing the current scene of the tutorial. These hotspots are present in scenes such as “Hotspot_Sharpening_Tornos” & “Intro – Part 2 – Sharpening Machine”.

To achieve this effect each hotspot that corresponds to skipping a scene has the script “HotspotButtonGaze_SelectScene” attached to it.

The way the script works is that upon gazing at the hotspot, a coroutine initiates the filling of the selection radial. As soon as the filling of the image is done, the method SelectScene(<scene_name>) is called and the corresponding scene is loaded through the GameManager script. An example of how the script works is shown in Figure 13.0.

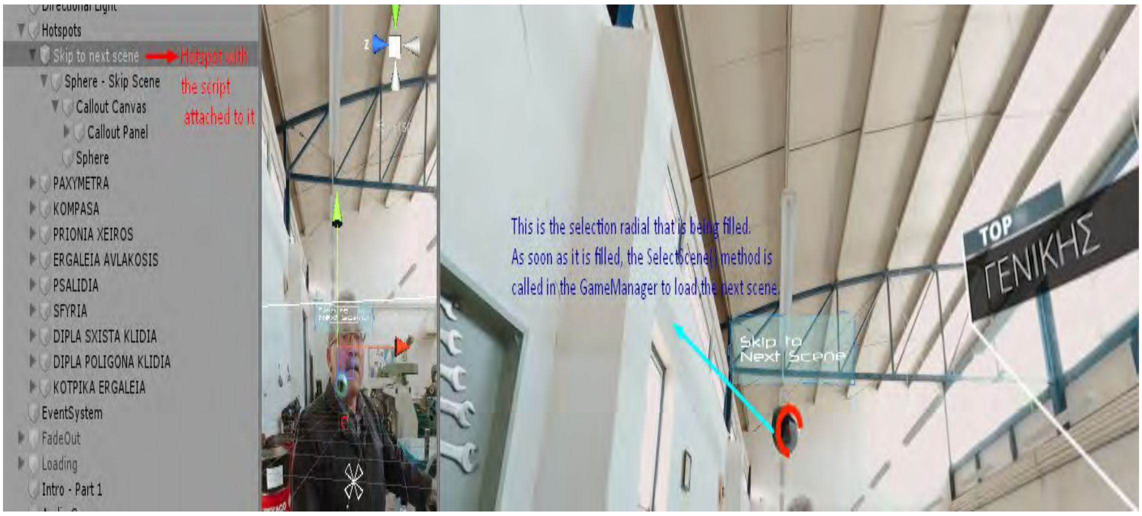

Figure 13.0 – Unity – Hotspot that skips scenes

6.6 Adding Sound & Animated Objects in the scenes

The scenes consist of a few basic sound effects that are triggered when the user gazes and selects certain hotspots within the scene to receive the appropriate feedback which in turn validates his selection. Sound effects also help into further enhancement of the user experience within a VR environment, as well as giving the acknowledgement to the user that something is clickable/interactable. Moreover, a few animated objects such as spheres and directional arrows were implemented into the scene to provide cues and hints as to where the user can look. An addition to the animated objects were also the use of textbox layouts which gradually revealed themselves at the beginning of specific scenes.

6.6.1 Sound Effects used in the project

The sound effects that were used in the project were provided by the Interactive360 Sample project of Unity which includes two very basic but yet effective sound effect regarding the user’s item selection. The aforementioned sound effects are called “MenuGazeOver” and “MenuSelect” and they were used for any kind of interaction between the user and the hotspots located within the scenes.

The implementation of these sound effects into the scenes was achieved by creating two separate Audio Source components within all the scenes that had hotspots and attaching those AudioSource components as references in the hotspots’ script’s audio fields.

6.6.2 Integrating Animated objects to enhance interactivity and user control

In various scenes such as “Hotspot_Sharpening_Tornos” or “1.MainMenu_Gaze” hotspots appear in the form of animated spheres that rotate and several guiding arrows are spread across the screen as seen in scene “1.MainMenu_Gaze” to guide the direction of the viewer in case they are lost.

Starting with the animated spheres, the spheres are located at specific spots within the scenes that do not prevent the view of the user by blocking important parts of the video

(Such as the instructor's head for example) and they consist of a frame of the video that follows when skipping to the next scene as shown in Figure 13.1.

Figure 13.1 – Unity – 3D Sphere of next scene

To properly place any kind of object within a 360 scene in Unity, the desired 3D object is created and then its position is aligned properly by playing the scene and adjusting the position of the object relative to how it looks in Play mode. This takes an amount of trial and error till the desired position and look is achieved.

Moreover, since every hotspot included an image and a collider on its own, the image was first used to properly align the sphere at the same position of the hotspot by using the image's position. Then, the image was disabled through the Inspector window and the collider of the Sphere was disabled as well to prevent any kind of interference with the VR Interactive Item script on the hotspot which triggered the aforementioned actions above. An example of the alignment was done is shown in Figure 13.2

The spheres were also animated to slowly rotate during the entirety of the scene by using the Animator and keyframing the Rotate value in the Transform Settings.

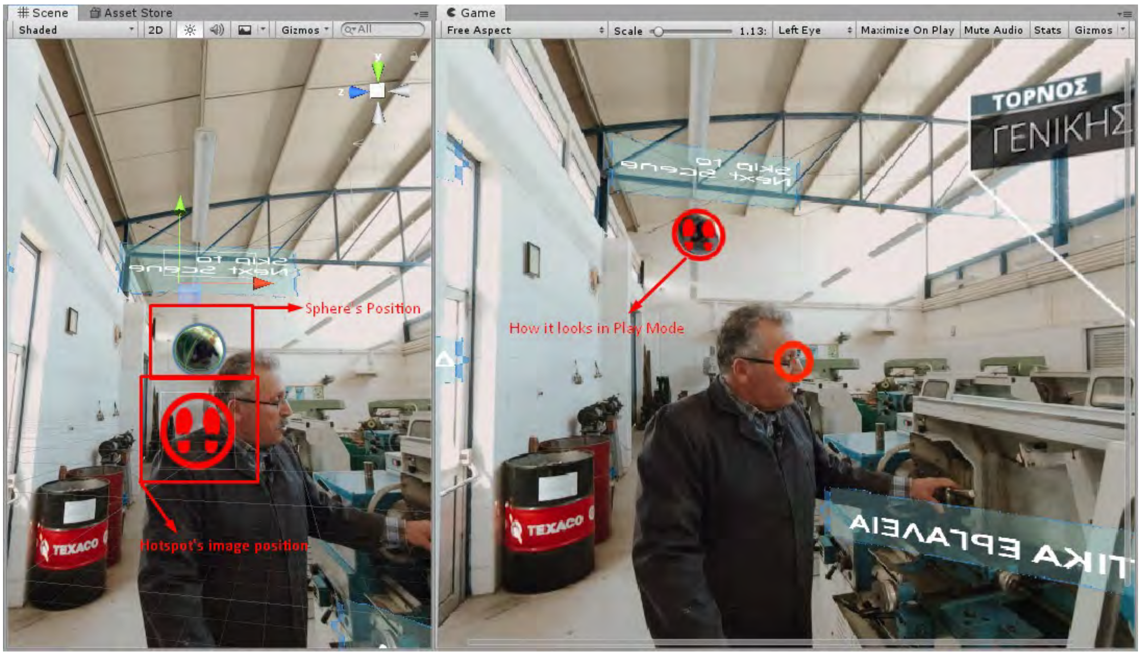

Figure 13.2 – Unity – Hotspot placement adjustment

In addition to the spheres, several text elements were added in the scenes and more importantly in the introductory scene at the toolbox. The placement of the of the text elements follows the same principles as the placement of the spheres which includes several attempts of trial and error till the proper position is achieved. However, an important thing to note is that, on the Callout Canvas the script "Canvas Face Camera" script provided by Zenva Tutorials[46] was used so that the text always faces the direction of the camera. An example of how the text titles were placed is shown in Figure 13.3.

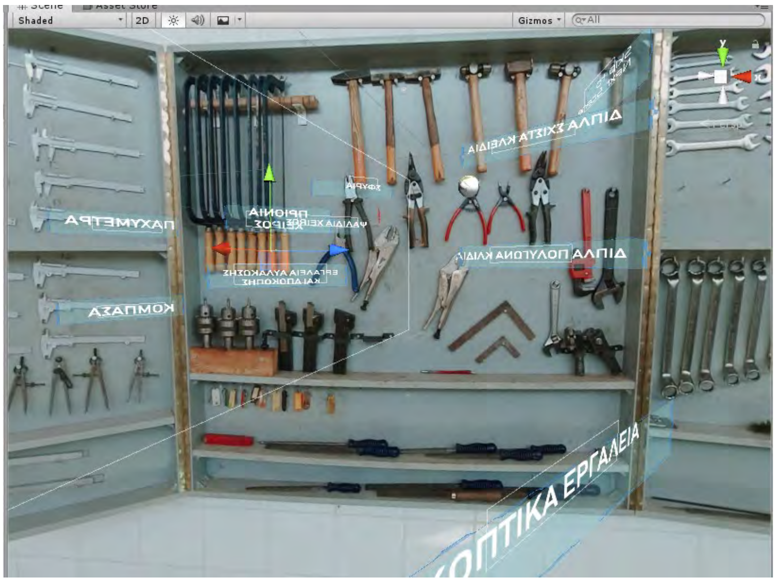

Figure 13.3 – Unity – Placement of text labels in introductory scene

46 *Zenva Tutorials - https://academy.zenva.com/product/unity-vr-development-360-photos-experience/*

Last, but not least, the guiding arrows used in scene “1. MainMenu_Gaze” were placed at the left and right side of the user’s initial field of view so that they would be guided to the proper direction where the Menu Selection is located. This was implemented after several tests were conducted with a prototype of the project on individuals which mentioned that they were initially lost and did not know what to do in the scene. To further enhance the guidance of the arrows they were animated to move towards the direction they are pointing.

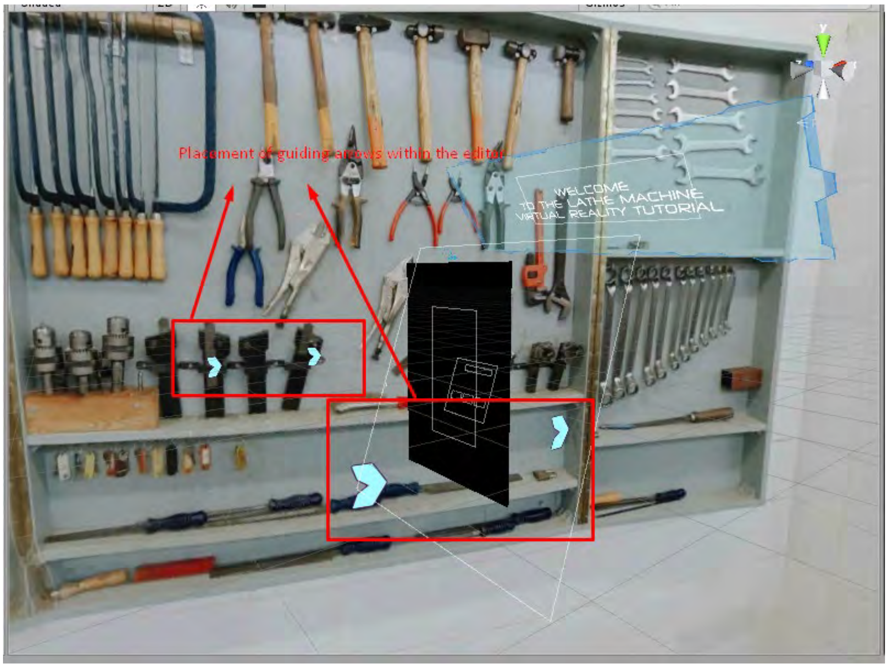

Figure 13.4 – Unity – Placement of guiding arrows in Edit Mode

Figure 13.5 – Unity – How the guiding arrows look in PlayMode

6.7 Android Development

As the project is targeted for Android Devices the proper configuration has to be setup in Unity prior to exporting the final APK for the most optimal playback. After numerous tests, experiments and research, the procedure that follows is considered the best method to properly setup Unity for VR apps on Android.

6.7.1 Installing the required Android SDK & JDK

The first thing to do when developing an android app in Unity is to install the appropriate Android SDK for the targeted Android Devices. Since the lowest compatible Android Version for VR is Android 5 (Lollipop)[47] and the current highest available Android Version as of the writing of this thesis (25-04-19) is Android 9 (Pie), the API Level was that was chosen during the Android SDK installation was Level 28. It is recommended to always choose the highest API Level through the Android SDK Manager during the android sdk installation instead of Unity. The steps that were followed to install the appropriate Android SDK & JDK are located in this video[48].

6.7.2 Setting up the proper Android SDK & JDK Paths in Unity

Upon installing the appropriate Android SDK as mentioned in Chapter 6.7.1 the Android SDK & JDK paths have to be defined. This is done by navigating to Edit->Preferences -> External Tools. Below the Android category, at the SDK field click Browse and locate the folder in which the Android SDK is installed.

Regarding the JDK Path, below the JDK category, at the JDK field click Browse and locate the folder in which the JDK is installed as shown in Figure 13.6. Please note Android Development in Unity works SOLELY with JDK 1.8 due to the JVM used in Android Devices.

47 What do I need for Virtual Reality? - https://support.matterport.com/hc/en-us/articles/224728887-What-do-I-need-for-Virtual-Reality-

48 How to setup Android SDK + JDK With Unity 2018 - https://www.youtube.com/watch?v=ojt7ITyklGk&t=615s

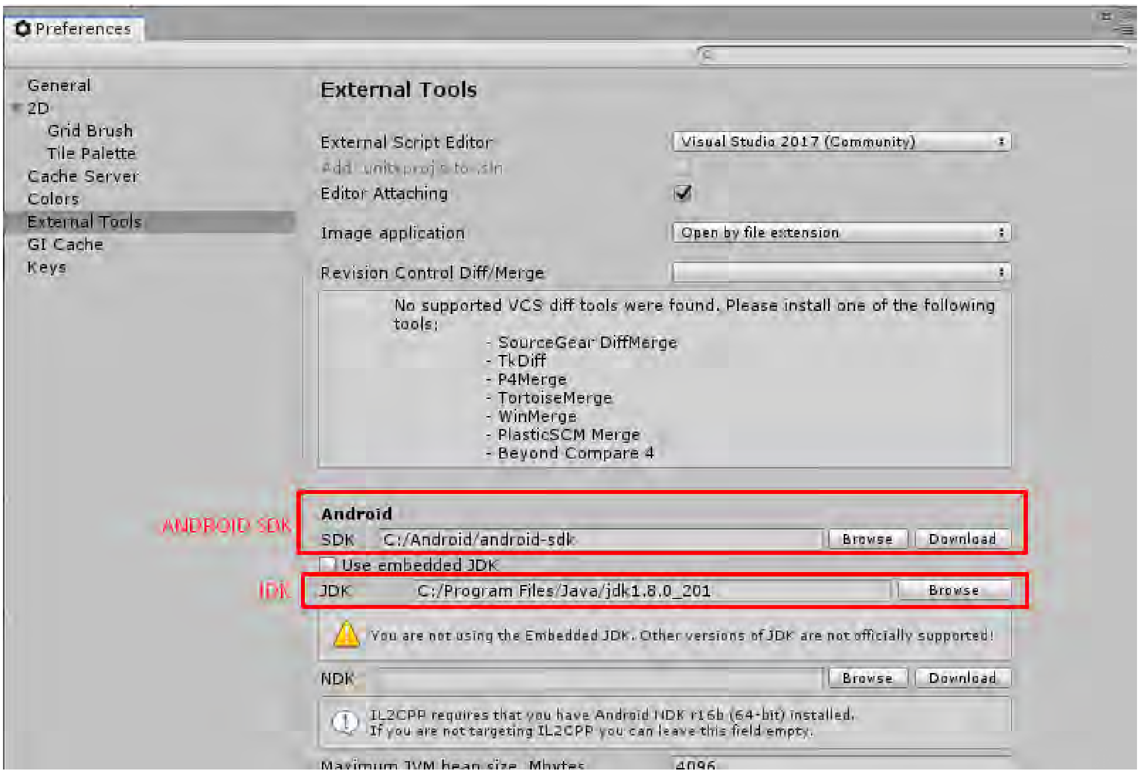

Figure 13.6 – Unity – Android SDK & JDK Paths

6.7.3 Android Export Settings

There were many failed attempts where the exported APK did not start at all or crashed when experiment with it on a OnePlus 6. After further research and trial and error the following export settings that are accessible through the Player… menu in Build Settings were chosen for the most optimal playback as shown in Figure 13.7:

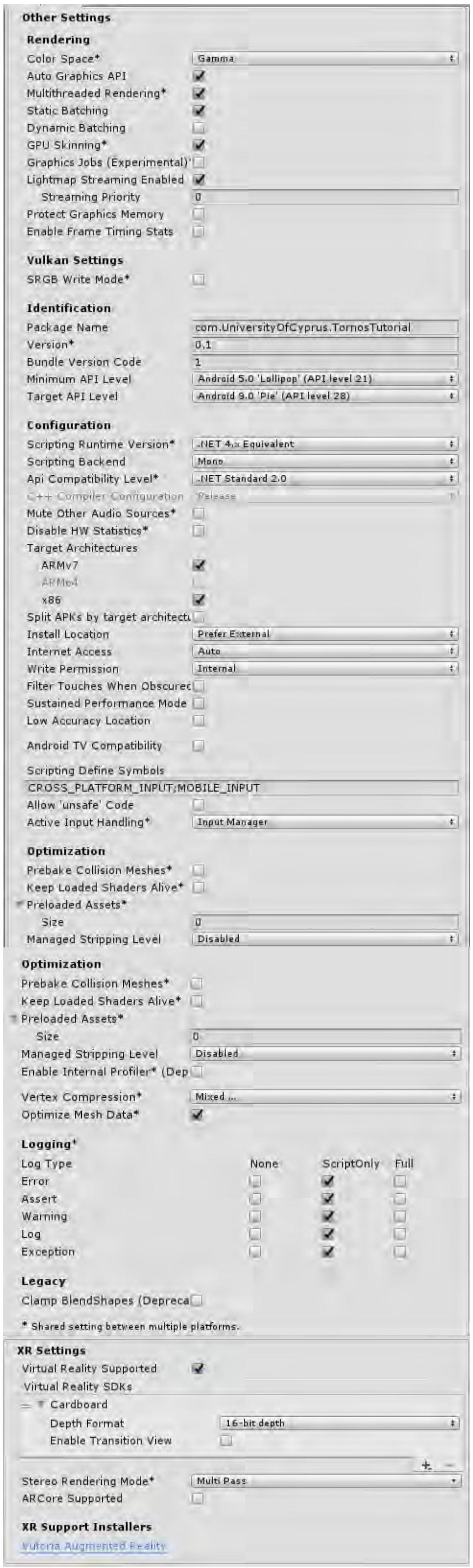

Figure 13.7 – Unity – Android APK Export Settings

Chapter 7

Evaluation Analysis

7.1 Initial feedback

When the first version of the application was released (when only one filming session was done), the application was given to Dr. Kleanthis Neokleous to test the features that were implemented in the VR app. Upon using the app, Dr. Kleanthis pointed out that in the introductory scene the toolbox located in the lathe machine laboratory was way too close to his field of view (due to the positioning of the camera) when viewing the tutorial through VR Goggles and that led to symptoms of dizziness. Additionally, the audio recordings were of poor quality since the camera's built in microphones were used and the 360 audio experience was not as immersive as he pointed out. Moreover, the stitching between the lenses caused digital artefacts during the video playback which also contributed to the feelings of dizziness as Dr. Kleanthis said. The same version of the app was also tested by the client, Mr. Thomas Antoniou, who on first inspection, was very pleased with the results of the footage and he explicitly expressed how immersive the tutorial was. However, he agreed that the toolbox was way too close and that an additional re-filming had to be scheduled.

7.1.1 Participant Feedback

The app was also given for testing to various computer science students of the Human Interaction course taught by Dr. Kleanthous Styliani Loizou in the University Of Cyprus to gather more feedback from individuals who may or may have not experienced VR before. Firstly, the app was tested by Dr. Loizou who had a deep background of human interaction theory. While navigating through the tutorial, she said that more UIs should be present in various spots of the scenes to indicate that 3D objects can be interacted with because it was not clear from the start that various spots in the scenes could be interacted with at first glance. She said that no guidance should be needed by a third party (such as the developer) when viewing the tutorial and that everything should be easy and self-explanatory to the user viewing the tutorial. Additionally, she said that more functions should be implemented such as skipping or changing scenes on demand since the viewer may not want to watch the entire tutorial from the start. Overall, she insisted that the experience was immersive and enjoyable even for a tutorial that explains a subject out of her field.

Then, the VR tutorial was also tested by 5 computer science students who had no prior VR experience before. For most of the participants, there were no issues with the navigation and exploration of the mobile application. At first glance, they knew exactly how to place the mobile phone in the goggles and started navigating through the tutorial. One student described the application:

"You feel like you are in the room with the instructor yourself and taking action rather than just standing somewhere remotely and watching a boring procedure. This actually makes you feel part of the entire procedure that's taking place".

Another student said:

"The tutorial was 6 minutes long and I didn't feel time passing by, there was always something more to do or watch as the tutorial guided you through the entire process."

To the contrary though, one out of the 5 students noted:

"The quality of the image is a bit blurry at first but you get used to it as the tutorial progresses."

Who then explained that this may be due to the quality of the VR Goggles that was given to them, which was indeed the case and the VR Goggles were immediately swapped for a pair of better quality ones.

7.2 Final Version of the VR App

After re-shooting and re-editing the 360 tutorial videos as described in Chapter 4 and taking into consideration the initial feedback that was given, the app was further enhanced with a better field of view, a plethora of interactive elements and crystal clear audio. Prior to giving the app to participants for testing, the app was tested again by Dr. Yiorgos Chrysanthou, Dr. Neokleous and Mr. Antoniou to further experiment and validate the components that were implemented into the 360 tutorial.

When Dr. Chrysanthou first watched the tutorial he was amazed by the quality of both the image and audio. He explicitly said how professional the overall result looked and he mentioned that he instantly noticed the 360 audio. Additionally, he mentioned that the popup closeup videos were a very nice addition to the experience as they offered a closer view which was perfectly timed with the action that actually took place in the VR footage. He also liked that the user had the option to switch scenes and the gaze-based interaction was very intuitive and easy to use as no controllers were needed as well.

Upon launching up the tutorial, Dr. Neokleous pointed out how much better the field of view of the tutorial was as it offers an extremely intuitive and immersive experience. While navigating through the scenes within the tutorial he expressed his excitement regarding the precense of true ambisonic audio which was evident by the change in audio gain within his headset when moving his head. Additionally, Dr. Neokleous said that the video quality as well as the audio quality were very satisfying for Android Devices. Moreover, he said that the interaction between the user and the 3D objects was easy and navigation throughout the tutorial was clear as the instructor present in the video directed his attention where needed. Finally, he emphasized the importance of implementing a similar app in educational institutions as a project of this caliber and nature, has high learning potential through Virtual Reality.

When the app was tested by Mr. Antoniou, he instantly commented on how real the experience felt and he said it did not feel like he was watching a video at all, but rather, that he felt part of the process and the place in the virtual tutorial. He was very impressed by the motion tracking titles that appeared on the tools demonstrated by the instructor in the video and he also said that the field of view was perfect compared to the initial version of the app. Next to that, he was very persistent on the fact that this project has high potential in academical applications and he was eager to cooperate further in regards to developing even more similar projects for school courses. He said that VR technology is the new way of learning and students of today would be greatly benefited by leveraging everything virtual reality has to offer. Finally, he expressed how pleased and satisfied he was with the final result and could not wait to show his students the final result.

7.3 General Findings

According to the feedback that was collected from the population sample regarding the use of the mobile applications, the majority of people who tested the VR app said that they have used an educational application before. Some used them in their free time to learn about different topics such as languages and brainteasers while others used applications to help them with their studies in mathematics and programming.

When they were asked about their experience with the applications, 20 out of 25 subjects who used mobile applications for education said they had a positive experience. A student mentioned that it was a good way of killing time while learning. Others who did not find mobile applications useful mentioned that they rarely used them or could not learn anything from the applications.

Additionally, it was found out that 15 out of 25 subjects have previously used a VR device and the responses of the experience with VR were mixed. For instance, when asked about their experience, one student who had a positive experience with VR mentioned that it was very unexpected; it felt real and has lots of possibilities. On the other hand a student who was not fond of the experience felt that it was only interesting for the first 30 seconds and that she ended up getting motion sickness and headaches. Another student felt that he was not fully immersed and it was lacking, which could have been caused by the resolution of the screen or the adjustments of the lenses as he explained. Two particular students emphasized that they had never used a VR device before and did not know what to expect by using the VR Tutorial that was developed in this project.

7.4 Prototype Testing

7.4.1 Non-VR

For most of the participants that tested the final version that was described in Section 7.2 above, there were no issues with the navigation and exploration of the mobile application that was developed. One student from the Computer Science Department of the University Of Cyprus described the application:

"The audio immersiveness is something that I have not experienced before. You can clearly feel that someone is behind you speaking if you completely rotate your view 180 degrees."

Another said:

"There's so much interactivity within the first scene already. Especially, when the instructor starts explaining all the various tools on the toolbox you can easily see the names of the tools as easily as taking a glance at the tool, no controller needed".

During the testing the participants were also asked whether the text in the graphical elements that appeared was readable and whether the popup videos distracted them from paying attention to the actual tutorial that was taken place. Most participants, found the graphical elements and the popup videos very appealing, one student who preferred the app said:

"I like how the graphical elements are perfectly timed to pop up as the instructor mentions them, it gives a sense of continuity and you instantly know which tool he's talking about. It is not distracting at all. When I watched the instructor operate the lathe machine I was wondering how I could have a closer look until the popup videos with the closeup angles appeared on the screen. That was a very clever addition and it instantly solves any kind of issue of a VR camera not being able to reach tight places. I love it."

While another participant who works as a graphic designer mentioned:

"Some of the graphical elements and 3D Spheres should be placed at a more appealing spot to make them look as if they are part of the scenes. Most of the elements are placed nicely and they do not cause any intrusion, however I'd prefer the spheres to be placed in specific spots of certain scenes and have them glowing to make them more noticeable".

Additionally, the participants were asked if there was too much information popping up at once and if that caused them any type of confusion, the response from one student who had tested the first version as well was the following:

"The final version of the tutorial is much better than the first, especially in the introductory scene where every graphical element pops up in a slower place at the toolbox as the instructor speaks and with more subtle sound effects. The sound effects that were initially used in the first version were very disturbing and did not match the style of the video. The sound effects used in the final version are elegant and do not cause any type of irritation to me."

And Mr. Antoniou said:

“Being present both in the filming and the testing of this application, I have to say that everything is positioned perfectly across all the scenes and information is spread evenly in every part of the tutorial. As a teacher who teaches the material of the tutorial, I have to admit that my students would be relieved to watch this.”

The participants were also asked whether the background elements and the surroundings were distracting while reading the text labels that appeared on screen, since they were a key part of the tutorial. One student mentioned:

“I would say mostly I don’t see the surroundings when I’m reading something on the screen. More often than not I can clearly read what appears on screen but sometimes it may be a bit distracting.”

And Mr. Antoniou also commented on this:

“I think it’s not distracting, in fact it would help. I would use it as a teacher to introduce a subject to my students. It directly navigates your view where needed.”

Overall, it was a very positive experience and according to one student:

“I would prefer this way if the university or schools were providing us with such applications, we would learn more and enjoy learning at the same time. I can think of many situations where a VR course would be simultaneously applicable and helpful.”

7.4.2 VR

The VR experience was pleasant for the most part, there were no issues for most participants to navigate and explore the application. The issues that did occur were mostly about the placement and adjustment of the Goggles until the desired view had been configured. The majority of the participants found VR to be an interesting and enjoyable experience. One student of the Science of Education department said:

"I feel really concentrated to the tutorial, the main reason is that I don't get disturbed by the surroundings and just focus on what I am supposed to do."

And another student who never tried VR before said:

"I'm amazed, I never used Virtual Reality before but I would love to learn more about the subject demonstrated in the tutorial, even though it is not related to the course of my studies!"

Another student compared the VR application to YouTube VR Videos they casually watched and said:

"Most VR videos on YouTube are either a showcase of landscapes or drone shots above cities with nothing exciting. I never expected a VR tutorial to be this exciting and I'm not a person who reads a lot of text, but now that it's in front of me I just want to read it."

Mr. Antoniou also presented the app to one of his students who mentioned:

"I never thought I would ever see my teacher in a VR video, let alone him being the lone actor of the tutorial. It was really fascinating to see the material of my class in a VR video and it certainly makes it more exciting to learn!"

Regarding the learning aspects of the VR application, a female student told us:

"Since a lot of people learn better with emotions and audiovisual cues, when you are greeted to the tutorial by the instructor, you instantly connect with him as he guides you through the tutorial. You associate with the material on hand and it might help you learn better, it's really nice."

It was also pointed out by another student that:

"The VR app presented a different way of learning, a more modern and targeted method of teaching which aligns with the current trend of the young generations. This could become a new era of learning and teaching, both for teachers and students."

The participants were also asked whether they experienced any unpleasant feeling while or after using the VR application. One male student who never had an experience with VR before and got motion sickness as soon as he wore the VR Goggles said:

"As soon as I wore the VR Goggles, I got very dizzy, I could not handle the field of view and I felt symptoms of nausea".

However, as he explained this may had been related to him not getting used to wearing VR Goggles and not having a screen so up close to his face.

One concern that was raised by a few participants who at the time did not experience anything was that they believed longer exposure with the VR application would result in headaches. After testing the application, it was apparent that, this was not the case as the majority of the participants watched the full length of the tutorial which was 7 minutes long without removing the headset. Out of the 25 participants who tested the VR app, 20 had no sickness after using the tutorial, 2 out of 25 participants felt a bit dizzy, 1 out of 25 felt minor unpleasantries and 1 out of 25 participants felt extreme nausea and headaches.

7.5 Overall Conclusion

Overall, the VR application received a very good amount of feedback regarding the functionalities and interactivity of the tutorial. The entirety of the participants mentioned that such an application would have a great impact in educational scenarios as it combines both learning and playing in a smart way. After testing the VR app, the participants were asked whether they would consider buying such an app to help them with their studies or courses if it was to be released to the public. 23 out of 25 participants said they would consider buying it with consideration of the final price.

Additionally, Mr. Antoniou was asked whether he would be interested in integrating more VR material into his school and he remarkably mentioned that his supervisor was very excited and eager to move forward with this project as he had many clever ideas to implement.

In a nutshell, it is evident that the current market for mobile educational VR applications, is mainly targeting a younger audience and therefore it does not appeal to the broader public, since the participants of the study consist of mainly high school and university students with educators. Therefore, we can conclude that VR is highly efficient and beneficial in the educational field.

Chapter 8

Discussion - Conclusions

8.1 Conclusion

We set out to evaluate the learning potential of a VR Tutorial that was based on the highest interactivity level possible within the area of education. In order to accomplish this task, we to make sure that the VR application was being evaluated in terms of interactivity and experience by various individuals of different backgrounds to reach the most trustworthy and unbiased results. To accomplish this, we firstly had to make sure that we had the proper background knowledge regarding the factors that affect the interactivity in the VR world established as well as the required filming experience that would aid in both directing and editing the footage that was shot. After developing and testing the application we gathered our feedback from the tests that were conducted on various participants as mentioned in Chapter 7, where we let the participants try the application on their own and then provide their insight regarding their experience and the interactivity of the tutorial.

In the Evaluation Analysis that was conducted as well as the initial research that took place in Chapter 1 which is also further explained in Annex C, it was found that the important characteristics of VR consist of, first and foremost the immersive experience, where the user can be a part of the virtual world; this provides the user with the sense of exploration and involvement in Virtual Reality. Virtual Reality is also an active experience, especially when VR incorporates active learning. Because the user is so immersed and involved into the virtual world they're experiencing, they concentrate a lot more on the Virtual Reality while simultaneously becoming isolated from the real world.

A very important discovery was that the benefits of using VR are that it paints a picture of the subject, in this case, the lathe machine operation which allowed the users to experience first hand what needs to be done in order to properly operate the lathe machine. In other fields, such as medicine, it has been used to show the anatomy of the human body. In parallel with that, it also allows users to perform tasks that carry safety concerns or tasks that cannot be achieved under real life circumstances. In the architecture and design field, it encourages users to be creative.

The most remarkable discovery however was, that VR technology, can actually be used in a variety of educational fields, mainly the fields that require simulation or 3D presentation. From simple subjects like interactive environments to teaching children about basic science facts and small lab simulations to a more advanced and higher education subjects like mechanical engineering, architecture and medical studies. The value Virtual Reality offers to these subjects is unprecedented in terms of what can be done and to what length, as the only thing that prevents someone from creating and learning in a virtual world, is definitely their imagination. Next to that, history and geography are other fields VR can be used into, to further enhance the learning experience of the students as it offers the ability to relive historical events or explore places in the world in a 3D virtual environment which will be the closest real life experience a student can get.

With VR becoming more affordable and accessible to the general public, it is definitely a necessary tool in education in the near future. The unique way of delivering information through an immersive virtual experience is something that cannot be rivaled or reproduced by any other type of tools used in education today and when it is used in the right way, VR can provide a tremendous amount of help for both educators and students alike.

8.2 Future Work

As previously mentioned, the benefits and features Virtual Reality offers are tremendous in terms of teaching and learning. The findings of this thesis prove that by the use of a mobile phone and the knowledge to develop a VR application can easily help solve problems that a solution could not easily be found before. Having that said, it would be even more intriguing if comparisons between VR and other educational tools such as the computer or tablet devices could be evaluated to further understand the impact of VR in education. Furthermore, more comprehensive studies regarding the actual learning benefits should be deeply explored and recorder over a longer period of time in order to see what kind of effects VR has on education compared to the traditional teaching methods. By doing so, we can further evaluate and prove the effectiveness of Virtual Reality as an educational tool.

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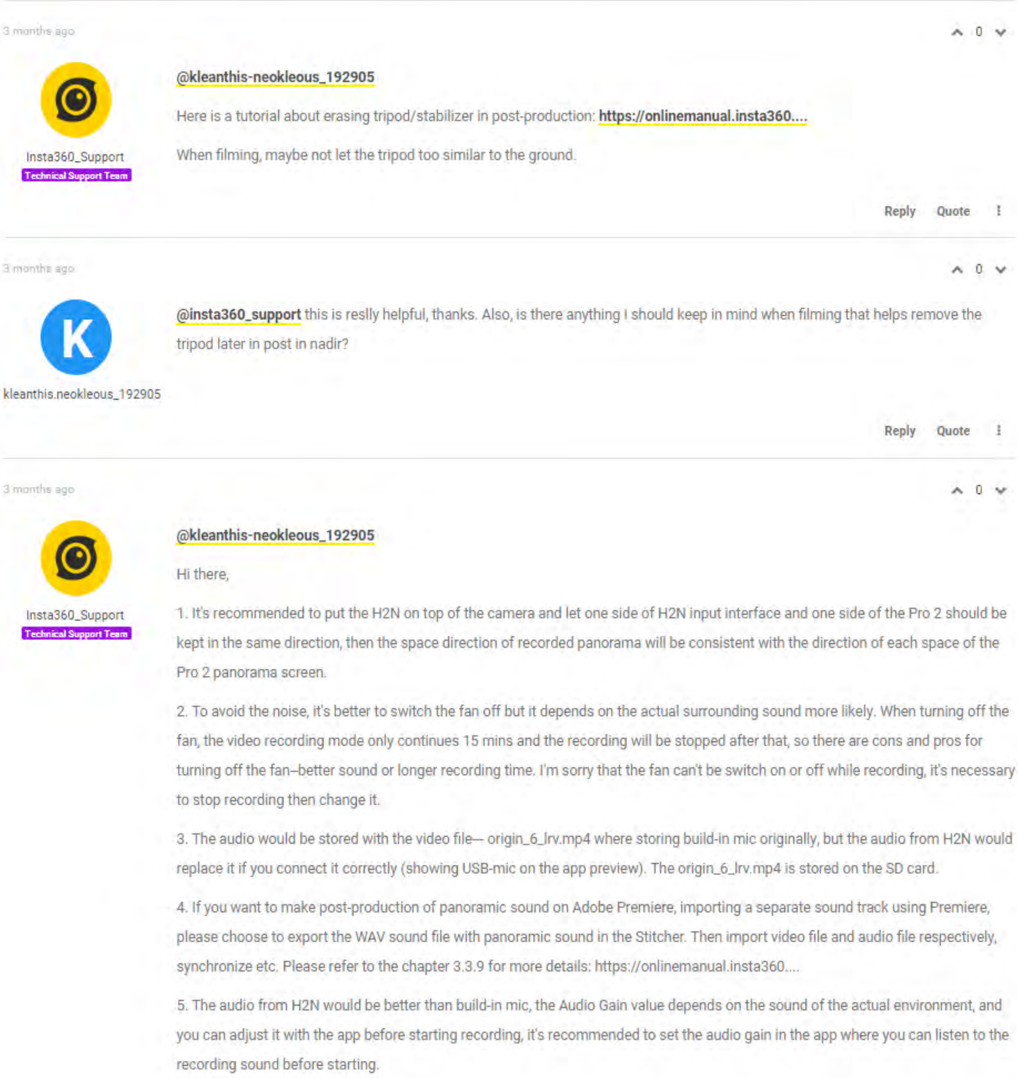
Annex A

This appendix includes the forum replies that were posted by the Insta360 Support forum and YouTube comments that helped during the development of the project.



3 months ago

Insta360_Support
Technical Support Team

@kleanthis-neokleous_192905

Here is a tutorial about erasing tripod/stabilizer in post-production: https://onlinemanual.insta360....

When filming, maybe not let the tripod too similar to the ground.

Reply Quote

3 months ago

kleanthis.neokleous_192905

@insta360_support this is reslly helpful, thanks. Also, is there anything I should keep in mind when filming that helps remove the tripod later in post in nadir?

Reply Quote

3 months ago

Insta360_Support
Technical Support Team

@kleanthis-neokleous_192905

Hi there,

1. It's recommended to put the H2N on top of the camera and let one side of H2N input interface and one side of the Pro 2 should be kept in the same direction, then the space direction of recorded panorama will be consistent with the direction of each space of the Pro 2 panorama screen.

2. To avoid the noise, it's better to switch the fan off but it depends on the actual surrounding sound more likely. When turning off the fan, the video recording mode only continues 15 mins and the recording will be stopped after that, so there are cons and pros for turning off the fan–better sound or longer recording time. I'm sorry that the fan can't be switch on or off while recording, it's necessary to stop recording then change it.

3. The audio would be stored with the video file— origin_6_lrv.mp4 where storing build-in mic originally, but the audio from H2N would replace it if you connect it correctly (showing USB-mic on the app preview). The origin_6_lrv.mp4 is stored on the SD card.

4. If you want to make post-production of panoramic sound on Adobe Premiere, importing a separate sound track using Premiere, please choose to export the WAV sound file with panoramic sound in the Stitcher. Then import video file and audio file respectively, synchronize etc. Please refer to the chapter 3.3.9 for more details: https://onlinemanual.insta360....

5. The audio from H2N would be better than build-in mic, the Audio Gain value depends on the sound of the actual environment, and you can adjust it with the app before starting recording, it's recommended to set the audio gain in the app where you can listen to the recording sound before starting.

Figure 13.8 - Insta360 Forum Reply – Audio setup for Insta360 Pro 2

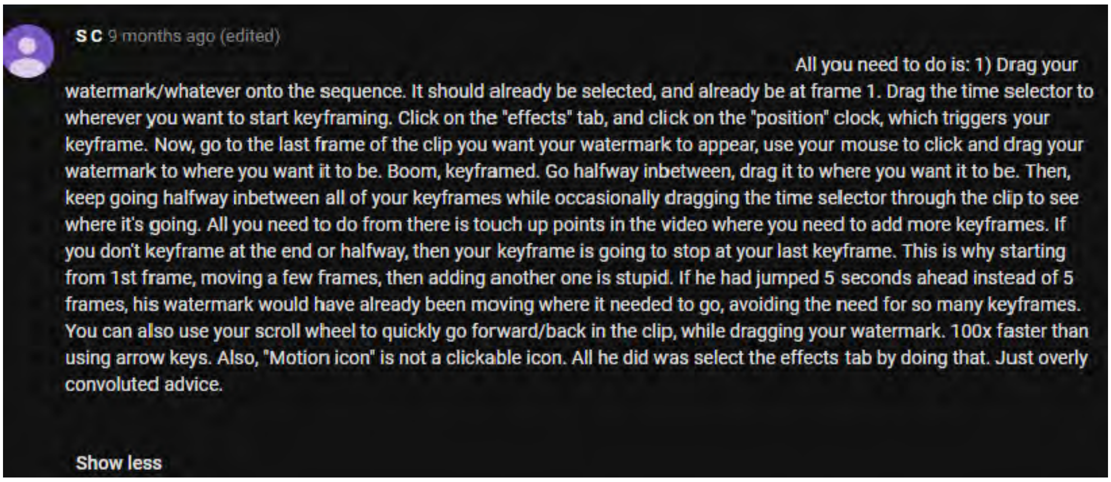


Figure 13.9 – Premiere Pro – How to manually motion track in Premiere Pro – S C

Annex B

This appendix includes the various scripts used in Unity to help speed up the development process as well as customized code to better cater to the project's needs.

<u>VideoController_for_Sharpening_Main_Angle - Loading the video from a specific frame and onwards:</u>

```
void prepareCompleted(VideoPlayer v)
    {
        // Prepares the video
        Debug.Log("The name of the Video Object in Main_Angle is " + video.tag);

        Debug.Log("Video Player finished preparing");

        // Checks if another angle was chosen by the user and skips to the
       last frame the video was paused at
        if(GlobalVariables.angleVideoDone == true)
        {
            Debug.Log("Angle change adjustment in the main video");

            // Skips to the last saved frames
            v.frame = GlobalVariables.savedFrames;

            // Sets angle changed to false
            GlobalVariables.angleVideoDone = false;
        }
        PlayVideo();
        isDone = false;
    }
```

<u>LoopPointReached method that is used in the extra sharpening angles script:</u>

```
void loopPointReached(VideoPlayer v)
    {
        Debug.Log("Video Player Loop Point Reached");
        isDone = true;

        // If sharpening machine angle is done then flag as true
        if(video.tag == "Part 2 - Sharpening Angle 1")
        {
            GlobalVariables.extraSharpening = true;
            GlobalVariables.angleVideoDone = true;
        }
        else if (video.tag == "Part 2 - Sharpening Angle 2")
        {
            GlobalVariables.extraSharpening = true;
            GlobalVariables.angleVideoDone = true;
        }
        // Checks if the SIDE shot has finished to switch to
       "Intro - Final    Ending"
        else if (video.tag == "Part 4 - Tornos Process - SIDE")
```

```
        {
            GlobalVariables.tornos_SIDE = true;

        // Checks if the INSIDE shot has finished to switch to
        "Intro - Final Ending"
        }else if(video.tag == "Part 4 - Tornos Process - INSIDE")
        {
            GlobalVariables.tornos_INSIDE = true;
        // Checks if the Intro - Final Ending scene has finished to switch to
       the  demo scene that indicates the end of the tutorial
        }else if(video.tag == "Intro - Final Ending")
        {
            GlobalVariables.finalEndingDone = true;
        }
```

<u>The coroutine that is responsible for changing scenes when gazing at a hotspot that changes scenes:</u>

```
private IEnumerator FillSelectionRadial()
        {
            // At the start of the coroutine, the bar is not filled.
            m_RadialFilled = false;


            // Make sure the radial is visible and usable.
            Show();

            // Create a timer and reset the fill amount.
            float timer = 0f;
            m_SelectionImage.fillAmount = 0f;

            // This loop is executed once per frame until the timer exceeds the
            duration.
            while (timer < m_WaitTime)
            {
              // The image's fill amount requires a value from 0 to 1 so we
              normalize the time.
                m_SelectionImage.fillAmount = timer / m_WaitTime;

                // Increase the timer by the time between frames and wait for the
                next frame.
                timer += Time.deltaTime;
                yield return null;
            }

            // When the loop is finished set the fill amount to be full.
            m_SelectionImage.fillAmount = 1f;

            // Plays the selection audio clip
            audio_select.Play();

            // Turn off the radial so it can only be used once.
            m_IsSelectionRadialActive = false;

            // The radial is now filled so the coroutine waiting for it can
            continue.
            m_RadialFilled = true;
```

```
    // call OnClick now that the selection is complete
    // m_Button.onClick.Invoke();

    // Load Specific Scene
    Debug.Log("Changing to the next angle!");
    GameManager.instance.SelectScene(nextScene);

    // Once it's been used make the radial invisible.
    Hide();

}
```

Annex C

This appendix includes the results of the research that was conducted after extracting the project's requirements by the client. Since the project was heavily dependent on the interactivity level of the project a research would further help understand what kind of knowledge and equipment would be needed to accomplish the highest interactivity possible.

What makes 360 video interactive:

Virtual reality video has seen exponential growth over the last few years. Ever since Virtual Reality video has come to everyone's attention, filmmakers and content creators alike have been constantly trying to create as immmersive 360 films as possible. This resulted in its own set of issues as filmmaking in VR vastly differs from traditional filmmaking. More specifically, guiding cues that work in traditional filmmaking such as match cuts, properly framed scenes to guide the viewer's attention, zoom ins and zoom outs and close-ups which contribute into catching the viewer's attention, might not work at all in Virtual Reality[1]. This is due to the fact that by using a head mounted display to watch 360 movies such as Google Cardboard for example, viewers have the freedom to choose the direction of view and as a result choosing the visible part of the movie. This leaves room for many issues, such as the user's misdirection or confusion since the user might not know where to look at and possibly missing an important part of the story in the 360 video. Based on the research conducted by Heinrich Hubmann[49] the attention of the viewer can be guided by sound, light and movements **within** the video. All these three elements can also be described as cues.

Diegetic and Non-diegetic Cues:

These cues are separated into diegetic and non-diegetic cues and they derive from film theory. In simple terms, diegetic cues are any type of elements that derive within the film a viewer is watching and they correspond to what they're seeing, such as a singer

[49] *Heinrich Hubmann et al., November 2017, p.1, "Diegetic Cues for Guiding the Viewer in Cinematic Virtual Reality"*

singing at a concert[50]. Non-diegetic cues are any type of elements that do not exist within the world of the video but enhance the experience of the user. These are added in post-production such as background music, voice-overs, animated guiding arrows or a HUD (Heads Up Display)[2]. Thus, when a viewer hears a sound in the 360 video they instantly search for the source of the sound and as a result they're guided towards the direction we want within the video even if the sound is not spatial at all.

Spatial Audio:

That being said Spatial audio is a crucial part of making an immersive 360 video to maximize the user's experience. Spatial audio can also be referred to as "ambisonic" audio which corresponds to a technique that mimics the way we hear in real life by using a full sphere surround-sound technique[51]. Spatial audio differs from the traditional surround sound as surround sound consists of 2 channels whereas spatial sound consists of 4 channels. Surround sound creates an audio image for a predetermined array of speakers such as 5.1 surround to six, 7.1 to eight which explains why it is a dual channel audio system.

Whereas, the audio signal that is created by an ambisonic sound recorder is not designated for any specific type of speakers but, it is rather adaptive to the specific array of the speakers that the ambisonic audio signal is decoded upon. Therefore, ambisonic audio can be played by any array of speakers and it has the ability to reproduce a full 360 sphere of sound regardless of the limitations of the speaker array. Therefore, when a viewer rotates the scene they are viewing through a VR headset, as the screen moves, the audio spreads amongst the screen evenly and smoothly and thus achieving a 360 audio signal which corresponds to the viewer's movement of the VR Headset[52]. As a result, a VR headset user can hear any sound that comes from above or below, or even towards their front or back as if they were viewing the scene in real life.

[50] *Unity, User Interfaces for VR, Ch. "Types of UI"*
[51] *Storyhunter, October 2017, "Why You Should Use Spatial Audio for Immersive 360 Videos"*
[52] *Waves, October 10, 2017, "Ambisonics Explained: A Guide for Sound Engineers"*

As mentioned above, the ambisonic audio signal consists of 4 audio channels which equal to full 360 degrees within the VR video and it is widely known as the 4-channel B-format or first-order Ambisonics B-Format.
The four audio channels the ambisonic audio signal consists of, are known as W, X, Y and Z. Each one of these channels correspond to a specific audio direction within the 360 spherical video:

- Center (W)
- Front-Back (X)
- Left-Right (Y)
- Up-Down (Z)

The way these directional audio channels work is that each one of them has a positive and negative (inverse) side. Hypothetically speaking, if we record audio from channel X, when an audio signal is recorded from the front of the sphere within the video, the front side of channel X will contain all audio deriving from the front of sphere. Similarly, any sound deriving from the back of the video sphere will be contained by the inverse / negative side of channel X. The advantage of the bi-polar axis however is that, the audio gain recorded by each direction is different because as you move away from the center of the bipolar axis the gain drops and thus mimics the distance that exists between the viewer and the sound they hear within a specific spot in the video. The same theory applies for the other channels (X, Y, Z) in their respective directions[53]. It is also best advised to monitor ambisonic sound by using a pair of headphones since the end-product will be viewed by a user on a VR headset with built-in headphones.
This is greatly impacted if the sound derives from a moving object within the scene as both movement cues are used in conjunction with sound cues. Additionally, it was discovered that moving objects and more specifically, moving light such as a spotlight or light cone, greatly affected the user's attention to move their view towards that light's direction. By acknowledging and leveraging these findings, one can direct the view of the viewer in a VR

[53] *Waves, October 10, 2017, "Ambisonics Explained: A Guide for Sound Engineers"*

environment at that exact spot they want the viewer to pay attention to and thus expanding the story that gradually unfolds within the video.

Spatial UI (User Interfaces):

Another important factor which contributes to the entire interactivity of a 360 video is User Interfaces. Unity introduced the term of Spatial UIs which corresponds to User Interfaces placed within the "space" of a 360 video sphere which look as if they are part of the 360 video world compared to traditional 2D UIs. These user interfaces could be anything from guiding arrows, in-video user controls to small informative windows popping up above objects in the 360 video. The placement of such UIs is important as anything too close to the user can cause eye strain and anything too far may not be readable at all. The size of the UIs need to be considered as well since the user will be viewing various parts of the video which may require dynamic resizing of the UI based on where it is placed within the video. By taking these two points in consideration, integrating a UI into a VR environment makes the experience more enjoyable and contributes to guiding the viewer's attention[54].

Unity offers a vast amount of assets which contribute to the entire interactivity of a VR project and thus we examined the various options that are offered and recommended to use in Unity's VRSampleScenes[55].

1. Instructional UI that follows the movement of the user after a short delay:

   In many VR games, the user is most likely to encounter an instructional message regarding the playstyle of the game in a form of a "floating" UI window that the user can read and later dismiss by clicking an on screen button. In many cases, when the floating UI window was a flat element attached directly to the user's camera it would cause symptoms of discomfort and nausea as it wouldn't give room to users to check their surroundings within their 360 environment. Therefore, Unity recommends to

[54] *Unity, "User Interfaces for VR", https://unity3d.com/learn/tutorials/topics/virtual-reality/user-interfaces-vr*

[55] *VR Samples, Unity, https://assetstore.unity.com/packages/essentials/tutorial-projects/vr-samples-51519*

implement such UI windows that are presented to the user when the scene starts and remain at their initial position for a few seconds while the user is rotating their view within the 360 environment. After few seconds have passed, the UI window follows the movement of the user and gradually appears in front of their view again in a curved layout that corresponds to the curved sphere the users exist in. Thus, this makes it more convenient to the user to familiarize with their environment without any initial obstructions that would negatively impact their experience in the 360 video. This type of UI belongs to the Non – Diegetic Cues as it is added later into the VR environment in post-production.

An example of a flat laid UI and a spatial UI is shown in Figures 14.0-14.1 below (*Courtesy of Unity Technologies):*

Figure 14.0 – UI in Screen Space Canvas
Unity Technologies

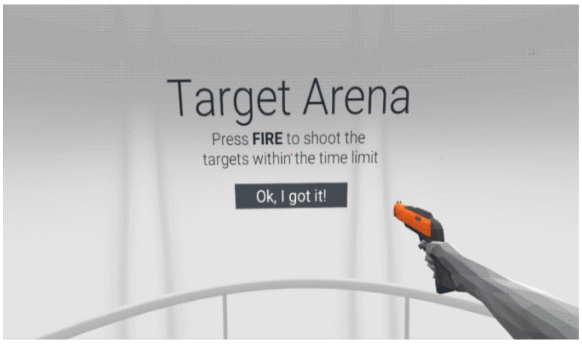


Figure 14.1 – UI in World Space Canvas
Unity Technologies

2. Guiding Arrows that direct the viewer's attention:

As good as diegetic cues at directing of the viewer's attention, sometimes a more prominent and obvious method is needed to make sure the viewer is facing straight to the action. Another non-diegetic element that aids the viewer's direction is guiding arrows. More specifically, when a user moves their view away from the point of interest we want them to see, small guiding arrows gradually fade into the scene that indicate to the user the direction they should be watching at. As soon as the user moves their head to the indicated direction, the guiding arrows gradually fade away without distracting the viewer's attention at all. These are very helpful in 360 environments where there is a lot of content for a user to observe and as the story of the 360 film progresses they might not know exactly when and where to move their field of view. An example of guiding arrows is shown in Figure 14.2 below (*Courtesy of Unity Technologies*):

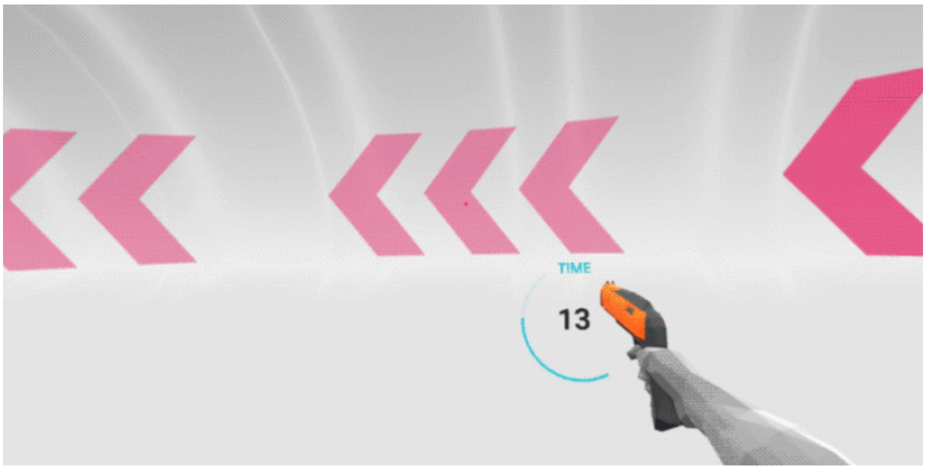


Figure 14.2 – Guiding Arrows Directing the Viewer's Attention – Unity Technologies

3. Informative UIs integrated on objects within the video that are triggered by the user's gaze:

   Besides the integration of non-diegetic cues such as guiding arrows or spatial UIs, a more discreet method to make a 360 video more interactive is the use of UIs on top of objects within the video. This type of UIs can be simply triggered by the user's gaze at a specific object in the video. When the user moves their gaze upon an object within the video, a small user interface window pops up that reveals information regarding that specific object. As these windows pop-up only by the user's gaze and not automatically as the video progresses, they add an additional option for the user to interact with the content of the video. Additionally, the integrated UIs upon objects within the video offer a more immersive experience to the user as they simultaneously educate and help the user understand better the purpose of the video as the story unfolds. In order to help the user understand where they're specifically looking in the video with their gazer, a small reticle is added at the center of the video through Unity. The reticle works as a ray that is cast towards the direction the user is looking at and specific interactive objects within the video are triggered. These fall under the Diegetic UI category as they are part of the elements within the 360 video. An example of an integrated diegetic UI upon objects is shown in Figure 14.3 below:

Figure 14.3 – Title that appears on the tool - Diegetic UI on the final

4. UI Menus that float within the sphere – Choosing the place you want to go to:

Another alternative option to making interactive experiences in VR is offering the user the opportunity to change scenery by a floating menu. The user can interact with the menu either with the use of controllers that cast a ray within the video to a specific spot or their gaze through the reticle method mentioned in section 3. When a user chooses the location they desire to switch to, the current scene fades out and the next scene fades in. An example of the user's interaction with the menu is shown below in Figure 14.4 (*courtesy of Unity Technologies*):

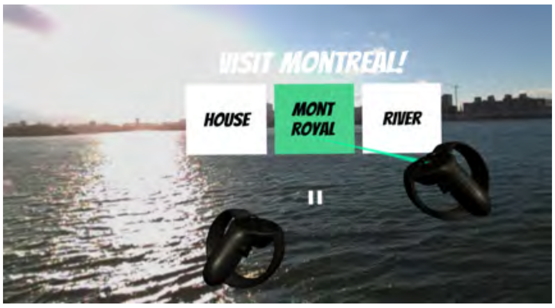


Figure 14.4 – Guiding Arrows Directing the Viewer's Attention – Unity Technologies

5. Hotspots that are gaze triggered and perform a certain action – Walking:

   Moreover, a user can mimic the act of “walking” into another scene by gazing at hotspots within the 360 sphere that transport the user to the corresponding place the hotspot was placed at. This is the most common way to walk in-between locations that are were filmed next to each other in the physical world as they do not cause symptoms of nausea to the user. The scene transition is once again done by fading in and out from one scene to another. During the research phase of this project the possibility of walking within one video to another without video transitions was examined. However, after many attempts to discover whether walking within 360 videos was possible, we were led to the following issues:

   - Combining two or more video spheres in Unity distorted the spheres themselves as one sphere would blend within the world of another sphere. It is impossible to blend two or more spheres together as each one of them contain different video content and they would not stitch together seamlessly.

   - Moving the user’s camera within the sphere’s perimeter did not work as expected as the act of moving was achieved by zooming into the sphere to make objects appear closer to the user and thus mimicking the walking part.

   - The slightest movement towards the sphere’s edge would greatly distort the quality of the video since you were actually zooming into it.

   - Any 3D objects placed within the sphere would become disoriented and misplaced as you “zoomed” into the video.

   An example of the blended spheres is shown in Figures 14.5-14.7 below:

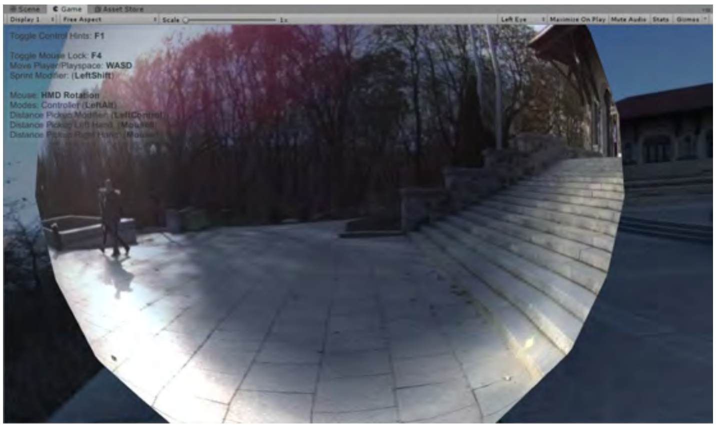


Figure 14.5 – How scenes look when the spheres are blended together

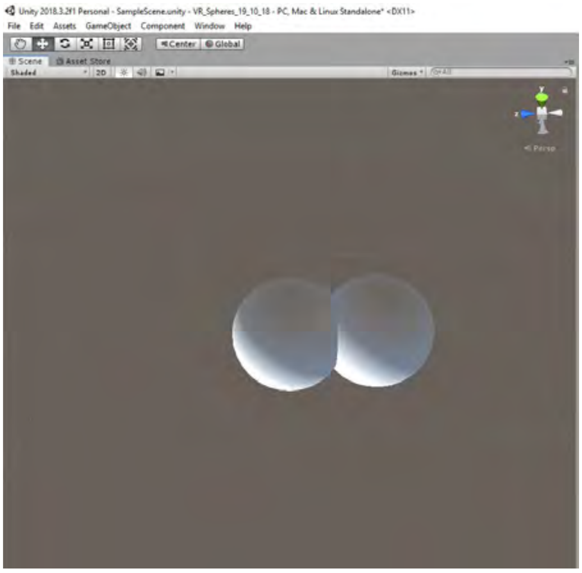


Figure 14.6 – How the spheres were blended together

<u>Thus, the option of adding hotspots to mimic walking was chosen and is shown in Figure 14.7 below:</u>

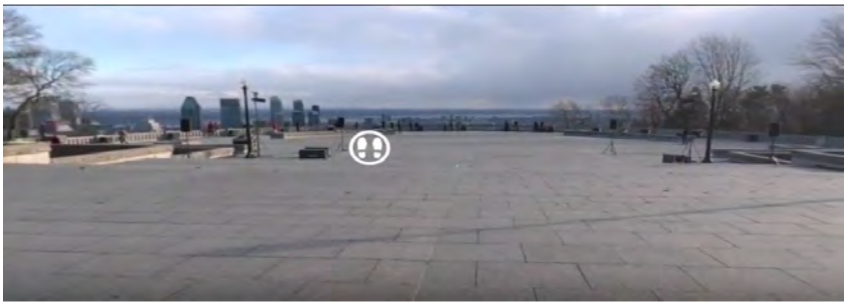


Figure 14.7 – Walking

Directions given by the subjects within the video:

Finally, one of the most important aspects of interactivity, especially within 360 videos is the narrative and guidance of the viewer by a third party. In instructional videos, it is strongly advise to have some sort of actor or instructor who guides the viewer either by their voice or both their voice and precense within the video. This leads to directing the user's gaze directly where we want them to by following the instructor's steps and directional cues.

Annex D

This appendix contains the issues that were faced during the filming process.

1. **<u>Sun flares hitting the lens of the camera</u>**

Figure 14.8 - What the Insta360 Pro 2 captures

When the Insta360 Pro 2 was placed at the spot indicated in the above picture we noticed that the sun's flares were directly hitting one of the camera's 6 lenses through the window indicated in the above picture which caused a distortion between the "blind" spots of the lenses. This would lead to an issue in post-production when trying to stitch together the 6 individual videos of the lenses as the flare would cause a distortion when the stitching algorithm would attempt to stitch the adjacent scenes together to offer a seamless 360 view of the place. An example of the flare is indicated below:

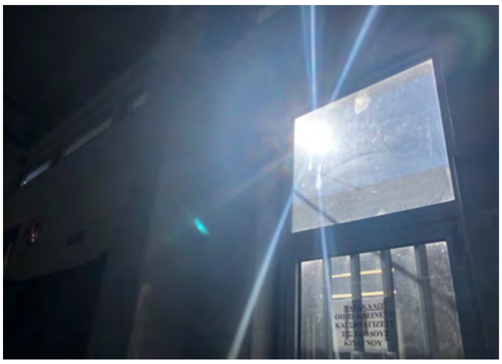


Figure 14.9 - Sun flare hitting through the top left

2. Lens angle adjustment when tools were raised

Whilst filming the tools which were raised up in the air by the instructor we noticed that we could distinguish the lens' angle of view by 2 blurred lines through the preview screen. The 2 blurred lines indicated where the scenes from the adjacent lenses of the current lens blended together and therefore a distortion between the object emerging from one scene to another was obvious.

3. Moving between different spots – Scene Transitions:

The lathe's machine procedure included the part of sharpening the knife that was going to be used on the lathe machine. Due to the sharpening machine's position in the filming room we had to move the Insta360 Pro 2 closer to the sharpening machine to demonstrate to the viewer how the sharpening is done in detail. Even though the Insta360 Pro 2 captures video in 360 the distance between the Lathe Machine and the Sharpening Tool couldn't be covered by its first initial position thus moving it was a mandatory part of the filming process. The position of the Insta360 Pro 2 is indicated in Figures 15.1 – 15.2 below:

Figure 15.0 - Initial Position of the Insta360

Figure 15.1 - Position of the Insta360 Pro 2 next to the Sharpening Machine

The issue that was faced due to the repositioning of the camera was how the two scenes would transition from one another in such a way that would make sense to the viewer and also preserve the film's continuity. In the film industry, editors use the method of matching similar movements of objects, actors or camera movements from one scene to the next to make the cut seamless without the viewer noticing the edit.

5. Audio Crackling from built-in microphones:

After the clips were imported into Premiere Pro the ambisonic audio which was recorded by Insta360 Pro 2’s built in microphones was checked for any type of playback errors. After inspecting the audio of the video clips some intense audio crackling was apparent at certain parts of the audio recordings. After contacting the Insta360 Support team on the insta360.com forum it was evident that the issue was caused by the quality of the built-in microphones[3]. Apparently, they are prone to peaking and adjusting the Audio Gain within the Insta360Pro was the only solution to some extent. Even thought the Zoom H1 was used to record spatial audio, it was not the recommended sound recording device for the Insta360 Pro 2 as it does not offer spatial audio recording natively. Therefore, the Insta360 Support team insisted on using the Zoom H2n to acquire authentic spatial audio along with the video. By doing so, the audio within the videos would derive exactly by the direction it was recorded from and thus offer a more immersive experience. The Figure 15.3 represents the forum post that was made regarding this issue to the Insta360 Support Team:

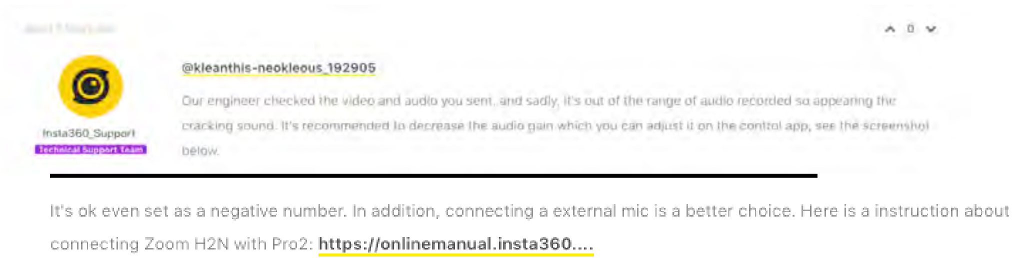


Figure 15.2 – Insta360 Forum Reply regarding audio crackling

As a result, the clips recorded the first time during the filming process were unusable for the project and they would not provide the best possible results.

3 Insta360 Support Forum – Insta360 Pro 2 - Audio Crackling when recording: -https://forum.insta360.com/topic/673/insta360-pro-2-audio-crackling-when-recording/8