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Lucidity: Binaural Feedback in Virtual Reality

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Acknowledgements

Abstract

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Introduction

Virtual Reality devices (VR) have, despite less popularity, has been around since the 1830’s, developments such as the Stereoscope (Wheatstone, 1838), Link Trainer (Link, 1929), Sensorama (Helig, 1962) and experimental projects such as Ivan Sutherland’s Sword of Damocles (Sutherland, 1968). Alongside this the world of writing drew together fictional prototypes such as *Neuromancer*,  *Feersum Endjin* and of course *Hitch Hikers Guide To The Galaxy*, all showcased endless possibilities whilst warning of the consequential use of omnipresent VR.

Technological advancements have moved past the times of just pipe dreams, and with announcements for VR devices like the Oculus Rift Development Kit 2 (Oculus VR, 2017) delivers that high resolution and dignified VR experience. Meanwhile you have the HTC Vive (HTC, 2015) which showcased endless possibilities for room-scaled virtual reality furthering user experience of VR and with the announcement and release of the HTC Vive tracker (HTC, 2017) allowing developers to amalgamate it into their own controllers whilst opening a new door to object tracking, such as the Hi5 (Noitom, 2017) a glove that tracks individual fingers in real-time VR (RTVR).

However, despite these incredible advancements of VR, increasing user experience through immersion, a full user immersive experience has yet to surface (ref). Still there are many areas of immersion yet to be explored within VR. Sound has always kept an user at suspense when watching a film and is only now just starting to be embedded within the world of VR with many new research avenues opening up to fill the void that VR has created.

This project is aimed at showing what developments and possibilities sound has within the world of VR and where it can be positioned to deliver a lasting effect to the immersive industry created out of VR. Through experiments the author will show what sound is capable of building.

Background

The background from whence this project stands upon will be built from the introduction of haptical and auditory into a VR scene, the idea is to develop and perform multiple experiments as to how sound both on high or low frequencies can be used in creating an immersive user experience through the sensation of feeling rather than hearing.

The author decided on this type of research and development project as follows, the author has a strong connection to music and its immersive capabilities through dynamic hearing, however noticed at current only minimal implementation of music within VR. Applications simply confining to the ears of the user rather than allowing them to feel.

The project aims to sort through both existing and new mechanics of VR and how sound can be more efficiently applied to focus in the user through immersive sound on a binaural level that when eyes of closed the user cannot distinguish reality from virtual. There will be a lot of concentration on to what mechanics will benefit greatly from sound from the smallest of manipulations of sound, such as feeling the recoil velocity of an object.

Objectives

So with this background information to reflect on we can go into explaining the main objectives of this project, so there multiple objectives that do need to be met by the end of the project however based on the tasks at hand through the experiments and development of materials for these experiments some objectives may get focused more than others and could end with some not reaching the desired aim. However of course this is all experimental research and development as we delve into the void that is immersive sound on a binaural feedback level. Now the first objective is that this project must retain maximum priority above all of the authors projects within their time at University be it group projects or individual, now of course this being a project of personal connection to the author both through timeframe and application of their individual skillset, this project and its experiments should contain only developments that the author has indeed created (unless circumstances have led to increased development time due to the author lacking in the desired knowledge to circumvent development stages).

Our next objective upon developing each experiment to its fullest is to combine each into a single playable instance, whereby a user can navigate to each task at ease without time restrictions being applied as one experiment is shut down to open another. The next objective follows the application of negating the influence of the upper & lower frequencies so the user doesn’t feel what they hear through ears but feels something entirely different, for example the firing of a gun, you hear the shot but only feel the recoil. For this we want to create experiments that properly immerse the user through only sound even if it only has the slightest sense of feeling. The last objective depending on development time of project but may be done outside of the project scope, develop a hardware prototype that relays a feedback response based off of the immersive sound experiments.

Deliverables

Now as we look at the deliverables, which will be developed within a comprehensive Unity3D application of which will consist of an unspecified amount of experimental tasks, some of which may be discovered during the experimental process. These experimental tasks will be clear of any bugs that may impede tasks that the user intends to complete, the application should be optimised to run on computers of mid to high specification in accordance with HTC Vive recommended specification, so as to allow the user to interact with their environment as well as feeling through their senses of touch and hearing. Each task should have their own unique implementation of binaural feedback in that the user can realistically picture themselves within the scene of the experiment and detect the immersive traits that each experiment is set to deliver to the user. Each sound implementation should both contain rich sound that the user may hear but also contain an underlining tone that can only be felt rather than heard, this implementation of sound should not contain any influences from the rich sound that the user hears but may be masked in hearing depending of the frequency of hertz (HZ) through low tone deliverance.

Literature Review

**ABSTRACT**

This paper shows the both current and newly developed uses that haptical and auditory feedback has within devices used with virtual reality as tools used within both the educational and rehabilitation sectors.

Discussion on how both of these forms of feedback have helped in the rehabilitation of neurological limb impairment and educational research within the brain.

**Keywords**

Haptical Devices, Haptics, Binaural, Auditory, Tactile, Force, Pseudo, Rehabilitation, Education, Neurological, Brain, HTC Vive, Virtual Reality (VR), Tactile, Force, Haptitory

## INTRODUCTION

Haptical and auditory (or haptitory) devices have been around for decades however through recent developments in virtual reality, it has broadened the horizon on where these devices and their wave forms can be used in our everyday life. In particular we look into how haptitory devices are helping to change the way we look at medical psychical treatment and educational teaching both in corporate & everyday school life.

This paper looks into the current & latest developments in haptical & auditory based devices within virtual reality including both hardware & software solutions that being introduced to the playing field for consumers of rehabilitation, medical appliances & educational boards.

## Defining Haptitory

The world of virtual reality has always been a pipe dream to people, to be able to perform actions and experience life through an imaginative reality without the actual need to step outside of your living room. Now we’re seeing VR showcasing itself into many different walks of life that we hadn’t ever imagined it being required further expanding our knowledge of technology and its uses. Haptical & Auditory devices have been around for ages but it is only just recently that they’re starting to be expanded on their use of haptical feedback responses be it in VR or reality. Take your mobile phone for example, you get a phone call and your phone plays that common ring tone and also vibrates. We can call that mobile phone a haptitory device as its feed-backing both an auditory and haptical response to the user. Haptitory is a term coined as a representation of a device that uses both haptical & auditory feedback, any other device that uses either haptics or auditory feedback can be separated and defined through sound waves on the hertz scale. The human ear can receive sound from 2,000 Hz+ all the way down to 20 Hz, however anything below 150 – 200 (Choudhary, 2004) is considered haptical feedback due to the frequency level being so low it can’t be detected by human hearing. Thus we have our scale of what can be defined as haptical and auditory, and of course haptitory being in between combining both elements of lower hertz & upper hertz.

## KEYPLAYERS

Below are 5 examples that show the novel ways haptical & auditory feedback is being used in today’s world.

## SoleSound

SoleSound is a novel auditory-tactile based feedback device designed for embedment of a user’s shoe. This device was developed for easing the suffering to user’s suffering from Parkinson’s disease with in particular to its gait disorders (Zanotto, 2014). Parkinson’s gait which involved the user’s shuffling of small steps and the freezing gait whereby users lose their mobility for a few seconds often resulting in user’s being faced with a wakened balance and subject to fall. The device did this by using sensors in the shoe that detect both pressure and inertial measurements which registered back vibro-tactile feedback that helped to better regulate their gait and strengthen their balance.

## StrokeSleeve

StrokeSleeve is a wearable haptic sleeve that is used for providing tactile feedback to the user as a form of rehabilitation treatment in limb impairment (Kuchenbecker, 2012). Currently traditional treatments in physiotherapy involve repetitive arm movements which can lead to user confusion to the processing of information and shaping which involves a therapist placing their hand over the affected limb and moving it around in repetitive limb movements which typical results in being rather labor intensive and boring for both therapist and user.

The stroke sleeve however comes in the form of 2 sleeves placed around the bicep and forearm of the user, within these sleeves are 4 tactile actuators capable of providing feedback to the tapping, dragging across, squeezing & twisting of the user’s arm / wrist when the user moves their arm or it is moved it will provide the touch sensations they would previously encounter in everyday life. Through continued use of the StrokeSleeve it is possible to retain limb mobility at a more effective way than that of above methods.

## Audio Virtual Surfaces

Audio Virtual Surfaces or AVS (Boyer, 2015) for short is a space of virtual matter developed using a Leap-Motion that when activated through manipulation of hand movements and gestures based whilst also depending on the positioning / rotation of the user’s hand will deliver an auditory feedback response showing the state of interaction.

This a particular piece of work was taking a bit further through the development of a virtual water tank which used two separate sound engines, one being in charge of hand movements when skimming / slapping the top of the virtual matter and the latter if the hand is swiped underneath the virtual matter, based on the actions that the user makes with their hand is dependent on what auditory response is given either higher or lower pitched response.

## Soft Finger Tactile Rendering

SFTR (Perez, 2015) is a form of wearable haptics device that is placed on the finger of the user, the device itself is formed of 3 legs in a triangle format with a similar consistency to that of a spider’s leg. The device applies pressure to the user’s finger based on the positioning and relative orientation. For example if the user touched a square in VR with the left side of the tip of their finger, the device would respond by positioning itself to maintain a constant pressure on that touching position of the finger. Thus stimulating the tactile feedback of touch against a virtual object through cutaneous haptic rendering.

## UltraHaptics Touch Development

UltraHaptics Touch Development is a haptical virtual prototype which allows users to touch objects in thin air through the projection of Ultrasonic waves. These waves are essentially what can be best described as hot air which give off the touch sensation you would typically feel if you pressed against the likes of a balloon. (UltraHaptics, 2013) Although it won’t stop you pressing your hand through the virtual objects it however allow you to feel the indention of these virtual objects. The prototype works by using a Leap-Motion which tracks hand movement above the haptic rig and then summoning the virtual object so that you can feel it. This is being implemented into the likes of car interfaces to allow hands free interactions e.g. turning up volume on radio in thin air etc... It has also shown other uses as discussed recently at VRWC 2017 (VRWC, 2017) that it could be used in conjunction with blind users to showcase haptical graphs and charts, in a way that users can actually feel the results of the graph if they’re unable to see them.

## Summary

Through constant new development growth both haptical & auditory devices have started to make an impact everyday life. With those in the medical & education sectors reaping these new benefits, be it nurses & surgeons training with haptical embodied tools to learn how to do surgery, retraining the neurological connections within the body so that users can move their previously impaired limbs once again.

Likewise in the education sector you have technology developing through haptical devices using ultrasonic waves to allow you to feel objects out of thin air, this type of immersive power would have a major impact for education tools like computer & white board interaction through via a simple flick of the wrist.

## USP

Throughout the development of virtual reality, technology as a whole through both haptical and auditory device development has seen all new boom within the market. Haptics and audio play a major part within VR when trying to immerse users and it is through this immersion that they’re able to succeed and deliver viable solution to today’s problems within not only technology itself but everyday life. With the advancement of ultrasonic motors and having talked previously about haptical graphs for blind users. This could change or even create new equipment and help options for users of impairment to vision simply through the feeling of touch, this combined with the likes of AVS means it is very possible that you could create a haptitory device in the form of music creation, similar to the style of playing shown in a Theremin whereby one hand controls volume & the other controls pitch & length of pulsation.

SoleSound is very device in that through both collecting data to help out sufferers of Parkinson’s and preventing less falls it also provides an auditory sound to alert either the user or help staff. This could be potentially useful if it can be pushed to the likes of a mobile alert for care staff stating that a user is walking and displaying their current gait / balance status and through repeated use can help to better treat their individual needs.

If you look at SFTR & Stroke sleeve that is a possibility for the two to actually be combined. Not only can a user using the Stroke Sleeve grasp the sensation of mobility in their limb but there is also potential for feedback to be extended into the likes of their fingertips, again further tricking the brain on that neurological level to rebuild those neural connections to retrain its mobility & functionality to those fingertips.

## Technologies/Approach

## Virtual Reality

After being first introduced to the world of technology in 1957 with Morton Heilig’s Sensorama (Heilig, 1962) VR based off Charles Wheatstone’s (Wheatstone, 1838) Stereoscope design VR wasn’t all that popular in development and has only recently this past decade made a huge impact within the technological industry. In particular at the very start VR was seen more as a platform for gaming to allow users to experience a deeper level of immersion in their games this was showed through devices like the HTC Vive, Oculus Rift & Google Cardboard which was developed for mobile VR. However it has started to make heads turn within the medical industry through its many applications in simulators for example surgeons could learn how to perform a particular surgery virtually with no real-life complications. Another usage for VR in medical was shown through physiotherapy as discussed with StrokeSleeve as a post Stroke rehabilitation through the use of tricking the brain into relearning the behavioural patterns used to regain control of their weakened limbs by confusing its perception of reality with virtual reality.

## Haptic Feedback

Haptic feedback is designed to give the user a sense of touch & feeling in order to relay information back to the user, this can typically be seen in the likes of a mobile phone vibrating to say you have an important text message, or a games controller vibrating if you’ve taken damage or walked into an area you shouldn’t be (Moss, 2015). Much like VR haptic feedback has branched out into the world of technology to develop immersion through touch / feeling of objects with no physical vision of said object. Now there are 2 main types of Haptic feedback, Tactile which involves the sensation of touch much like was discussed on UltraHaptics able to touch something that wasn’t there in sight. And force which allows you to feel the sound waves produced on a haptical level rather than hearing. This can be shown through the likes of hardware called SubPac (SubPac, 2016) which is a backpack based subwoofer that converts low intensity hertz signals into vibrations allow you to feel the low bass of a sound file rather than being confined to headphones.

## Binaural Audio

Binaural Audio, is the term given to audio that basically if you close your eyes whilst listening to it (Akeroyd, 2006) you feel you’re actually (Kall, 2016) there in reality, this type of hearing is what’s known as psychoacoustics (Vassilakis, 2016), for example cars on a busy city street and people bustling on by. Binaural recording is done through recording of two separate microphones to replicate audio channels similar to that of left & right ear’s hearing range. This works as a very effective way in distracting the brain & the user’s train of thought which can be particularly useful should the user be pressured / stressed such as working in a classroom doing homework or a patient training in physiotherapy it can be almost therapeutic

## FIGURES

It is reported that the Haptic technology market in particular will be worth roughly $19.55 Billion by the year 2022 with a Current Annual Growth Rate (CAGR) of 16.20% between the years of 2016 and 2022 (Rohan, 2015). The key drivers that are helping to increase this growth is through the extended addition of haptics within electronic devices such as smartphones and tablets. Furthermore in use within game consoles and controllers as well as medical & automotive industries alike. As a result majority of the market is situated around Asia-Pacific area based off of majority production of electronic devices.

## CONCLUSIONS

In conclusion it is noted that the industry for both haptitory devices within a VR environment is growing stronger each year and is creating a meaningful impact although mainly in medical and not so much in terms of educational sectors however it can be used to create a useful tools within everyday life problems.

Without these developments & feats of innovation to our technological problems through the use of both haptical & auditory devices a lot of society would not be able to benefit as much as it currently does now. The sense of touching what is not there in reality but is in virtual space can be implemented in many walks of life with particular look at the blind community offers so many more opportunities to communicating previously unthinkable (Yu, 2000) presentation modules.

Software and Hardware

The main software being used for the development of the experiments if Unity 3D, reasons behind this is that Unity has a variety features that apply to C# which the author is best skilled in and offers an aesthetically pleasing user interface. Whilst also offering a bolstering community and documentation that far easier to use than that of other game engines such as Unreal which could to be an additional path to go down should the author wish to gain experience in.

The Unreal engine however does has its perks to that of Unity with the likes of graphic development and terrain generation being on top quality and can handle multiple effects and meshes without impacting hard on the performance of the software and uses C++ as its main programming language. However Unreal engine is typically used for the development of large scale games built by large teams of developers that make use of all of Unreal’s features in making a beautiful landscape. With C++ not being the strongest of languages of the author and the author having 4 years’ experience using Unity throughout University, Unity was chosen instead. Graphics were not important in this project as this project was made up of multiple experiments based on binaural feedback and not their immersion through sound not art.

Visual Studios will be the IDE provided for programming due to its full integration with Unity and its basic features have all become standardised, previously Unity offered support for MonoDevelop another IDE that came default with Unity however MonoDevelop has its problems with being a rather clunky and unaesthetically pleasing user interface, to which Visual Studios triumphs in.

As graphics and art was not important within the experiments development graphical / modelling software was not required. Also through lack of experience within modelling & graphical based software the author would outsource what minimal modelling was required to fellow peers as author can make do with stock based assets.

For binaural sound effect creation and editing, Audacity was decided upon. It is a basic piece of software that covers all necessary techniques and features within the recording and editing of audio within a minimal sized software package and of course is free. There was also a choice between using Adobe Cinema as this was readily available for the author to use within their time at the University however the author is more experienced in the usage of Audacity however it could prove another potential avenue for the author to go down but with the con that the author would need to shelve out money to pay for this software post-graduation.

For VR interaction for each experimental task will be involve using the HTC Vive, whilst there is also the Oculus Rift readily available, the HTC Vive is fairly recent and a delivers a lot more potential for developmental uses particularly with the CES 2017 announcement and release of the Vive Tacker in better real-time tracking, also within the University there is a dedicated room for the HTC Vive as well as Vive Kit being supplied by the Interactive System Studio that reside within the University.

For binaural and haptical feedback the SubPac M2 was chosen, due to its simplistic approach in that it is simply a subwoofer that is strapped to your back and converts low frequency Hz’s into vibrations that allow you to feel the sound as discussed earlier in the introduction.

Method of Approach

Discuss of the methodological approach that was taken for this project and alternative methodologies that could have been chose but weren’t will be discussed within this section.

This main approach followed the Waterfall methodology that consisted of a standardised development workflow including design of experiments, implementation of binaural feedback, user testing and finally release. The reasoning behind this approach was due to the ease of access that the author was able to switch between tasks should lack of knowledge impede the development of a certain task they could simply switch to much easier task whilst they built up their knowledge, thus allowing the author to circumnavigate development without being restricted to a set order.

An alternative methodology that could have been chosen for development would have been the Agile (Agile, ) methodology down to both having experience in this model through studying of other modules at University. The Agile model can have several forms such as Crystal Methods, Dynamic Systems Development Model (DSDM) and Scrum to name but a few. What they each all have in common is that they focus on the End User Product (EDP) by that meaning the end user has to test the product before they can then move on and iterate the next development stage. Specifications for products using this methodology are kept at a high stature so as to produce a simplistic sense of organisation. Regardless of iteration stages for the product, time will always be fixed throughout the development. Agile uses what’s known as “Sprints”, each sprint represents time until the next iterated version is released for user testing. By using a form of critical analysis this helps critical tasks to be completed before secondary task completion can be initiated.

Agile wasn’t chosen for this project due to being more suited in a team environment and as this is a one person project trying to fill in the different roles of research, development, audio and programming would be a strenuous regime to follow using this model. Also due to the nature of this project of researching new and existing areas of developing technologies this development model wouldn’t fit in with the components of the project being experimented on and developed.

Another methodology that could of fitted the build of this project would have been Extreme Programming Methodology (XP, ) designed with the Waterfall model in mind looks at reducing the changing costs within specifications throughout development. At current a Waterfall model will result in becoming frozen during development in that changing requirements later down the line require high cost something like this is common within reality, and some of its core practices include simplistically in coding by which the actual needs in the project could be better solved with a simple solution rather than something of high complexity and if solution becomes complex work to reduce it to simple. However like Agile this methodology focuses around team environment specifically a group of two developers, this is to allow forth another of their practice in that they can refer to each other reviewing development progress to have a collective shared understanding of what each other is developing at which stage. This wouldn’t work of course as this is a one man project, also one of its practices involves continuous processing of development rather than that of batch development / release. As a one man project having to constantly switch between tasks after task on your own instead of relying on team would very stressful and could lead to undeveloped progress being made through rushing of tasks resulting in less quality over quantity being shown.

Finally the last method to alternate to would have been Rapid Application Development (RAD, ) known also as RAD. As shown in the name RAD is known as one of the quicker methods and usually results in final production releases being of the highest standard. This model typically follows the process of producing specifications for the product through the focus groups and networking meetings that would help the product benefit, following this the developer would swiftly move onto prototyping and acquiring users to test the product through early development so as to obtain swift feature feedback. This method involves the use of predeveloped components through inheritance and polymorphism (morph, to save development time. However this also results in changes that might occur not being seen to until the iteration cycle. Communication with clients or team when using this methodology are usually seen with sense of reduced regularity and formality.

RAD wasn’t used in the developmental process down to the early prototyping through a fast-paced environment wasn’t suited to the author as the specifications were being drawn up by themselves, on top of this there was also a significant lack of experience in developing with this model with also lack of reusability to predeveloped components was also a trait into why this method wasn’t chosen.

Legal, social, ethical and professional issues

Starting firstly with legal issues that could be sourced from this project can be a result from either assets or any software used in conjunction with the experimental applications included within this project. This could either relate to any software being used to generate the experiments and any assets that have collected either through internet sources or the Unity Asset store.

Firstly assets, as discussed in the ProposalPID this project and its experiments will rely on stock assets with details such as modelling and design playing a minor role in the overall look of the experiments as they are mainly focusing on functionality rather making them look clean to the eye, however if time has been generous and spared then cleanliness to eye will be taken into account. Now due to the nature of the project and its experiments roughly 90% of all assets including scripts, sounds both of auditory and haptical response and any design aspects will have been developed specifically for any experiments in mind. However if in circumstances where the usage of a 3rd party resource would better showcase the result of experiments and curb time usage, then this will be duly noted and sourced accordingly.

Majority of sounds using an auditory response that could not be created to the specification required were sourced either free or purchased and tools such as Unity’s inbuilt free first person controller were sourced for free, so as to avoid legal issues research was done in regards to properly assert licences where needed on 3rd party assets requiring them.

Sound effects stated as having an auditory response were acquired under the Creative Commons 0 License and Attribution Licences where applicable, tools used in the development were accessible as a purchase or free download from the Unity Asset store and thus should conclude no issues of usage. All assets used will be referenced in both this report, project folder and within the appendices.

Now in regards to software, the experiments being experiments will not be released commercially however any sound effects using a combination of auditory and haptical response will be developed further and released commercially, this shouldn’t result in any issues with software, as this will be commercial release involving sound Unity will be of no issue in terms of commercial license. However later down the commercial venture, development will look towards a hardware based prototype being produced that will use Unity and the appropriate license will be acquired based financial turnover of that prototype. At current free versions of Unity allow commercially up to £100k to be acquired however any higher then appropriate licenses have to be purchased. Now with the sound effects development is currently being done in Audacity there is no need for licensing as Audacity is free software but it is limited in its features, an upgrade to the likes of Ableton Live or FL Studio will probably looked in so as to provide a more industrial standard to the sound effects, commercial use of these auditory software is covered in the standard license provided when purchased.

Now onto social and ethical issues with the project and its experiments, as these involve virtual reality and binaural feedback particularly of the haptical force type care must be taken to not allow users participating in the experiments to endure extended periods of time using VR and Haptical Feedback (HF) and allow them breaks to readjust to reality, those with back problems & heart problems based on placement of the HF equipment used in the experiments will be prohibited from participation in case of potentially triggering a state of pain. No findings on what VR and HF can cause on a user’s mind and body of this age and below, an unofficial age rating has been given to the participation in the experiments standing at 13+ using the PEGI rating system (PEGI, ) Oculus state “younger children are in a critical period in visual development” (Oculus, ) this further supports the age decision for this age rating. Any and all issues occurred also followed in accordance with the Code of Ethical Conduct (VR Conduct, ) produced by Michael Mandary and Thomas Metzinger as a code of conduct for VR supporting such issues stated that could potentially influence a user’s psychological state of mind through the induction of illusionary embodiment.

Finally professional issues faced during the development of the experiments, one in particular being that of resorting to the usage of 3rd party assets dependant on the specific circumstances, content such as sound effects and scripts were typically meant to be content specifically developed for particular experiments in mind however what started out as one experiment turn into fruiting many experiments to which skills were put to the test in developing worthwhile solutions to them, however workload to create sound effects that provided a solid auditory response was hard, so it was better to work with a 3rd party auditory sound effect and then manipulate the sound waves so that lower frequencies didn’t generate a haptical feedback response and then combined it with an separate sound effect that generated haptical feedback so that both sections were separate and developed no influence over the other whilst retaining as a simple sound effect. Through the time taken to learn the new skills in developing haptical feedback responses and lack of experience in developing auditory response feedback, it was better to source one online and manipulate it to the need of the sound effect.

Project Management

This section provides shows the workflow and developmental process the project went through during its development and how projects and experiments were managed. At the very start of the project, functional specifications were generated based off of the single experiment following a 9 stage incremental process which was mapped out over on Kanban Flow board displaying all tangible requirements for this experiment whilst also being mapped out on a Gantt Chart using GantPro (Gant, )

<Image>

However it was soon realised that the incremental stage process was resulting in unnecessary detail being applied to that one experiment and so detail for that workload was reduced and thus newer experiments and their specifications were added & applied.

<Image>

Furthermore some diagrams created within Creately showed the starting stages of each experiment’s components in both Minimal Viable Product (MVP), Ideal Viable Product (IVP) and Perfected Viable Product (PVP).   
  
Soon after tasks detailing for each experiment was created, Kanban was a tidier board to use than that Trello as subtasks could be more easily hidden and wouldn’t clutter up unnecessary space, Kanban was also used for displaying any note made by the Supervisor, also each task dependant on its importance was colour coded with red being of upmost importance, orange less critical and green being lowest priority but still the easier of the tasks to be completed.

<Image>

When each requirement for the experiments was finalised, then any research that was required for completion of each task of experiments would be completed before development of that specific feature would be implemented. Once a feature had been implemented it would then be given a brief testing to make sure all was working before then swiftly moving onto the next task. Tasks was setup so simplest solution would be applied first so that it was working before then a more efficient method of approach would be applied. If the efficient method didn’t work out then it would be reverted back to its prior state. After each day of development, new changes would be pushed through SourceTree into a GitHub repository, which would label each commit with the Version, Date and changelog of data changed within the latest push. With each push would also detail a changelog description as to what each pushed patch contain be it bug fixes or details on new bugs being created as a result of new fixes.

<Image>

This system of project management led the project to follow a smooth process with the waterfall approach suiting well to this technical workflow as well as scaling well to both size and growth of content throughout the development process of the project. Trello had been used through previous modules whilst at University however Kanban offer a better insight and cleanliness to project development hence why it was chosen instead of continuation of Trello in this project, mapping and implementation tools (Creately and GantPro) having only been introduced in final year proved to be very useful tools when it came to planning out the development paths whilst also applying critical analysis to tasks and tools for Version Control (Github and SourceTree) had been the top tools to go to since the late comings of the 1st year when they were introduced during modules as alternatives to simply bringing in a memory stick, which stood out as a better choice for keeping project management nailed.

Due to the nature of the project, development weekly supervisory meetings took place between the author and his supervisor however over time these weekly meetings turned to fortnightly as progress became sparse. Each meeting was followed by with a weekly highlight report which would detail current review of work produced throughout the project.

During these meetings advice would be offered as to next steps to be taken to progress further as well as feedback based current and upcoming developments. These meetings helped provide additional outlets that could be explored in helping the project and its experiments to progress whilst also maintaining a grip on any changes that could be made that might be impeding progress.

Haptical Feedback

Force Feedback

Tactile Feedback

Pseudo Feedback

Auditory Feedback

Haptic Devices in VR

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