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Supporting Accessible Multisensory Interactions in XR

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Supporting Accessible Multisensory Interactions in XR

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The advancements in virtual reality (VR) technologies has resulted in unique approaches for interface and interaction design comparative to conventional 2D methods. This poses a challenge when developing an application for extended reality (XR) devices, as current accessible interaction standards and techniques made available are limited. Many 2D interaction techniques have been directly translated to a virtual environment with no change to the interface interaction technique. By implementing assistive systems such as filtering user input noise, currently adopted interaction approaches can be made more accessible without re-design. By reducing fine motor requirements in interface selection, users have the opportunity for more accurate and consequently less frustrating environment interactions. A development study was conducted to understand the feasibility of implementing a tremor removal algorithm into a VR environment, while also discussing current XR interaction design philosophies. Analysis on evidence supporting multisensory feedback has been studied with further discussion on psychological models, accessibility guidelines and interface usability considerations.

CCS CONCEPTS • Human Centered Computing • Accessibility • Accessibility systems and tools

Additional Keywords and Phrases: Virtual Reality, Ergonomics, Physical Accessibility, UI

1 INTRODUCTION

New technologies can result in more features; tooling; hardware; capabilities which in turn can quickly adopt a Frankenstein design practice during the development process. Resulting in critical evaluations on interaction strategies at developer discretion without rigorous end user testing. Opportunities created by technological progress can lead to excess choice during the implementation stage of the development lifecycle. This resembles the current state of the virtual reality (VR) market today with no defined set of accessibility design philosophies to follow. An intelligent reduction of design choices collectively; can support a more efficient interaction system. It is for this reason amongst others that an accessible first approach should be considered focusing on user ability and not on disability as virtual reality makes the world more accessible with 15% of the global population having some sort of disability (1).

Cognitive strain can arise when increased accuracy is required to complete a task, both mentally and physically. Fine motor skills are a requirement to interact with 2D interfaces using input devices such as a mouse or stylus which themselves are prone to temporary accessibility problems. The same fine motor skills are required for 3D virtual environments using a controller with 6 degrees of freedom (DOF), however physical surface support is not made available for objects in free floating space, such as a user's controller whereas a mouse and keyboard has tangible feedback. Moving one's perception to a 3D virtual environment for interaction with traditional 2D interfaces can appear counterproductive as the significant increase in interaction space is not used. Rather than adapting the graphical user interface (GUI) as there is minimal user relearning required to interact with such widgets in VR, many VR applications are instead adapting the input mechanism to work with the traditional 2D interfaces. This is due to issues related to precise selection and manipulation of objects in 3D environments (2). In a comparable study, augmented reality hand tracking input was compared with a laser pointer for manipulating 3D objects using 6 DOF. The result was on average a 39.4% faster task completion time compared to other AR manipulation techniques such as using hand tracking which requires user hands to be elevated in the field of view from the Augmented Reality (AR) headset sensors. Notably, the resulting score of 8.51 on a fatigue test conducted using NASA's task load index (NASA-TLX) questionnaire showed a 15% average improvement over hand tracking approaches. (3).

Advancement in this field may require defying most traditional 2D interaction assumptions and creating new ones specifically for 3D spatial interaction. Canvas based interfaces are not necessarily optimal for all VR displays. Previous mediums such as the desktop monitor require 2D canvas layouts to display GUI components due to the nature of the desktop monitor being 2D. However traditional GUI primitives such as button; slider; dropdown; context menus; are still almost directly being translated to VR experiences without any adjustment or modification to their designed 2D counterparts. These systems have relied on a laser pointer to interact with the interface the same way a mouse would be used for a 2D GUI. There are over 30 of these UI primitives in 2D UI design that once combined on a canvas make most interfaces used today (4).

Prior to the adoption of the computer mouse, interfaces were command line based and interactable with a keyboard exclusively. Text based adventure games require users to type or use the arrow keys to move around on the screen interface. Users were reluctant to switch from their familiar command line interface with DOS to a GUI based pointer approach, but as graphics capability improved alongside the adoption of the mouse, interface design started to optimize tasks by developing these primitive UI tooling. Just like we tailor tools in the real world to complete a task for a specific environment, we inevitably improve; automate and substitute parts of its design with more technology because of progress. Accessibility therefore is an important hurdle to overcome when developing new interaction techniques for cross-reality (XR) devices. It is important that understanding of new components is quick, supported by intuitive design while also considering alternative more accessible approaches of design.

The design environment with 360 degrees of freedom and 6-axis of motion control in spatial context is considered as a new medium for interface design. Where previously a 2D window with a single pointer was the design environment. Further exploration with 3D interfaces can be considered with an inclusive first approach. There are no interface design frameworks for VR yet or direct translations of the top 30 UI primitives and how their equivalent should be implemented in XR. VR adds depth and 360 degrees of space to the environment, but we have thus far lacked to agree upon the interaction standards that should be followed to make it inclusive for all. 3D interaction can allow for a more natural interaction method to explore the virtual world as one might the real world. The physics that are anticipated in the real world when picking up an item can be accurately recreated in the virtual space to add immersive qualities such as gravity.

There is an opportunity in VR to design and develop an accessibility first design (8). Advancements in passive input mediums such as eye tracking allow for more interaction strategies to be made available, with the addition of an input medium such as movement in the jaw combined with eye tracking. Professor Stephen Hawking was able to interact with digital interface design specifically to his ailments and was able to achieve feats that of an able-bodied person because of a similar system. VR has the opportunity to reduce physical boundaries such as study (5) where user's Parkinson's tremors are reduced when they are using a VR headset.

This paper will take the above into consideration and aims to discuss a physical and cognitive solution when developing an inclusive interface for VR. A short study was completed using the 1 euro filter smoothing algorithm and demonstrated positive results in reducing simulated tremors with real time adjustments. It showcases an example of how an algorithm can provide a physical accessibility feature such as reducing user's tremors via an algorithm. This supports interaction with precision at a reduced cognitive strain (6). The design will reference what an accessible VR design framework may include with considerations at approaches, which can reduce not only cognitive but physical strain.

2 CORE CONSIDERATIONS

Olsen’s framework was developed to evaluate innovative interaction systems and to understand if new interface interaction techniques has resulted in true progress. It notes that for a new feature to be replaced in an interface, it is to be evaluated if it adds 100% increase to user satisfaction (4) and improves their workflow using the new tool over the legacy widget. This philosophy could lead into implementing numerous accessible features for a specific virtual reality experience, allowing the user to adjust their interaction preferences to match their specific needs. Challenges of implementing such a volume of accessibility options in an interaction system include feasibility and understanding user physical constraints may be. A VR user with neck mobility issues may struggle to use a locomotion system where virtual direction is bound to head movement. Using a 6-axis controller-based locomotion system will often use a joystick to move in the players head direction. If user's have restricted head movement it would lead to an “on-rails” experience, limited to one direction of travel or axis. An example of head movement being an advantage however is allowing users to use a fixed cross hair bound to head movement for selection of UI components for users who may have limited hand mobility, the head position provides an alternative means of navigation and selection.

With additional tracking hardware such as DecaMove (29), this restriction can be alleviated and allow the user's hip direction to lead the direction of travel instead of the user's head, freeing the torso to rotate and allowing the user's neck movement to look around the environment if desired, which is similar to natural world movement.

Supporting locomotion variants allows users to pick what form of movement they wish to use to navigate. Paper (7) discusses that designing for interdependence can facilitate communication with the VR headset user and those supporting them during the experience if they have physical impairments.

In virtual social applications, supporting inclusive representation for users' avatars gives the power to the user to choose to embody characteristics of themselves such as the use of a wheelchair, prosthetics, or hearing aids (8). Considering this, users height and width, avatar colour and custom special effects should be reviewed to understand if virtual situations can induce the likes of seizures or neck strain from using heavy HMD's when looking at avatars that are at a different eye level to the user. With a variety of customizable options available for a virtual avatar, standardization practices can provide an opportunity for users to still express and identify with an avatar but provide a less physically strenuous and inclusive environment.

2.1 Physiological and Physical Personas

Ability based design frameworks are used (9) to support developers' design decisions based on user ability. Accessible computing still poses a challenge to overcome and a central focus on disability could prevent users from using their abilities. Interaction systems are designed and controlled in a methodological manner by the developers therefore if the abilities of the current user do not match the assumptions made during development, there leads to an accessible gap. As described, there are many accessible solutions to leverage from when creating an interactive experience which is why Oculus have introduced psychological modelling known as personas (10) into their accessibility documentation which describes techniques that the industry uses if there are limitations related to testing or accessibility trial studies. Using ability as a central focus during the design process leverages the full human potential (9). The development of psychological models (11) is not a new concept for VR exclusively, it allows designers to gain reason and understand how the end user is perceiving the experience. Personas take this approach and involve taking on the perspective of a user with an accessibility ailment and playing scenarios in their application to understanding what features can be introduced to enhance the end user experience. This process would support in identifying if there is a mechanic or interaction that prevents the user from advancing.

2.2 Dependency Reduction

A large barrier to access is the input mechanisms. VR developers are often developing a mechanic to work with 6-axis motion controllers and mechanics will require serious development modification to work with another input device such as a joystick controller. Hardware locking input controls for an experience may be required but can be mitigated by using custom input bindings. Steam VR Input does allow this, where any controller can be mapped to complete a specific task. However, if an interaction requires a motion controller, then the developed mechanic will not work due to the requirement for positional tracking. It is in a scenario like this where the option to skip a task or mechanic that requires motion controllers would allow other aspects of the application to be experienced. Positional requirements for interaction should also be considered. Much like hardware locking, experiences can have hard movement requirements for room scale tracking and have a set location where the user's interface or menus will appear for interaction. In this scenario, user's may be forced to move into physical positions that are not optimal or comfortable for the user for interacting with objects or menu systems. If users cannot interact with an interface from any space in the virtual room, then the requirement for a room scale experience is a hard requirement, and therefore has many accessibility constraints associated with it. Having interfaces or areas of interaction available at the optimal ergonomic location for user's could help alleviate this issue of physically based anchored menu systems.

Using hand tracking is an alternative means of interaction or selection without the need for motion controllers. Oculus Quest 2 allows for hand tracking using inside out cameras which detect hand movement when a user holds their hands up within a specific field of view in front of the headset. Valve index headsets also have the option to attach the leap motion accessory to allow for hand tracking, again when the user's hands are in front of them. Such features are not without their limitations, however. Tracking issues related to occlusion are common, and recently Facebook (12) have developed a tracking algorithm which can track user's fingers when they occlude each other. This does require baking hand movements to be processed by their developed algorithm, however as technology advances this may be an issue of the past. Tactile feedback is also a limitation of hand tracking without additional haptic gloves, gestures as input mechanisms therefore audio and visual feedback to show the user that their input was registered. Gesture based input also is not advantageous to those with limited mobility or if users do not have the requirements for such a gesture such as all fingers; two hands, then its instantly a bottleneck into the user's ability to interact.

Notably with body tracking interfaces a clinical trial involving participants with Duchenne Muscular Dystrophy (DMD) (7) were tasked with interacting with interfaces with and without physical contact. Input mediums were therefore a touch screen interface, Kinect sensor interface and a leap motion interface. The transfer of skills learnt from using the interfaces into a real environment was surprisingly effective. Some wheelchair users required further upper limb support due the being raised for an extended period. The implications of this were a reduction in task performance. Such results can show that different interfaces can support different demographics of accessibility.

As highlighted in (7) after long periods of use, keeping user's hands in front of them can be fatiguing after a sustained period. To counter this issue, tracking of users hands must happen even if the user's hands are not in the limited field of view. Implementing such a solution would require additional sensors, potentially on the headsets or room scale tracking of user's head and hand movements allowing the user's hands to be tracked even when the user's gaze is not focused on their hands, tracking is still supported.

2.3 Forcing Mechanics

With much of the VR market tailored towards the gaming industry, there is an opportunity for those with physical limitations to experience another reality for a period and explore what otherwise would not be explored in the real world. Examples include digital reconstructions using photogrammetry scans of historical sites. Cognitive impairments can restrict a user's progression in traditional games with examples of low literacy or understanding the task to be completed but interacting with 3D objects like the real world has the potential to remove the literacy barrier with intuition due to interacting with objects and physics just like the real world. An example of forceful mechanics is Valve's Half-life Alyx, where users are presented with tasks such as holding onto a sphere with one hand and pointing to areas on the sphere without colliding with moving obstacles. Similarly, the wire loop game was ported to virtual reality and users had to pass this to unlock a feature or to simply advance to the next stage. Although user is having options to avoid these types of interactions, some are mandatory to progress through the experience. Those with wrist movement limitations or Ataxia are unable to complete tasks and advance through the experience and therefore missing out on content. A solution to this is to prompt the user at the start of the experience if they want to enable an accessible mode, which allows for certain sections to be passed without negatively intruding or impacting their experience. Further study needs to be completed to understand the benefits and implications of implementing such a system. A survey at the start of a VR experience could also identify what mechanics user's will and will not be able to do, and therefore the experience will be adjusted to include or remove certain tasks.

2.4 Text Focus & Rendering

Oculus VR check requirements list objectives that must be completed to ensure encourage options for scaling UI elements. Allowing users to adjust to their preferred reading size and contrast options. Considerations should be taken into the movements involved while reading text in VR including focusing user attention for subtitles during a 360-degree experience. Comparably the source of audio or UI components can prove problematic with a 360 degree of exploration without additional guidance. Spatial sound will provide for an omni-directional acoustic audio experience, which can assist in guiding user's perception of the information being displayed in the environment. Although considerations need to be taken for those with hearing impairments that may be unable to benefit from directional based audio. For this reason, W3 (13) recommend that a mono audio sound option be available to users. Spatial arrows that point the user to where relevant information may be displayed is another used approach. An alternative way to get user attention to subtitles or to view an area can also be accomplished using the haptic rumble in their motion controller to direct them to an area of interest. This approach was used in (14) where visually impaired users have access to an advanced haptic system using a three-axis brake mechanism to simulate interaction with objects in virtual space. For text interfaces to be friendly in VR, Oculus recommends a dyslexia friendly font such as a sans-serif family with 35% kerning of character width and spacing between words should be roughly 3.5x the character width. Further study is planned in this area to understand how users perceive different font types in virtual reality, highlighting if readability practices outside VR coincide with text in VR. However, this does not take into consideration text distance from the user.

2.5 Interface Scaling

Scaling of user interface components, such as font size at distances with their intended viewing distance can be calculated using distance-independent millimeters (DMM). This term was coined by the Google development team where an investigation on how to appropriately scale items for visibility at various distances. Angular distances such as diameter, size and apparent diameter or apparent sizes are used to understand object size at various distances. Angular distances are more commonly used in astronomy for celestial object size, however, can also be used to understand how large text or other objects will be on objects such as billboards.

DMM is described as one millimeter viewed one meter away, therefore scaling a unit of size to its distance. This allows for UI designs or objects to be created and then translated to the appropriate size based on the distance from the user's perspective, camera. This approach would work well with traditional canvas-based rendering where ray casting is used to intersect the canvas and get user input based on the ray. Google has recommended for text to be scaled based on its ray casting requirements. 64 DMM is recommended for ray-based text scaling, where a user will be intersecting a ray for the text selection. This is considerably larger than bodies of text where 24 DMM is recommended with 16 DMM padding (15).

Using this scaling approach, development of any text in the interface can be run through a design process where text is sized at the dimensions desired by the interface designer and scaled up in the engine. An example would be if a sign with text on it is to be read at 2.5 meters away then the text needs to be scaled by 2.5 to match the design by the interface designer where they expect text to be read from.

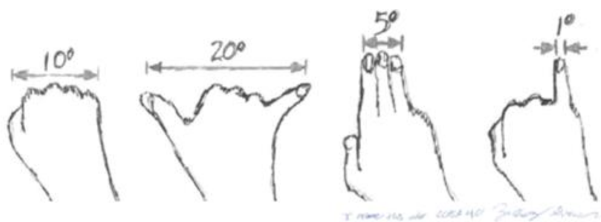

Figure 1: Angular Diameter Approximation Visualization in real world space. Guy Vandegrift. [Public domain], via Creative Commons. (https://en.wikipedia.org/wiki/File:Estimating_angular_size_with_hand.gif)

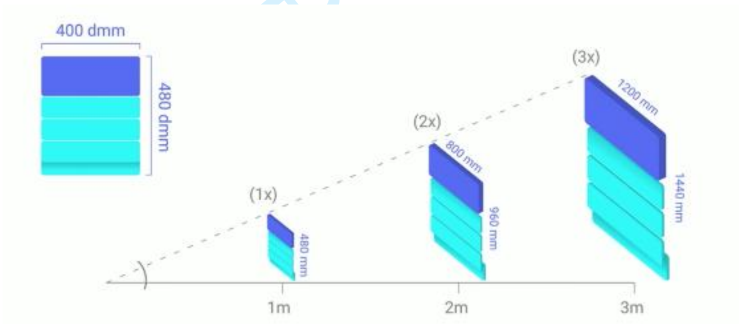

Figure 2: DMM Graphic allowing for scalable UI design for components at distance. Designing Screen Interfaces. [Google I/O 2017], via n/a. (https://www.youtube.com/watch?v=ES9jArHRFHQ&t=528s)

Interaction with text at distance will require fine motor skills due to the increased range, this is the reason for the increased DMM sizing for interactable objects over text. In the real world, a combination of senses is used to provide an actionable movement to our limbs. As vision is the sense used for distance, movements are increasingly slower and less accurate performed as distance increases (16). This is summarized in Fitts law.

$$movement\ time = a + b\ log^2\ (\frac{distance}{size+1})$$

Fitts Law Equation in where movement time is increased the further the target is.

3 XR INTERFACE ERGONOMICS

As described, areas of interaction that are not within arm's reach of a user will require physical movement to the location where the interactable component is anchored which can lead to fatigue during prolonged periods but also prevents those with any mobility restrictions, both from their current play environment and physical ailments. Locating the optimal spatial area for placement for VR interaction with a motion controller can be calculated considering user depth perception and headset field of view. The below formula assumes that d is equal to the maximum perceived distance. Field of View (FOV) is equal to the HMD's horizontal field of view and R is equal to the device screen horizontal resolution and the inter-pupillary distance (IPD) is the users particular value.

$$d = \tan\left(\frac{90-\left(\frac{FOV}{.5R}\right)}{57.2957795}\right) \cdot \frac{IPD}{2} \quad (1)$$

Depth perception estimation formula for a VR headset based on the device horizontal field of view by Mike Alger (18).

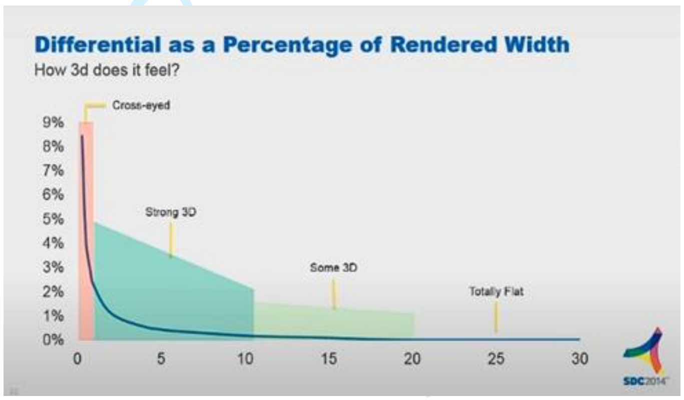

Figure 3: VR Design: Transitioning from a 2D to 3D Paradigm. Alex Chu. [Samsung Developer Connection], via Samsung. (https://youtu.be/XjnHr_6WSqo?t=1597)

Understanding depth perception per head-mounted display (HMD) can be estimated with the above equation. Previous studies into stereoscopic perception have shown that 20 meters is the maximum distance humans perceive depth, and with the above formula inputting headset specifications required the output ranges towards 20. This also coincides with another study (17) where users could see strong 3D up to 10m and gradually gets flatter and 2D the further away it is.

These areas of influence considered alongside the data used with data from Samsung study (FIGURE 3) show the ranges at which user's depth perception fade and ultimately lead to a 2D visual with no depth. Using this data, you can start to understand where information can be placed for a user and develop spheres of influence for interaction and 3D visualization. From an area surrounding the user which should never contain any interactable content as most of the space is taken up with the user's physical torso. To 0.5m out where the area is still a personal area of influence, the difference being that discomfort due to being cross-eyed can still occur at 0.5m distance from the user. When taking into consideration that VR headsets also are relatively large on the head, over prolonged periods there can be discomfort when looking down directly or up vertically, the personal space should be left with no interaction in it.

3.1 Accessible Movement Range

For understanding how head rotation can influence user comfort, Alex Chu's research (17) discovered that users head rotation has a range of comfort levels with varying degrees whilst wearing a VR headset.

The formula below is also using figures found by the study. It shows the subjective perception of comfort from participants head rotation. However, each HMD has a different horizontal and vertical field of view (FOV) therefore it should be considered an estimate on user comfort range when rotating their head (18). By overlaying all the figures, we can establish a baseline for where content should be rendered in VR for a comfortable experience.

$$Min\ Comfort\ Angle = \left(\frac{FoV}{2}\right) + 30$$

$$Max\ Comfort\ Angle = \left(\frac{FoV}{2}\right) + 55$$

Formula to calculate comfort ranges from a study on subjective comfort head ranges. Samsung VR study (17)

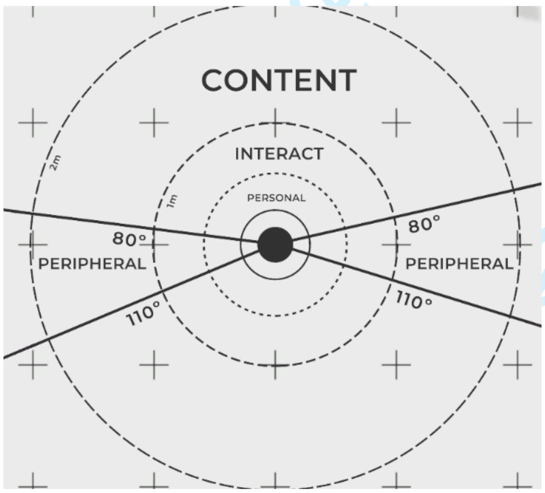

Figure 4: Visualization of areas of influence into a single graphic using formulas by Mike Alger's content zones (18)

The interaction zone lies at 0.5m to 1m from the user where 3D depth perception is at its clearest, without cross-eye discomfort. With the user's arm span on average the same as a user's height, it would be possible to scale this template algorithmically down or up accordingly based on user height while wearing the headset, however, there would need to be an additional study that takes comfortable user arm reach into consideration for a more accurate result. Arguably this zone is optimal for interactable components due to the comfortable legibility and with reference to office ergonomics where monitors are about 70cm away from the user's eye gaze.

The content zone is therefore between 1m and 2m as depth perception is still perceived, it is too far away to actively interact with the environment so requires locomotion movement in the virtual space or physical space. Alternatively, interaction with objects in the environment at range to prevent the use of a locomotion system can cause nausea to those susceptible. Optimally it is proposed to avoid anchored menu systems that require user movement, alternatively ensuring interactable components are within the comfort range of 0.5m to 1m would ensure users can visually read content without strain from being cross eyed.

4 GENEROUS MULTISENSORY INTERACTION

Accessibility design considers both the interfaces and the interaction techniques used to take the users input selection. Widgets that can be interacted outside of a user direct field of view and requires users to recall physical locations of interactable components with their precise input mechanism. Traditional interface design will use generosity to prevent users from straining while selecting or inputting values. Users' inability to operate controls in VR was discussed in Sutcliffe's book on multisensory interaction. Whereby using multisensory interaction, we can leverage other senses and abilities to inform or support the user's selection choice. Various design approaches have been proposed to solve this issue and can lead to improved understanding of the virtual or real environment. NAVIG (19) is an example where AR was used alongside semantic audio recordings to assist in guiding visually impaired users around the environment, aiding in user understanding of the localization of objects. This raises the question of what design approaches can be used to take advantage of as many senses as possible. The first investigations into physiological properties of human understanding of multisensory interfaces drew attention to four areas.

The criteria for multisensory interaction have previously been described by Sutcliffe. A novel 3D virtual reality slider which is further discussed in section 5.1 was developed following these design criteria. **Effective perception** is one concept, it ensures information can be seen and heard. As described in section 3.4 audio cues and on-screen markers can be used to support spatial awareness. **Appropriate comprehension, Integration and effective action** are other areas to consider for a multisensory interface. Comprehension will display an interactable component that is relatable to the task that the user wants to achieve, for example expected use case for a slider will increment and decrement a value. Comprehension is supported by intuition; by predicting how the user will interact with the system. By integrating feedback for the senses such as haptic vibration; auditory; visual stimuli you open the opportunity for more comprehension and understanding based on the user abilities, not inability. To reduce cognitive strain intuition can drive understanding by using the users' previous experiences with similar interfaces, although it has been studied in psychology that people tend to overestimate their competence, therefore developing with forgiving interaction design can prevent frustration, such as being able to retry an interaction quickly or by providing a forgiving learning environment, such as a virtual tutorial to demonstrate how a feature works (20). A study conducted (21) attempted to quantitatively measure intuition, designing interaction that compliments all the senses can alleviate limitations in user understanding the feedback of their interaction. Rather than an afterthought, by integrating numerous sensory stimulations and not isolating a sense initially; will support user understanding of where they are in the interactive process.

Current interaction techniques in virtual reality have examples of using 2D canvas environments, where accessibility design practices can be transferred from traditional media. However, 3D object user interfaces are relatively unexplored in research, and has the potential to provide a more generous interaction style for users due to the addition of another dimension and the support for haptics. Sutcliffe notes that creating interfaces that appeal to users should be a pleasurable interaction.

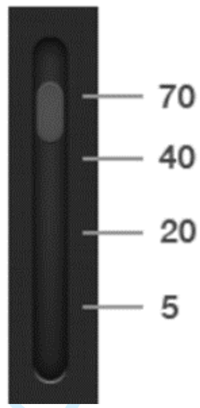

Figure 5: Logarithmic Slider with variable increments. Dmitry Fadeyev.

(https://usabilitypost.com/2011/08/31/weighted-slider-increments/)

4.1 VR Interfaces

Making interactions require less fine motor skills and leaning towards more gross motor skills such as utilizing upper arm movement, has the potential to reduce user fatigue and frustration during interface selection. Using a laser pointer with a 2D panel emulates functionality of cursor movement. An alternative to 2D interaction is to use natural interaction techniques such interaction with 3D components. A study (22) on 3D interaction showed positive correlation with user satisfaction when direct touch and grab of objects were available compared to gaze and pinch. This would suggest that users in VR have the capability to interact with their environment in a more natural way by grabbing objects using a motion controller by the user in 3D space. Adding in another dimension into interface design opens the opportunity for more gross motor interaction techniques to be adopted. An example using design philosophies discussed, a 3D logarithmic slider was developed to demonstrate 3D interface functionality in a VR environment. Once the slider toggle has been grabbed using a desired button mapping, the slider toggle can be moved at a distance decided by the user due to the flexibility of the toggle's physics. By fixing the slider thumb to the x-axis but leaving y and z-axis transforms unrestrained, it allows the user to move their hands to a desired position that may be more comfortable or now achievable. By implementing increments into the slider, haptic feedback can also guide the user's selection.

Combining incrementing audio with movement in a logarithmic slider demonstrates the modalities of a richer tactile feedback that corresponds to each incremented weight, providing additional confirmation on the current state of the interface component. Visual stimulation of moving the toggle in 3 dimensions with a spring physics effect aligns with UI design trends with motion design reinforcing user feedback and selection. This is becoming more accessible to develop with and with VR being in a 3D space it would appear as an opportunity for VR to pursue this area of visual feedback with materialistic motion design making interfaces feel natural, responsive, and enjoyable to user (23). Initial UI systems could not have motion or animations due to processing restrictions; we can now have 3D UI that is interactive and runs on systems.

Interacting with the toggle works the same way as a traditional 2D slider however an additional axis is used to allow users to move their hands closer to their body while still moving the slider. A spring is attached to the toggle, resulting in the toggle returning to the desired position once moved. Ensuring that the slider has effective perception properties will prevent users from having to learn via tutorial or text what this UI widget is and how it works. Generous interaction design is not new for real time development (24) but allows users to be close enough in selection allowing the interface design to take care of most of comprehension. A robust accessible design should also consider the options of binding the slider toggle movement to other input mechanisms. An example of this would be rather than using arm movements to move the slider, eye gaze or HMD focus of the interface component followed by using a finger slider or 6 degrees of freedom (DOF) joysticks along a desired axis is also an appropriate input mechanism to control the slider widget. The concept of brain computer interfaces (BCI) can also support. By avoiding hardware locked interfaces, you can support more assistive technologies such as the example above, where support for alternative control schemes can still provide a full experience for the user. As previously discussed in section 5, supporting feedback will support comprehension of selected values in a UI widget such as the slider allowing users to input the desired value after they have completed their interaction with the slider.

Study (25) showed that the addition of passive-haptic feedback for use in precise UI manipulation tasks increased performance when manipulation problems were presented. Additionally, by supporting the calculated area displayed in FIGURE 4, we can ensure the location of the interactable components are within optimal area for users.

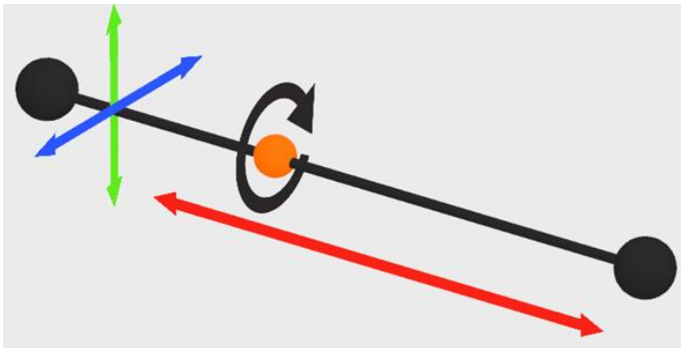

Figure 6: Wireframe diagram showing 3D slider and the range of motion that is available for selection.

5 TREMOR REMOVAL

A previous premedical trial using 10 participants looking into removing tremors with Parkinson's patients was conducted using the Oculus Rift VR headset for involuntary hand tremors specifically. The study found that tremors could be abolished with the use of algorithms for their digital hands, impacting positively on the patients their real life with being able to complete tasks that otherwise were impossible or difficult to complete such as signing tax documents. Noticeably, the tremors reduced in real life when the patient was using the tremor reduction algorithm in the virtual reality headset.

The method used in the study was to implement equalizer algorithms which were developed long before virtual reality headsets had the capability today and previously designed for normalizing communication channel data to combat the intersymbol interferences effect (26). Traditionally this would require previous data recordings to learn from and algorithm input values adjusted to output the optimal normalization result. Oculus Touch controllers record data of rotational angles and cartesian positional coordinates up to 1000Hz. Parkinson's disease tremors have ranges of tremors of 4Hz which the trial recorded at.

5.1 1 Euro Filter

The removal of user tremors using algorithms can also have design implications when creating interaction mechanics for the XR platforms. Noisy signals are common when tracking human motion (28). It is in the area of human computer interaction where the 1-Euro Filter algorithm can be used to assist interface selection whilst avoiding using filters using a moving average. Where in its foundation, the 1-Euro Filter was designed specifically for normalizing input related to interface. A short study was completed to explore how such an algorithm would be implemented for use in a virtual reality development environment and highlight issues of implementing such an algorithm real time using the Unity game engine.

The filters normalization parameters are Frequency, Minimum Cutoff, Beta and DCuttOff values, which can be adjusted in real time to allow a tailored experience for the user at the desired frequency. The implementation of equalizer algorithms (5) for tremor reduction are effective however the 1-Euro Filter is intuitive and a practical alternative due to its simplicity in its implementation.

This could open the opportunity for tremor reduction where exact tremor Hz is not known, but the user can adjust the experience in real time and tailor it to their preference.

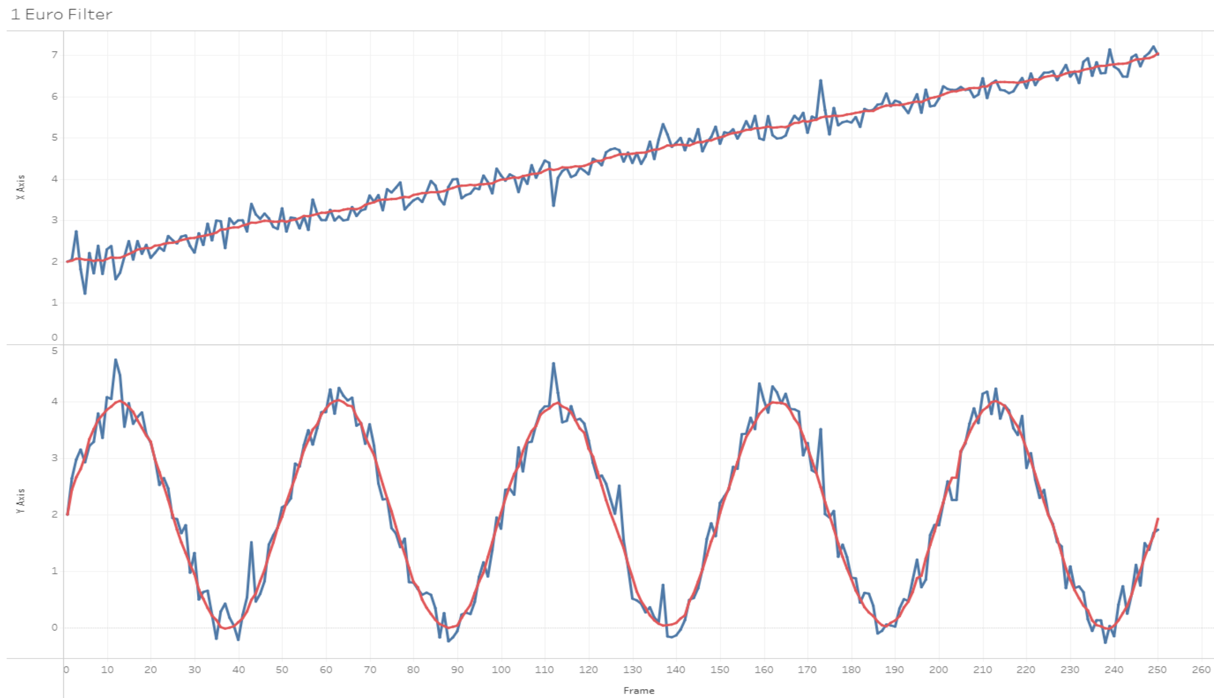

Figure 7: 1 Euro Filter demonstrating tremors in blue and the same tremor normalized using the filter in red.

5.2 Method

The primary objective of the study is to understand the feasibility of introducing a normalization algorithm into an XR development environment to highlight issues associated with its implementation. The Unity Game engine was used with integration tests on a Valve Index HMD. The Unity XR plug in framework was used to interface with the OpenXR plugin which is now becoming a widely adopted standard to support a one build solution for compatibility with numerous HMD headsets. The hardware used for development and running of the study meets the minimum specifications required for the experience to run at 120hz at 120fps with hardware as follows; i9 9th generation CPU, 32GB of 3200Hz RAM; GTX 3070 GPU. This hardware is assumed to produce high graphical fidelity support for the purpose of this study, introducing minimum to no jitters or unintended processing spikes for this developed experience.

The study simulated vector noise on two 3D objects; A and B which were children in hierarchy to the VR controllers. Noise was simulated using a constant multiplied by the Random.Math() function. The returned value was then applied to the objects X and Y transforms. Additionally, the Z value during data recording was set to 0 as the objects had a cosine function applied to the controllers, simulating controlled movement across the X and Y axis. The two game objects were being manipulated with the same random vector values, where object A had the filter enabled at runtime and object B disabled. The output vector values for each object was recorded resulting in the outputted graph displayed in figure 7. The movement and filter were applied in a FixedUpdate() method which restricts frame rate to 50fps. This was to prevent fluctuations caused by various machine background processes and added an additional control element to the simulation. Both objects X position and Y position were stored for 500 frames or 10 seconds into a CSV file where post-processing was completed on the data using Tableau.

Implementation of the 1-Euro filter algorithm started with (27) implementation with further modifications to support the XR environment. As described in the algorithms release paper (28) the algorithm uses low resources and works by completing an initial first order low-pass with a frequency cutoff. During low movement speeds, the cut off value stabilizes the signal by **reducing jitter** and as the speed increases the cutoff value is increased to **reduce lag** on the applied object.

Issues associated with the implementation was related to design decisions of integrating the algorithm with a VR controller. The decision to either directly filter the user's controller positions or filter an object set to a child of the controllers. As VR controllers have 6 DOF, storing the users desired position in a buffer and then applying the filtering algorithm can lead to increased latency, furthermore, by filtering the users hand or controller movement directly will cause the user tracking to not feel responsive and can therefore cause frustration. Not having 1:1 tracking can also contribute to breaking immersion. The solution was to implement the filter on objects set to children to the tracked controller. Functionality of the filter is then limited to interaction systems on this object, such as the user's laser pointer. This allows the users tracking to be 1:1 accurate and representative of the real-world positional tracking, while the laser pointer and interaction system has the smoothing filter applied.

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