Django

VR Controller

Designing Game controllers for Gamers with Hand Amputation

Master Thesis

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Integrated Product Design

Designing Game controllers for Gamers with Hand Amputation

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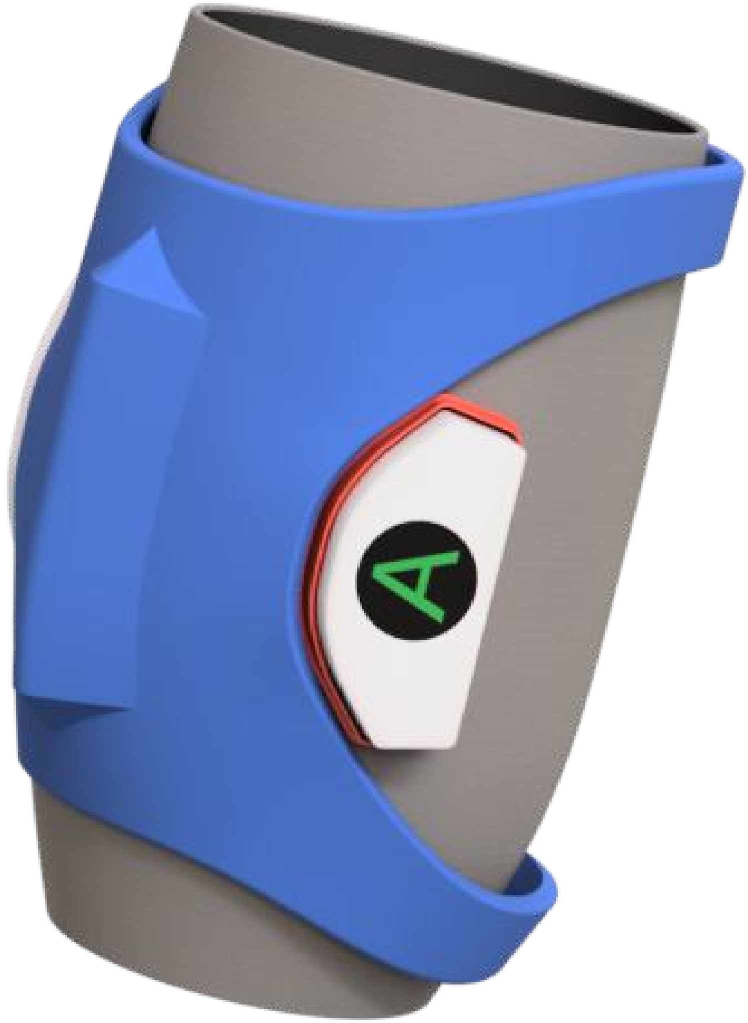
Preface

This thesis represents the culmination of my work over the past months on designing accessible Virtual Reality (VR) controllers for users with hand impairments, particularly those with hand amputations. The motivation for this project stemmed from my personal connection to video games as a powerful medium for storytelling and immersive experiences. Throughout my life, I have been profoundly influenced by stories across various mediums, and video games have played a significant role in shaping my perspective. It is therefore disheartening that one of the most engaging and impactful ways of storytelling remains inaccessible to a considerable number of people due to physical limitations.

This project is my attempt to bridge that gap and provide access to a portion of that user base, enabling them to interact with games and other VR/AR applications. The journey involved extensive research, user interviews, co-design sessions, and iterative prototyping—all aimed at understanding the unique challenges faced by individuals with hand impairments and finding solutions that work for them.

Through this work, I sought not only to create a functional and inclusive product but also to deepen my understanding of the complexities involved in inclusive design. This project is a stepping stone for me in my pursuit of designing products and services that are as inclusive as possible, without compromising on the impact and user experience they deliver, regardless of the user or their challenges.

I hope that this work contributes to the ongoing conversation about accessibility in technology and inspires further innovations in this crucial area.



Acknowledgement

I want to express my deepest gratitude to all those who contributed to the successful completion of this project.

First and foremost, I want to thank Marijke, my chair, for her unwavering support and guidance throughout the project. Your support and feedback taught me valuable lessons and helped me connect with users who were crucial to my work.

I would also like to thank James, my mentor, for his steadfast guidance and support. Our weekly meetings and discussions constantly challenged me to think critically and reflect on the project, significantly shaping the direction and depth of my work.

My sincere thanks go to the users and expert (Ties) who participated in this project. Your willingness to share your experiences, challenges, and insights gave me a deeper understanding of the issues at hand—an understanding I could not have gained otherwise. Your input, feedback, and suggestions have greatly enriched the quality of this work, and without them, this project would not have been possible.

My heartfelt thanks go out to my family and friends for their unwavering financial and emotional support during this time. Your understanding and encouragement have been a constant source of motivation, and I am truly grateful for your belief in me.

Thank you all for your contributions to this project.

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(Minecraft Wallpapers, 2023)

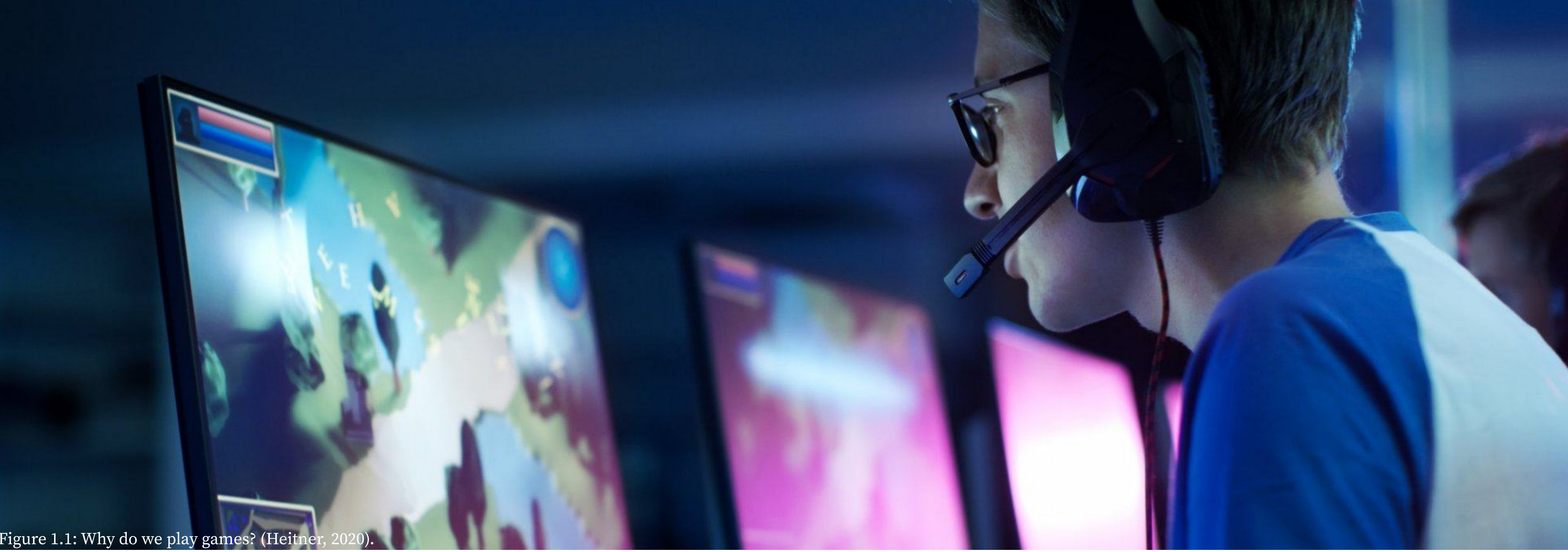

Figure 1.1: Why do we play games? (Heitner, 2020).

Gaming and Why People Play?

Why do we game? Well, because it is magical. It is a culmination of art, story, technology, and skill that grabs people's attention and makes them think, ponder, cry, laugh, and create memories. All of these have the potential to entertain, educate, and, in many cases, change people's lives altogether. Users play video games to experience the freedom of exploring another world, to be creative by constructing new worlds or solving puzzles in a new way, to socialise and bond with their peers or meet new ones (all over the world), to relax, and to have an avenue for escape from the mundane tasks of the natural world. Sometimes, it's just fun to play.

Gaming has evolved into one of the most engaging and immersive forms of entertainment available today. It has the power to change lives and reshape our perspectives; it can inspire and transform us. Users can now not only consume content and stories (like movies, TV shows, books, etc.) but also experience them by actively engaging with the content. For the first time, the content reacts back to the user's actions. Therefore, it is one of the most potent storytelling methods. No other entertainment medium allows users to freely explore, take control, modify, and change an imaginary world that reacts to their behaviour.

Figure 1.2: One of the biggest E-sports tournament (Biggest Esports Tournaments of 2023 | Nerd Street, 2023).

The state of gaming

In 2022, the video game industry boasted an estimated 3 billion players worldwide, generating a net revenue of $184.4 billion (Arora, 2023; Bankhurst, 2020). This figure surpasses the combined annual income of the music and film industries more than threefold. Video games uniquely engage users, transporting them to virtual worlds like no other. The sheer numbers speak for themselves.

Gaming now significantly influences social media, trends, professions, the entertainment industry, and even research. The rise of gaming communities has opened up new ways for users to earn a living. Many play games to earn, react, and share their experiences online (e.g., Let's Play streamers), while others have been inspired to join the industry because of its profound impact on them. In some niche cases, games and software are utilised for rehabilitation, training, and research applications. Moreover, video games have permeated our smartphones, with increasingly powerful hardware capable of running games that were unimaginable a decade ago. What began as a simple ping-pong game in a wooden box has evolved into a thriving industry and one of the most potent modes of engagement. Players can now immerse themselves in fantasy worlds and share these experiences with their peers. This transformation has influenced how we express artistic ideas, implement technology, and socialise.

Players engage with video games for fun and to experience compelling stories, offering an impact similar to movies, music, and other forms of entertainment. Gaming has revolutionised social interaction, allowing users to connect and engage in activities from the comfort of their homes. Video games have genuinely changed the landscape of entertainment and socialisation, maintaining a consistent impact.

Future of Gaming

Video games have been evolving for quite some time now. While they have technologically progressed from using a CRT mono-colour monitor to high refresh rate colour-accurate displays, from using analogue controls to now using a combination of high precision analogue and digital controls that can accurately monitor and recreate a user's physical movements in a virtual world, they have also impacted our culture, experience, social practices, and more. There is one metric that has always remained constant and synonymous with video games throughout this journey, however, and that is immersive engagement. Throughout the evolution, while technologies changed and revolutionised the industry, it was all to improve players' immersive experiences. Today, virtual reality and augmented reality are the obvious next steps. It is an experience that can now truly transport players to another world. Although VR/AR (figure 1.3) has been in development for quite some time and has seen significant advancements, such as the release of devices like the Oculus Quest 2 and the recent release of the Apple Vision Pro, it is still not fully mature or capable of delivering the truly immersive experience that conventional gamers expect. But, with companies like Meta and Apple increasing investments and pouring more and more resources in this direction, alongside the steady improvement in hardware capabilities and content development, there is likely to be a substantial shift in how we experience our media entertainment.

Figure 1.3: People playing VR Games (Team, 2023).

Problem?

At least 20% of the nearly 3 billion gamers experience some form of disability (AbleGamers, 2024). When video games significantly impact our lives, it is unfortunate for some to be unable to experience them. The problem is quite complex; it is a culmination of rapid evolution, complex medical issues and low market shares. By the time people started to look into the accessibility of the video game industry (figure 1.4), the environment had already matured into a well-oiled machine. The development process of games and hardware were so in sync and related that any attempts to change or modify the system would lead to a massive outrage from loyal fans to game studios trying to adapt to the hardware. Moreover, the future of gaming (VR and AR) could also go in the same direction.

Nevertheless, as of now, this region of the (VR/AR) technological landscape still needs to mature and, therefore, the perfect fertile ground for laying out initial frameworks and roadmaps that can eventually help make the system more inclusive.

Figure 1.4: A user with disability accessing conventional games using the Xbox adaptive controller (Xbox Official Site: Consoles, Games and Community | Xbox, n.d.).

Chapter 2

Evolution of controllers & Accessibility

Game controllers have evolved quite a bit since the introduction of pong. From using completely analogue-based inputs to compact motion tracking sensors that can translate the user's motion in 3D space, we have come quite far with how we interact and play games. This section will explore the evolution of games and game controllers, how they evolved and what are the current Accessibility options available for Gamers.

Figure 2.0: Evolution of Game controllers (Magnify,2021)

Evolution of controllers

Analogue Control | 1D Movement | 2D Movement | Action button | Ergonomic | Add. Buttons

Figure 2.1: Pong Console with controller

Figure 2.2: NES controller

Figure 2.3: PlayStation controller

1975: Atari Home Pong Console
It is widely regarded as the first commercially available console. This system started it all; the game (Pong) was so successful that Atari made an entire console just for it. This system also has Controllers attached to it. The controller consisted of two knobs that were used to move the paddles on the screen. The controls were simple and easy to use and started the Home Console Revolution.

1983: Nintendo Entertainment System (NES) Controller
A rectangular plastic casing with two buttons on the right and a D-pad on the left. The NES controller allowed the user to move characters in 2 Dimensions. Although simple, the layout has influenced controllers' design to this day.

1994: PlayStation Controller
The Play Station took the NES layout and modified the controller's shape. With elongated grips, the PlayStation controller was the most ergonomic on the market. With the added buttons and shoulder triggers, the controller can provide additional functionality for more complex games launched.
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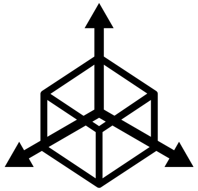
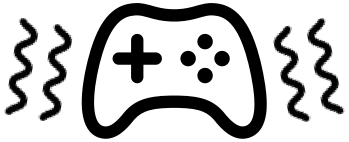


3D Movement



Vibrational Feedback

Figure 2.4: N64 Controller

Figure 2.5: PlayStation Dualshock

Figure 2.6: Xbox Controller

1996: Nintendo 64 (N64) Controller
The N64 controller was the first controller to add an analogue joystick. This was also the era of the first 3D games. The analogue joystick gave users the ability to navigate in 3D worlds. Although the 3-handle design didn’t hold up, the implementation of the joystick changed the gaming environments from 2D screens to 3D worlds.

1997: PlayStation DualShock
Widely regarded as the first modern controller, Sony kept everything that worked with the original dual shock and added two analogue joysticks for seamless movements in 3D worlds. The controller additionally added the analogue rudders predominantly used in racing games.

2001: Xbox Controller
Also known as the “Duke” (due to its size), Xbox took the conventional controller and changed the position of one of the analogue sticks to make it ergonomically more comfortable. Its size also made it very comfortable to use.

Wireless

Motion control

Figure 2.7: Nintendo Wii Remote

2006: Nintendo Wii Remote

The Wii Remote finally allowed gamers to access motion-based games in their homes. The controller has conventional buttons and a D-pad so that users can play both motion-based and traditional games. The controller houses an IR sensor to track the user's movements. The success also prompted Xbox and Sony to develop their motion-based controller and systems.

Wireless

Figure 2.8: PlayStation 4 controller

2013: DualShock 4

The DualShock 4 improved on its predecessors by making the controller wireless and adding motion control with the controller and touchpad while maintaining the original design and layout.

Controller Perfected

Figure 2.9: Xbox One Controller

2013: Xbox One Controller

Xbox finally perfected their controller with a more angular design and solid feel. The Xbox One controller’s design was so well received that its design and layout have never changed.

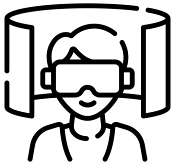

Portable


Wireless

Figure 2.10: Nintendo Joy-Cons

2016: Nintendo Switch Controller (Joy-Cons)

A portable controller for a portable console. Each switch console came with 2 Joy-Cons attached, allowing you to carry two controllers simultaneously while innovatively using the new layout for multiple games. The controller connected wirelessly and had motion sensors for supported games.


Virtua reality

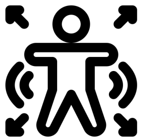
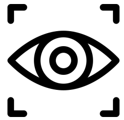
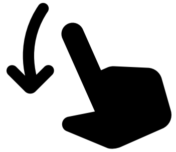

Motion control

Figure 2.11: PlayStation VR Controllers

2023: Modern VR Controllers

VR controllers utilise most of the layout of a conventional controller while splitting it into two. These devices have built-in accelerometers, gyroscopes, and IR sensors to accurately track the user's movements.


Eye tracking


Gesture Control


Voice command

Figure 2.12: Apple Vision Pro (Apple, n.d.).

2024: Apple Vision Pro

With the release of the Vision Pro, users can now interact with virtual environments using simple gestures and voice commands. The device also uses eye tracking to realise and choose objects in virtual environments accurately. While unsuitable for gaming, it significantly changed VR/AR interactions

Figure 2.13: Pong home console (right) (Interfoto/Alamy Stock Photo), Apple Vision Pro (left) (Apple, n.d.).

Game controllers have evolved quite a bit from their analogue origins. From bulky knobs to low latency, ergonomic and wireless controls. However, while the technology aspect of the controllers has evolved, some elements like the layout, button sizes, and shape have remained the same since the early 90s. This evolution also indicates that companies were more focused on keeping up with the competition and evolved rapidly to outdo the competition. While this has led to considerable improvements in game controllers, it also meant that companies rapidly changed systems and devices and could barely focus on the group of users who could not access their gaming peripherals. Furthermore, because the layout and ergonomics have remained consistent, companies now have a loyal fanbase that can react negatively to any minute change in their favourite controller features. Even revolutionary changes like the VR controllers still utilise many modern controller layouts and schemes to cater to current users and their familiarity with the existing controllers.

Accessibility

With nearly 20% of all gamers suffering from some form of disability, it is crucial to realise and include the users who want to play. As observed with the evolution of game controllers, companies have constantly innovated and developed ways to interact with games, the same holds for developed games. Game studios were also competing and innovating to give users a more immersive, interactive and memorable experience. In the process, Users with disabilities were not given full attention by either game studios or hardware manufacturers for a long time. Additionally, the smaller fraction of users with disabilities in the overall gaming community has contributed to the lack of focused research and development in this area and most professionals in the industry do not pay as close attention to the latest research and innovations on accessibility (Aguado-Delgado et al., 2018).

However, some gaming studios, hardware manufacturers, and designers are trying to implement accessibility features in their products and games. For example, nearly all modern games give users the ability to re-map their buttons; this could mean the difference between pressing a button multiple times and pressing a button once to simply pulling the trigger or mapping a frequently used button that's further away to a button that's a lot closer to the user's fingers, making a huge difference for users with limited motor control of their fingers or for users who cannot press buttons rapidly or frequently. Another great example is Mojang changing the (decade-old) textures of ores and elements in Minecraft to make it easier for colour-blind users to differentiate different ores by pattern alone (Fairfax, 2021).

Now, while these advancements are more than welcome, they do not still bridge some of the more obvious gaps (access to users with physical disabilities, better compatibility with more niche hardware, etc).

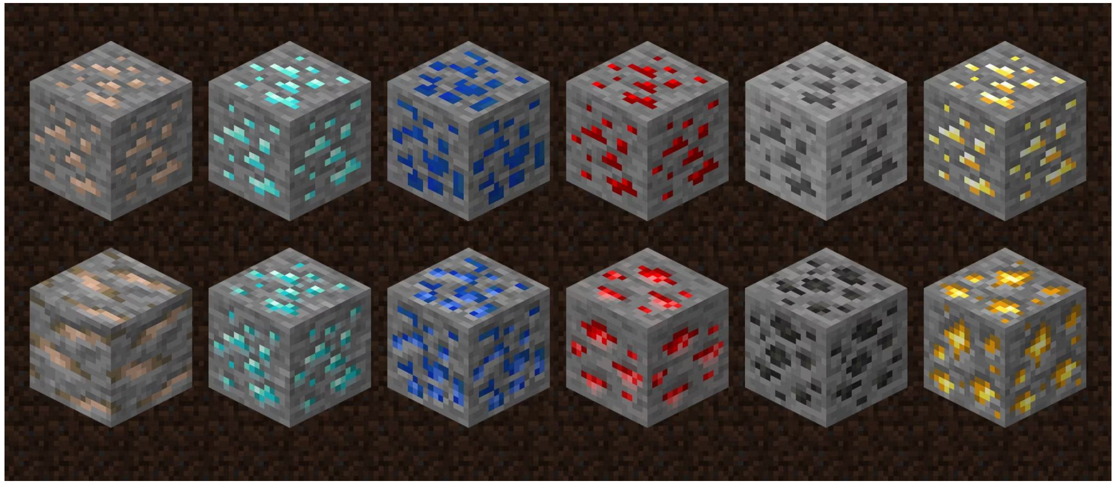


Figure 2.14: The Old Textures of ores (Top) with same patterns changed to more easily recognisable unique textures for each ore (Fairfax, 2021).

However, while these advancements are encouraging, they still do not address several critical areas. For instance, users with physical disabilities continue to face significant barriers in accessing certain games, and there remains a need for better compatibility with more niche hardware, which is essential for inclusive gaming experiences. Something Xbox tried to solve using the Xbox adaptive controller (detailed further).

Challenges

Despite the massive advancement in technology since the advent of the first gaming console, the support for disabled gamers is still low. There are many reasons for this. The most important one is that disability is not just one case. It is always a spectrum. Two users can have the same disability and yet may face different challenges in their everyday lives. Every disabled user’s experience is unique and different from that of others, and therefore, it is almost impossible to have a “one size fits all” solution. Attempting to create a universal solution for all disabled gamers could lead to compromises that diminish the overall quality and enjoyment of the gaming experience for many. This is because the diverse needs of individual users may conflict with each other, making it challenging to develop a single interface that caters effectively to all. It could further lead to the segmentation of the players (Aguado-Delgado et al., 2018). Therefore, solutions (Hardware and Software) must be varied and versatile to accommodate every user. Frameworks usually depend on a specific technology, which limits developers as most designs and solutions use third-party technologies.

Nonetheless, DIY projects have become famous for addressing hardware accessibility issues because they offer unparalleled freedom to customise solutions for individual needs. With the rise of affordable 3D printing, users and developers can design, test, and iterate on these solutions quickly, making it possible to create highly personalised and effective accessibility tools. As the gaming industries evolve, it is necessary to foster an environment that supports diverse, adaptable and customised solutions, thus ensuring all gamers, irrespective of their impairments, have equal access to gaming.

Figure 2.15: DIY 3D - Printed add-ons for making controllers (PlayStation 5 controllers (top), Nintendo Joycons (below)) (Akaki Controllers, n.d.).

Figure 2.16: The Xbox adaptive controller (Xbox Accessories & Controllers | Xbox, n.d.).

Xbox adaptive controller

The Xbox Adaptive Controller (XAC) is Microsoft's attempt to bridge the gap between disabled users and Gaming. We know that the current gaming practices are complex to change. Therefore, a total redesign with new buttons, button mapping and interfaces would be complicated to adapt to the current gaming ecosystems. One of the main reasons there hasn't been a universally accessible controller is the sheer number of impairments humans can experience. Each user has different conditions and needs, which is a massive roadblock for developers and designers to cater for the disabled sector of the market. While personal DIY projects help users with the lack of standardisation of parts, the technology used (3D printing, custom electronic systems/kits, custom software, etc) results in an arduous development process.

Therefore, the only way to cater to every user, every impairment, and every case was to have a universal hub that could communicate with any input hardware. And that's what Xbox did.

The XAC is a game controller hub that can connect to 19 external input devices, from joysticks and simple buttons to custom DIY peripherals created by third-party developers. Additionally, the hub works just like any other Xbox controller and can be used to play on consoles and PCs. Microsoft also realised the importance of having an open platform and, therefore, has digital developer kits and guides available for free to the public. It is truly an honest attempt at bridging the gap between disabled gamers and gaming.

How do you use the XAC?

Step 1: Choose the Input device that best suit your need (Figure 2.17).

Step 2: Connect to the XAC to the desired button map. For example mapping one of the buttons to X action button(Labelled “**X**” in figure 2.18), using the touch sensor for the Right-trigger button (Labelled “**RT**” in Figure 2.18).

Step 3: Physically set up your controller (Figure 2.19) & you are ready to play!

Step 1

Figure 2.17: Some of the input devices supported by the Xbox Adaptive controller (Xbox Accessories & Controllers | Xbox, n.d.).

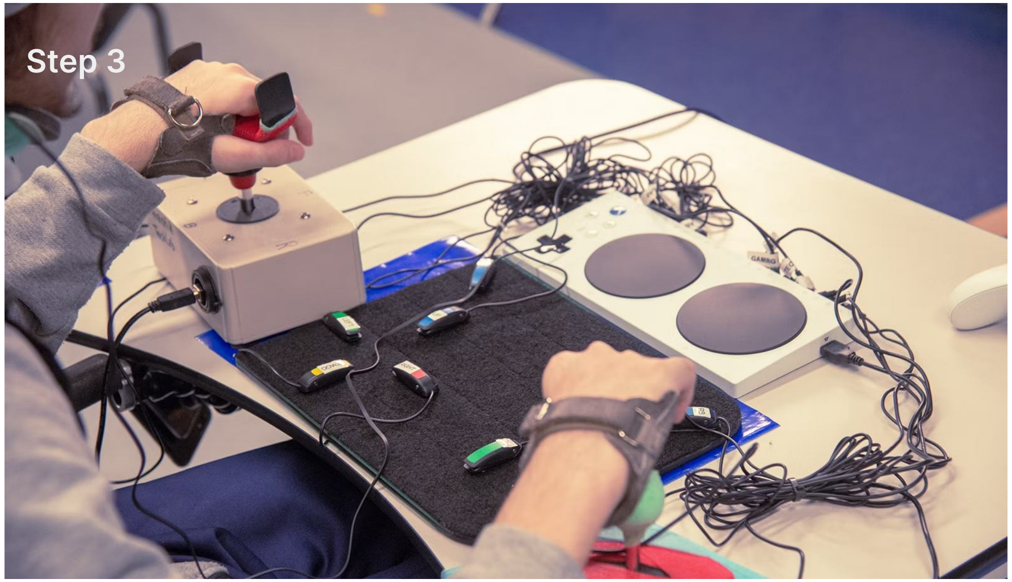


Figure 2.19: A XAC setup of a gamer with disability (Langridge, 2018).

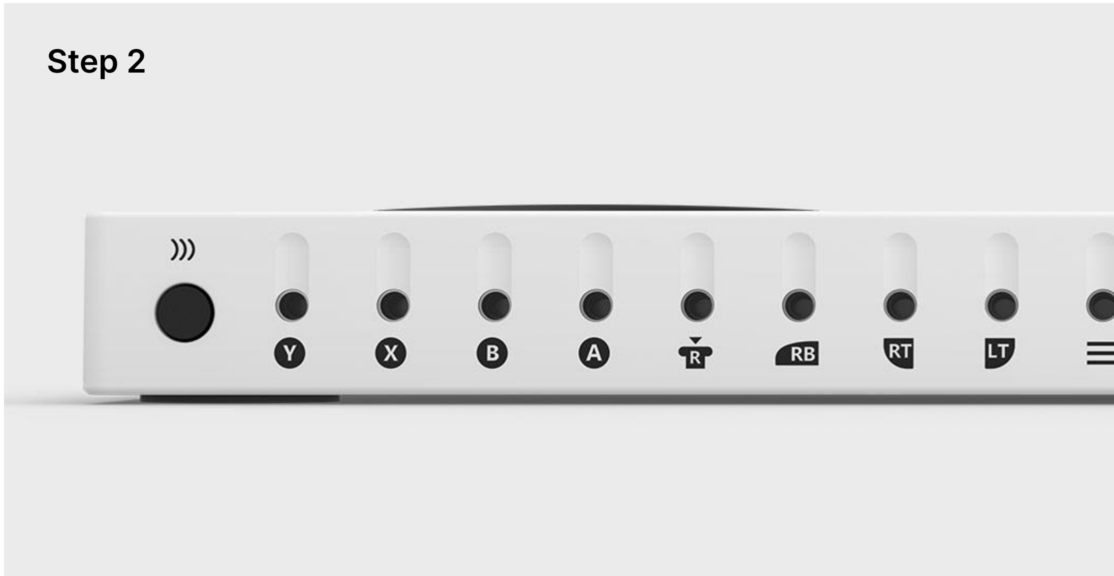


Figure 2.18: Input devices are physically mapped by connecting them their respective ports (Xbox Accessories & Controllers | Xbox, n.d.).

Conclusion and Key Takeaways - Evolution of controllers and Accessibility

It was clear that companies and organisations put in some effort to cater to gamers with impairment. However, the effort could be more consistent and, in some cases, mandatory (Strebeck, 2020). What we do know, however, is that some of the simplest features can provide the biggest relief. The ability to button map, tune audio, and modify video Settings can provide many relief and support to many people.

One of the most successful accessible gaming hardware today is the Xbox adaptive gaming controller. As discussed earlier, impairments and disabilities are complex conditions; in many cases, users would be suffering from more than one kind of impairment that might still prevent them from accessing a solution. XAC works because it is not a general solution that solves all problems, nor is it a very specific solution that solves just one type of problem. It allows users with their DIY projects and inventions to find a way to work with existing systems. As the name suggests, it is an "adaptive" controller that adapts to different hardware the user wants to use.

Key Takeaways

- It is hard to satisfy and solve a problem for everyone, even if it is just one type of disability.
- Key to good accessibility hardware is its ability to adapt to the user's preference and choice of (in this case) hardware.
- Have simple features like
  - Button mapping
  - Multiple modes of input (two types of input doing the same task, for Example, users can hit a button on the keyboard or click the mouse button to execute the same action).

Chapter 1

Virtual Reality

This chapter delves into the world of Virtual Reality (VR), exploring its evolution, current state, and the technologies that power it. The chapter will also examine the core components of VR systems, such as headsets, controllers, and tracking systems, and discuss their roles in creating immersive experiences. Additionally, it will address the challenges and limitations of current VR technology, particularly in terms of accessibility for users with physical impairments.

Figure 3.0: Meta Quest 3

Virtual reality has gained much traction over the past couple of years, and although it didn't live up to the hype of the past, it didn't wholly disappoint either. Sales of VR systems have steadily risen over the years; analysis has shown that the main driving factor behind VR system sales is primarily through Gaming (Variety VIP, n.d.). Now, this makes sense, as VR doesn't necessarily change what you consume (Games, Movies, Creative outlets) but "How" you access and experience it. Virtual reality is a more immersive way of doing what we do.

Like any promising platform, VR has gained traction in many sectors. From Gaming in a virtual world to production facilities in Hollywood for easier production. With every year that passes and technology that improves, VR slowly gains more importance and standing in our everyday lives. This evolution is also accompanied by gaming studios and companies constantly producing immersive and more interactive experiences for users, bringing in newer users and further changing the field.

Of course, as mentioned earlier, although the field has steadily improved, its mode of interaction and means to access them haven't changed that much. While it is a significant technological achievement not to use controllers (like in Apple Vision Pro, Quest 3 and others), it still requires users to make delicate hand and finger-based gestures to interact within the VR world.

This improvement in gesture-based inputs and technology overall, however, still doesn't improve accessibility to users with no hands or limited hand mobility. Let's look into the VR system and what it entails and explore some research conducted in this field.

VR and Accessibility: A Literature Review

While the Xbox Adaptive Controller (XAC) provides disabled gamers a way to play conventional games, no product on the market offers similar accessibility for VR controllers. VR technology is still relatively immature, so consumer-based applications that fully utilise its capabilities are limited. Furthermore, significant advancements are needed to make VR a viable mode of interaction for a broader audience.

VR is predominantly used for gaming, professional applications (such as filmmaking, design, and architecture), and other niche uses. However, recent developments by major tech giants, such as the release of the Apple Vision Pro and Meta's investment into the Metaverse, indicate that VR technology is poised for broader adoption and will soon revolutionise how we interact with digital content.

Research on User Interactions

Several studies have focused on how users with disabilities interact with VR environments. For instance, other studies have worked on hybrid controls, using gestures and controllers to interact in the VR world. While the users' performance using the hybrid interaction method improved, several other roadblocks could have also been improved. Namely, when users are given multiple options, they can frequently choose the wrong device or method. The wrong pairing of devices would lead to the varying performance of the dominant and non-dominant hands (Huang et al., 2020). Moreover, users interacting in the VR environment tend to prefer single-handed interactions over dual-handed ones. In scenarios where dual-handed interactions are necessary, there is usually an active and a passive hand, and it is recommended to rely on interactions that use the shoulder's flexion and abduction movements (Nanjappan et al., 2018). These insights can be valuable in designing more accessible VR environments.

Challenges and Gaps

Due to its niche position, current VR technology results in the industry and its players overlooking the accessibility issues. When studied, these issues are a lot more complicated, highlighting challenges not just in hardware or software barriers but also ethical barriers as well.

In its current state, VR/AR tech is not only not built for users with impairments, but they don't have alternative avenues to experience them either (Creed et al., 2023). Inherently embodied interactions used for control inhibit certain users with impairments from executing them; these controls create barriers for disabled users where there are no obvious pre-existing solutions, further limiting access to the system as a whole (Power et al., 2023). Moreover, while there is some work on interaction in VR/AR, the locomotion side of the technology hasn't changed much. Many of the applications and games still use Walking in Place or Joystick/controller-based navigation within the environment. This, however, is not limited to games, as most of the research on locomotion also uses the same methods (Boletsis, 2017). This further proves that as long as a system works for most users, the tech doesn't necessarily evolve that much unless there is a considerable shift or evolution in the system as a whole.

Opportunities and Future Directions

However, several studies and projects have tried to tackle accessibility issues with VR/AR. Researchers have gained many insights on efficiently interacting in VR/AR with the least or minimal fatigue. For example, exploring VR environments while lying on the bed is also a valid approach. Surprisingly, the illusion of standing up in a VR world still holds even when the user is lying down.

However, this would only hold good if the user doesn't have to interact with the environment. Even the simplest interaction proves challenging when lying down (Van Gemert et al., 2023). This would still be a valuable way of experiencing VR worlds for users who are bedridden or have severely limited mobility. Additionally, giving the user the ability to choose the size and location of a couple of buttons is immensely helpful for interacting with a head-mounted display. When users were given the freedom to choose buttons of different sizes and to place them in their preferred layout (for example, some placed it on their thighs), it proved to help users with upper body motor impairments to interact with a head-mounted display (Malu & Findlater, 2015). This approach aligns with the principles of the XAC, where users can decide on the type of inputs and layout they want. Clearly, some of the old principles still apply to VR/AR. Given the current state of VR, it is an opportune moment to develop frameworks and standards for accessibility.

Despite ongoing research, there has been no substantial disclosure from companies and organisations regarding efforts to make VR and AR accessible to disabled users. Therefore, it is crucial to create inclusive design frameworks and standardise accessibility features in VR and AR before the sector becomes saturated with a rigid and exclusive ecosystem. By addressing these issues now, we can ensure that VR and AR technologies are inclusive and accessible to all users as they continue to evolve and expand.

VR Systems

The virtual reality system has two main components/devices: the head-mounted display (VR headset) and the VR controller.

The VR headset

The head-mounted display (Figure 3.1) consists of two screens that display the virtual world in front of the users. The headset is also filled with sensors (infrared for position and motion tracking, accelerometer and gyroscopes for attitude information, cameras and receivers to track the user's movement visually in an enclosure, and any other input mechanisms) and speakers for audio output to the user. The headset also houses the main computing unit of the system; the headset takes in inputs from all the sensors and calculates accordingly to give the user a consistent and fluid experience.

VR Controllers

The input device for most VR systems is their corresponding controller. Some mixed reality devices do not need a controller, namely the Apple Vision Pro and the Microsoft HoloLens 2. These devices only require your hands as a means to interact in the virtual environment (figure 3.2). While this works well for formal VR/AR applications, physically demanding tasks like gaming, modelling, and other creative endeavours can take a toll on the user when using the system for prolonged periods of time. Research has also shown that users do not prefer using only their hands as a means of interacting with VR environments (Johnson et al., 2023). This is understandable, as repeatedly performing specific gestures for interactions can become tedious and physically exhausting over time, especially when compared to the simplicity and efficiency of pressing a button or using an analogue joystick.

Figure 3.1: The Meta Quest 3 headset & controller (Meta Quest 3: New Mixed Reality VR Headset – Shop Now | Meta Store, n.d.)

Figure 3.2: Operating VR controllers primarily relies on precise finger movements and hand dexterity (Jimenez, 2023).

VR Controller layouts

Joysticks: These are analogue input mechanisms similar to the ones used in conventional controllers; they, too, are used to move around in the environment.

Action Buttons (XYAB buttons): Two on each controller; these buttons can be mapped to any action within the game. Unlike conventional controllers, their usage in the virtual world has been significantly reduced to make minute interactions (unequip/equip, pause game, etc.).

Primary (left) and Secondary (right)Triggers: These analogue input methods are primarily used to interact with objects within the virtual environment. They are used to select/ deselect, move, equip/unequip and rotate objects in an environment.

Looking at current VR controllers, it’s easy to see where they came from. A glance at the buttons and the analogue input mechanisms shows that these devices evolved from current gaming controllers (figure 3.3). They maintained the same layout.

Familiarity: Users have been using game controllers for decades, and moving on to a completely new foreign layout would take the users significant time and energy. Further, keeping the tried and tested layout makes much sense with games populating VR app stores.

Ergonomics: As discussed above, current game controllers have been ergonomically perfected to ensure users have a comfortable experience. The button layout, shape, form, colour, position, and weight have all been slowly perfected over time.

Technology limitations: Although some modern systems do not need controllers, a technology gap prevents human movements and hand gestures from being accurately recognised in real time.

Furthermore, pressing a button, in some cases, is a lot easier than making a gesture with your hands every time.

By doing this, however, the controller significantly reduces its reach to many users with limited mobility who live with any form of hand amputation or other impairments. The current controller, although a feat of engineering, requires precise body control and dexterity while having no other option, both software and hardware, to bridge the gap. This, along with the reduced functionality of the action buttons, shows us how the platform affects how we interact. Most of the interactions made by these mechanisms have now been replaced with natural movements.

Figure 3.3: The VR controller has many of the same buttons and input mechanisms as the conventional gaming controller in the market.

A scenario

We know how the controller looks and what it does, but how do we use it? Let's take a simple scenario that covers all the basic types of interaction mentioned above and executes a very simple task. Use the default button mapping of the controller (Figure 3.4)

Scenario: Find a torch on the table, equip and use it on the wall by stepping to the right of the table. After, drop the torch and pause your game.

While this might seem like a simple task, it requires all the basic interaction methods to execute.

Grab: Selecting an object to move around within the environment.

Equip: Selecting an object and equipping it to one of the hands to be eventually used within the environment, for example, Equipping a pick axe to mine ores, picking up (equipping) a ball to throw in the hoop, etc.

Use: Using the Equipped object in Hand.

Unequip: Letting go of an already equipped object in one of the hands.

Locomotion: Moving around in the environments using the VR controllers.

Pause/Resume: Pausing or resuming the user's experience while in the virtual environment.

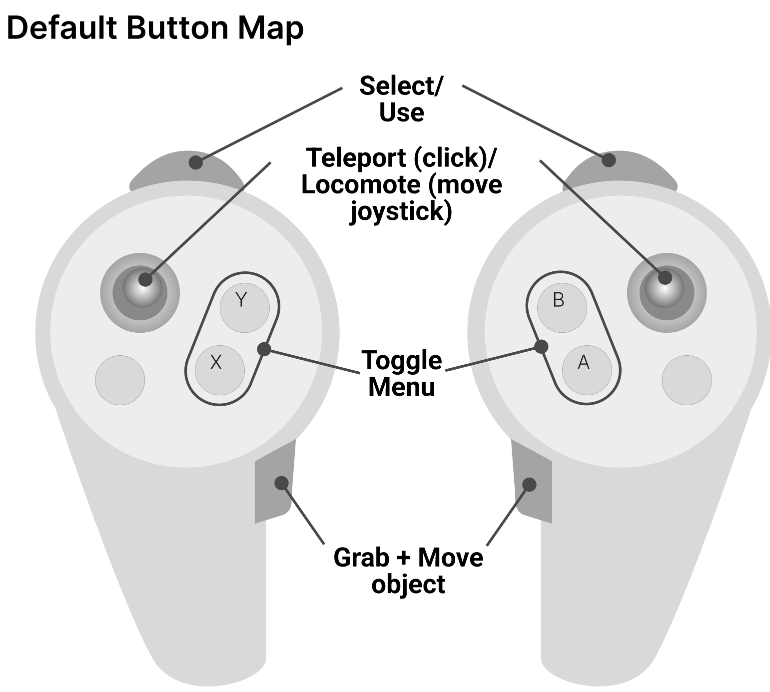
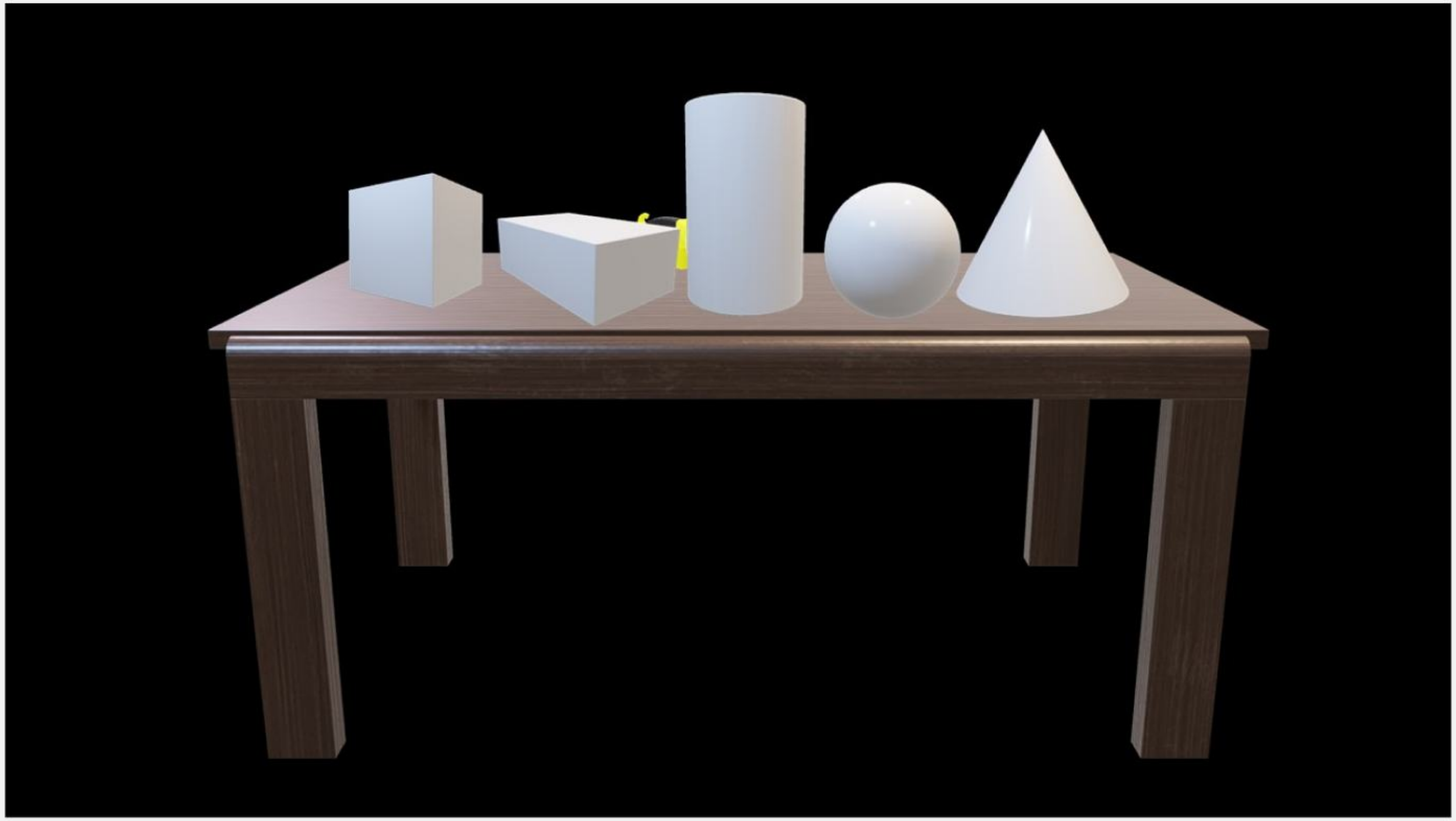
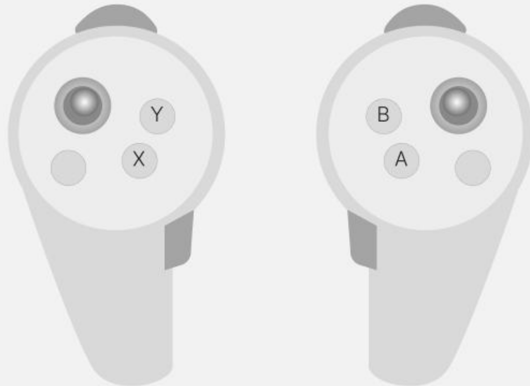


Figure 3.4: Default Button Map for the Quest 3 controller.

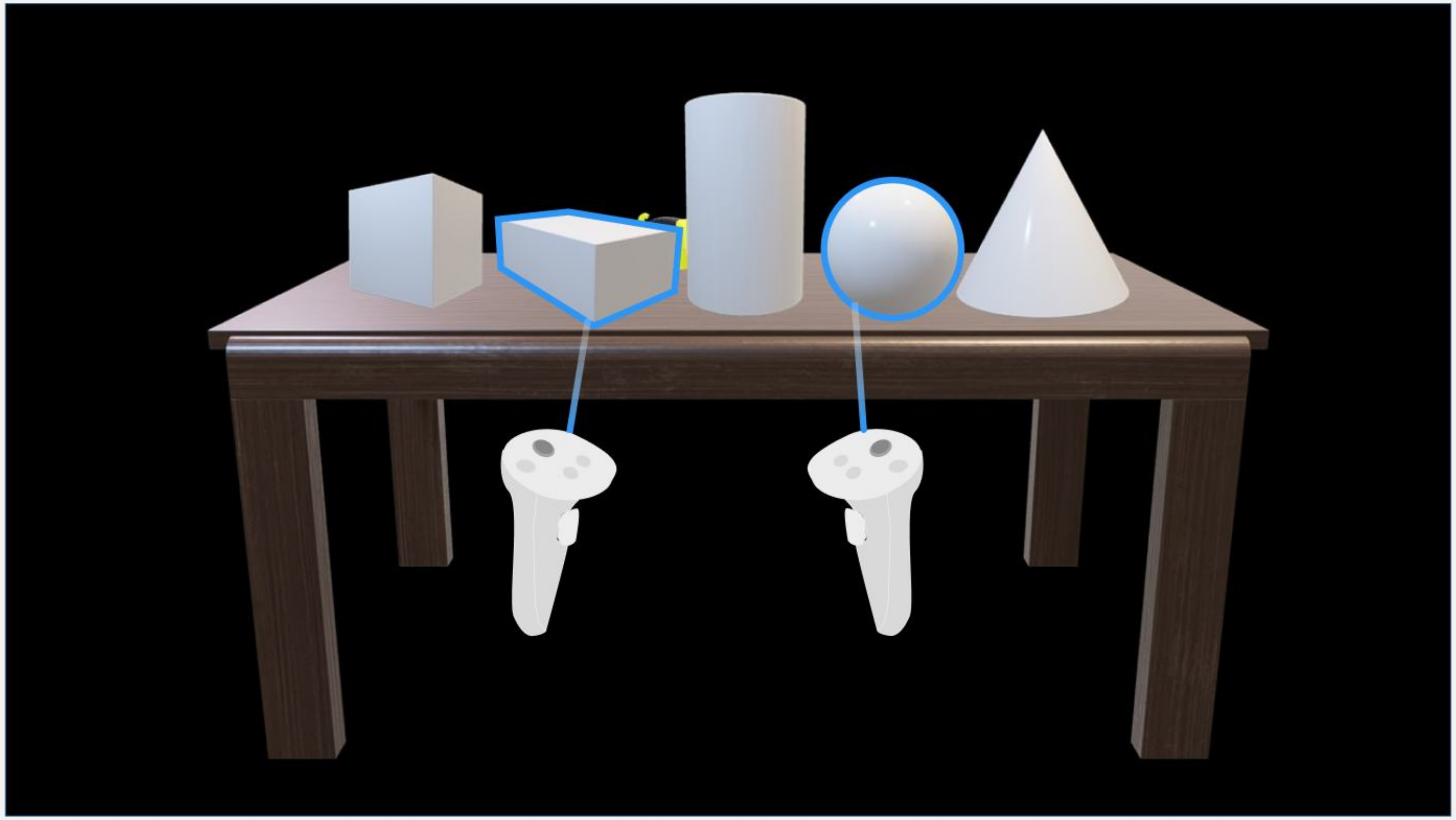


Input mechanisms pressed or actuated



The Scene

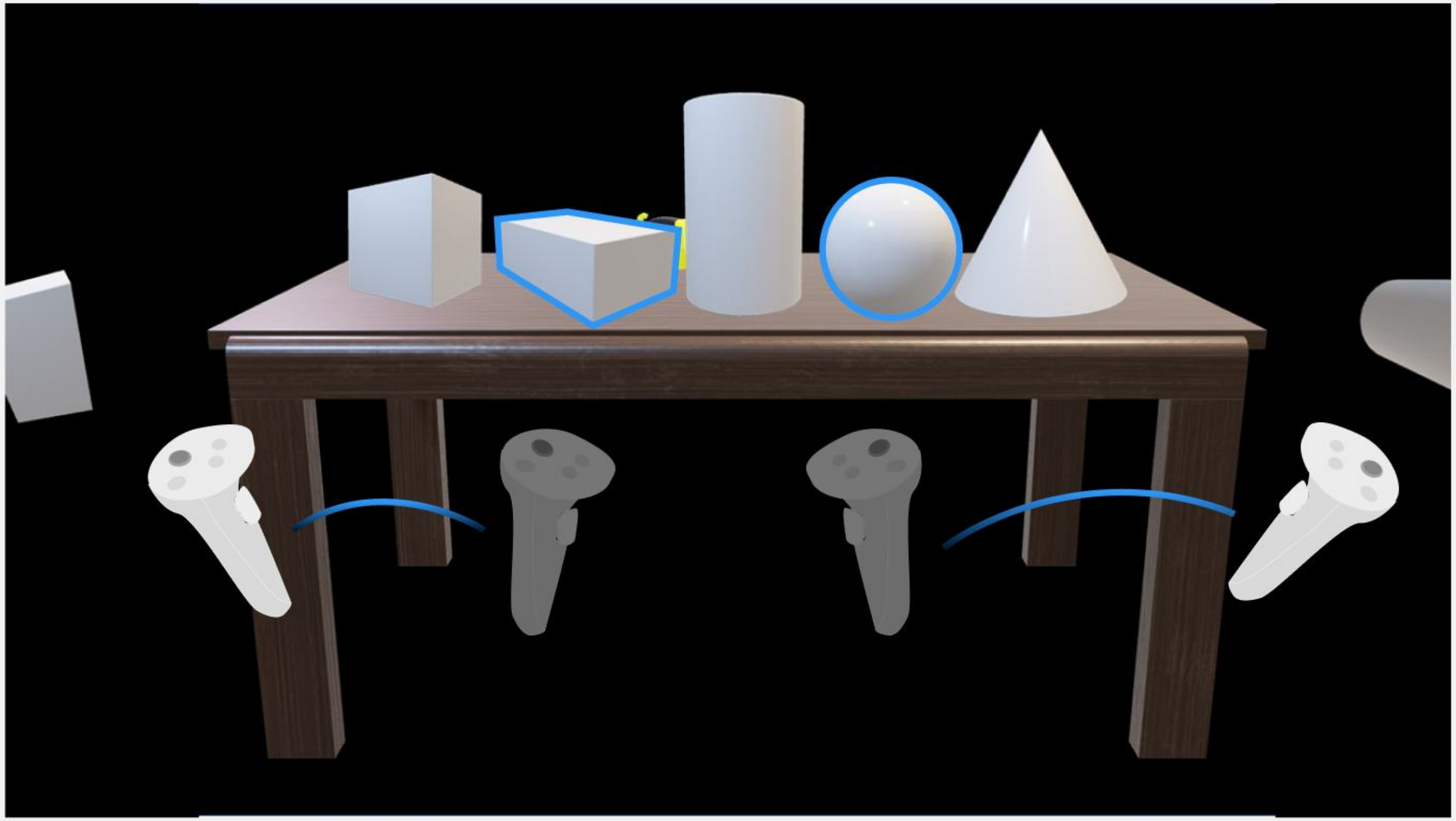
A table with a bunch of random 3D objects on the table. Users need to grab and move the objects out of the way to fully uncover the torch.



Input mechanisms pressed or actuated

Grabbing two objects simultaneously

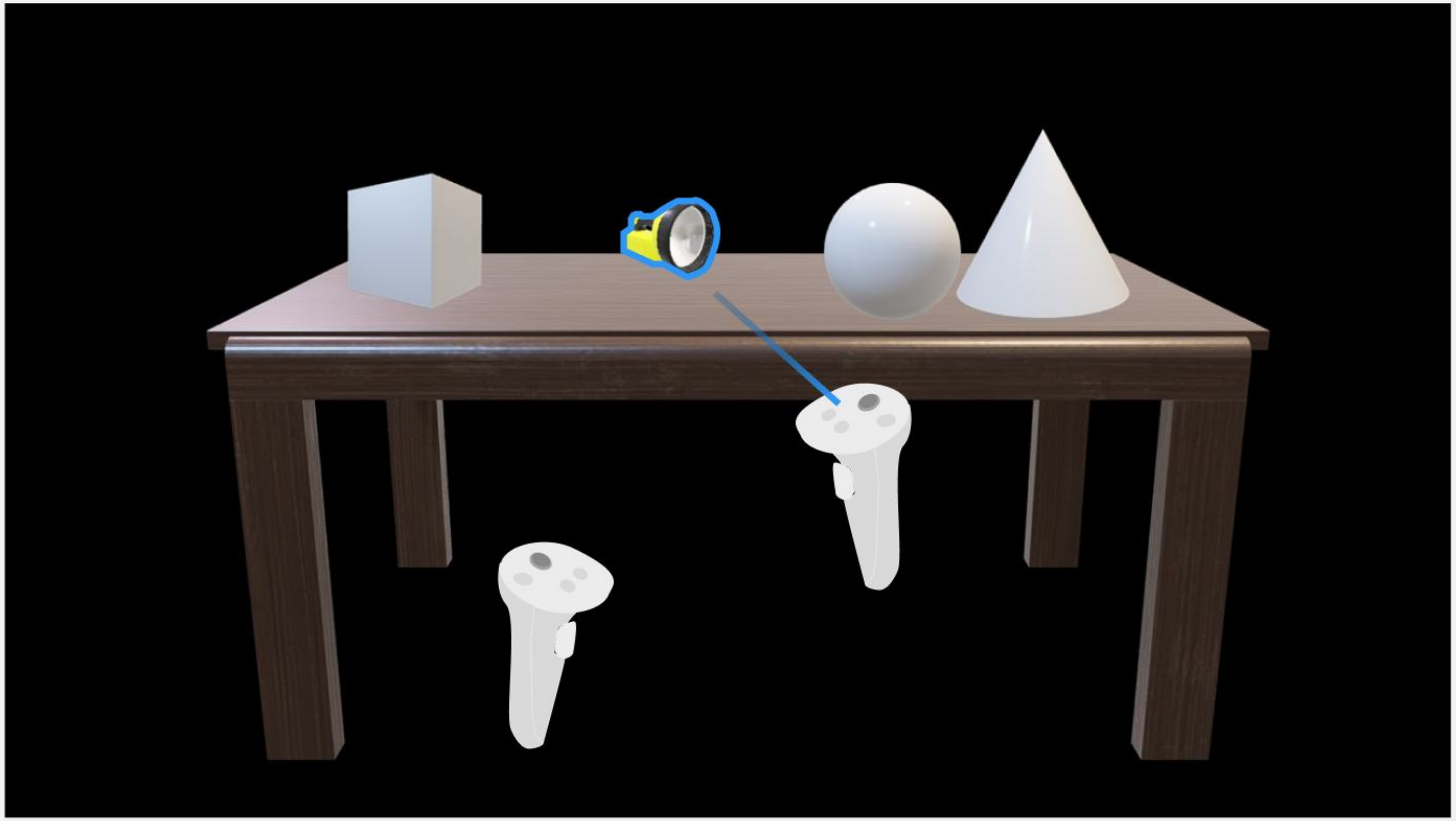
Hold the grab button and then move the objects out of the way. Games and applications usually have some form of audio/visual cues to notify the users that the object is locked on. This is generally through a visual highlight and/or a small audio clip.



Input mechanisms pressed or actuated

Moving two objects simultaneously

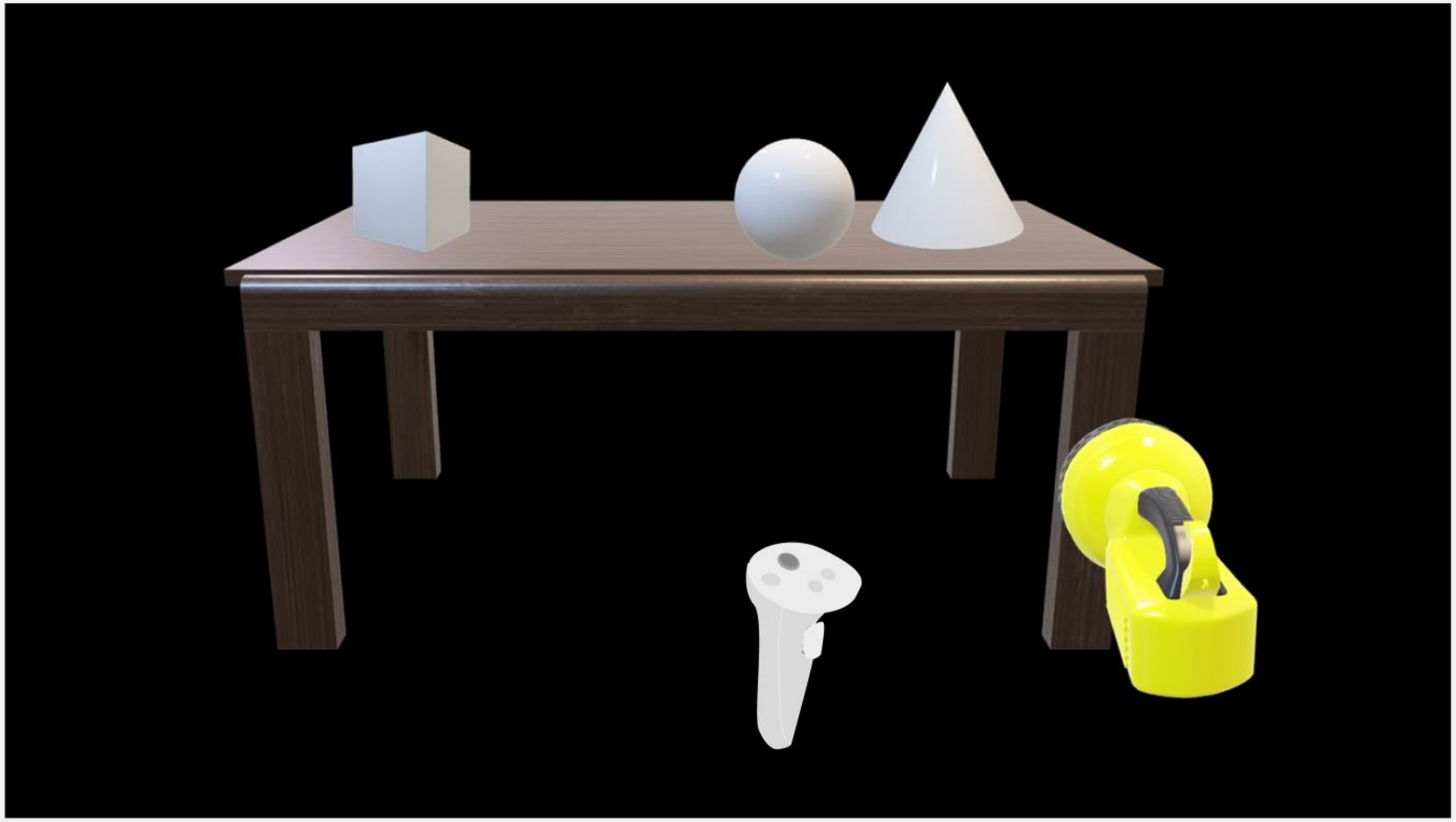
Once locked on to the object, users can then manipulate and move from it’s initial position by physically moving their hands. All while holding the grab button.



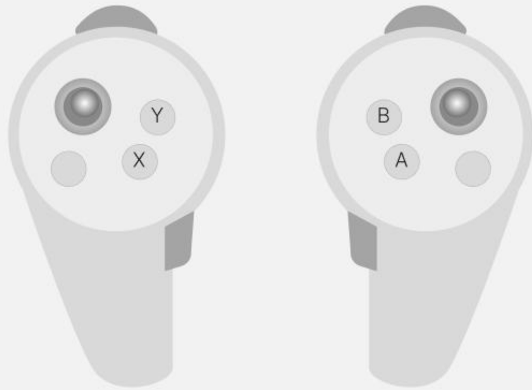
Input mechanisms pressed or actuated

Equipping a tool

Equipping or holding an object is executed differently with each game/application. Some applications ask the users to select the object by aiming and pressing the select button while others require users to press the grab button (as shown here) and combine it with a physical motion. Both work and its implementation depends on the user, game and the developer.

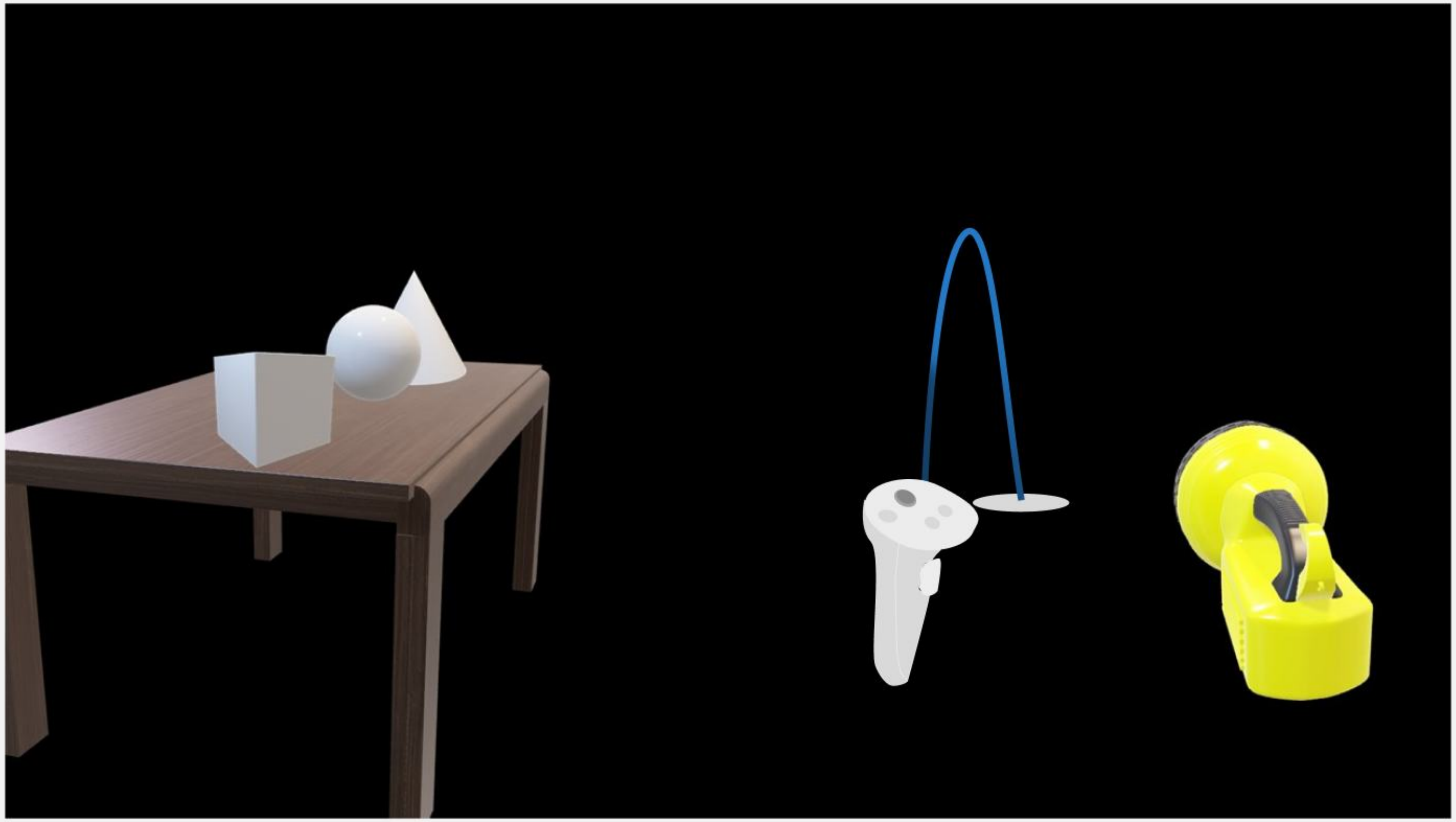


Input mechanisms pressed or actuated



Object Equipped

In this case, while the right hand is equipped with the object, the left hand is free to manipulate and move around in the environment. In some games, users are even allowed to use the equipped hand to further grab and move objects, as equipping a tool/object doesn't require pressing a button.



Input mechanisms pressed or actuated

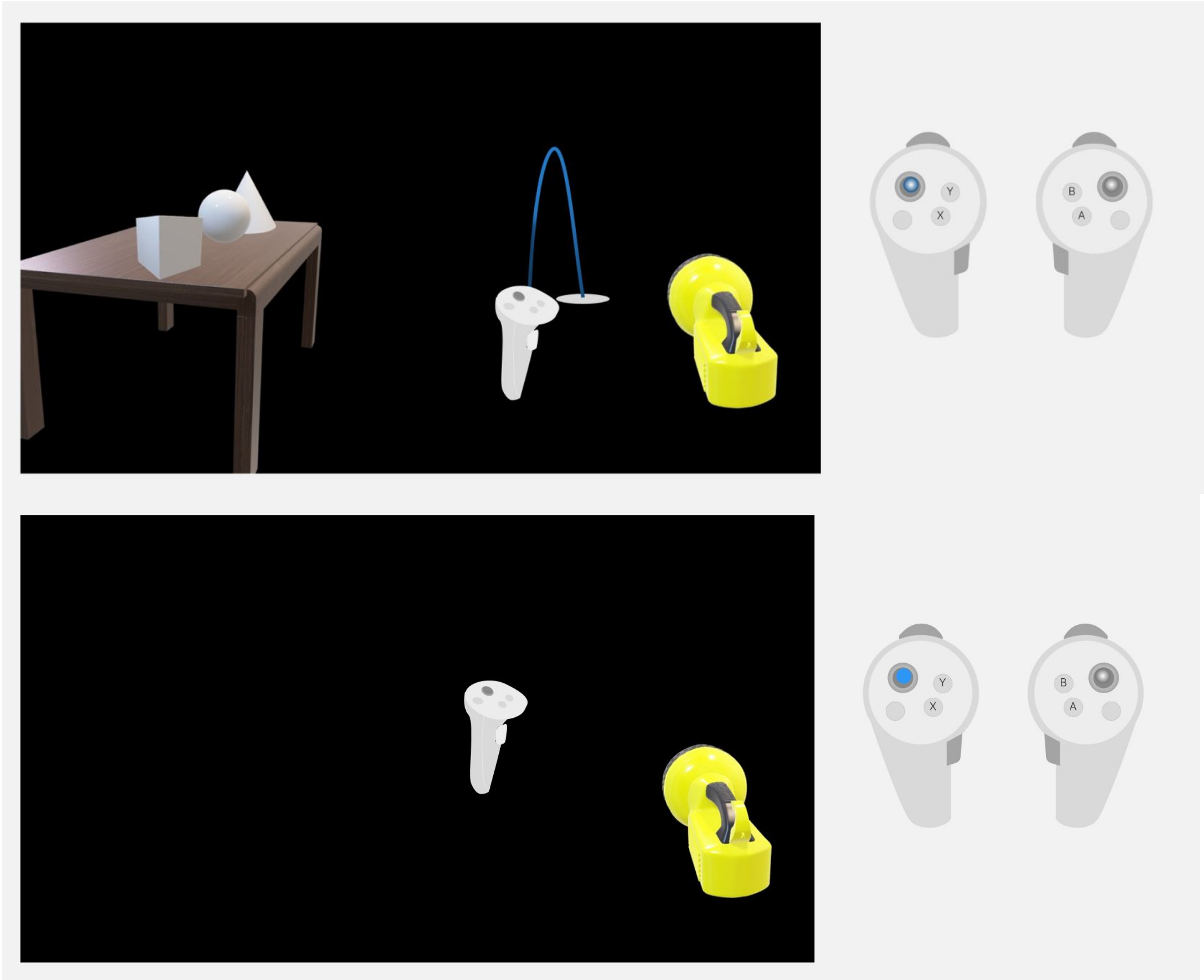
Locomotion

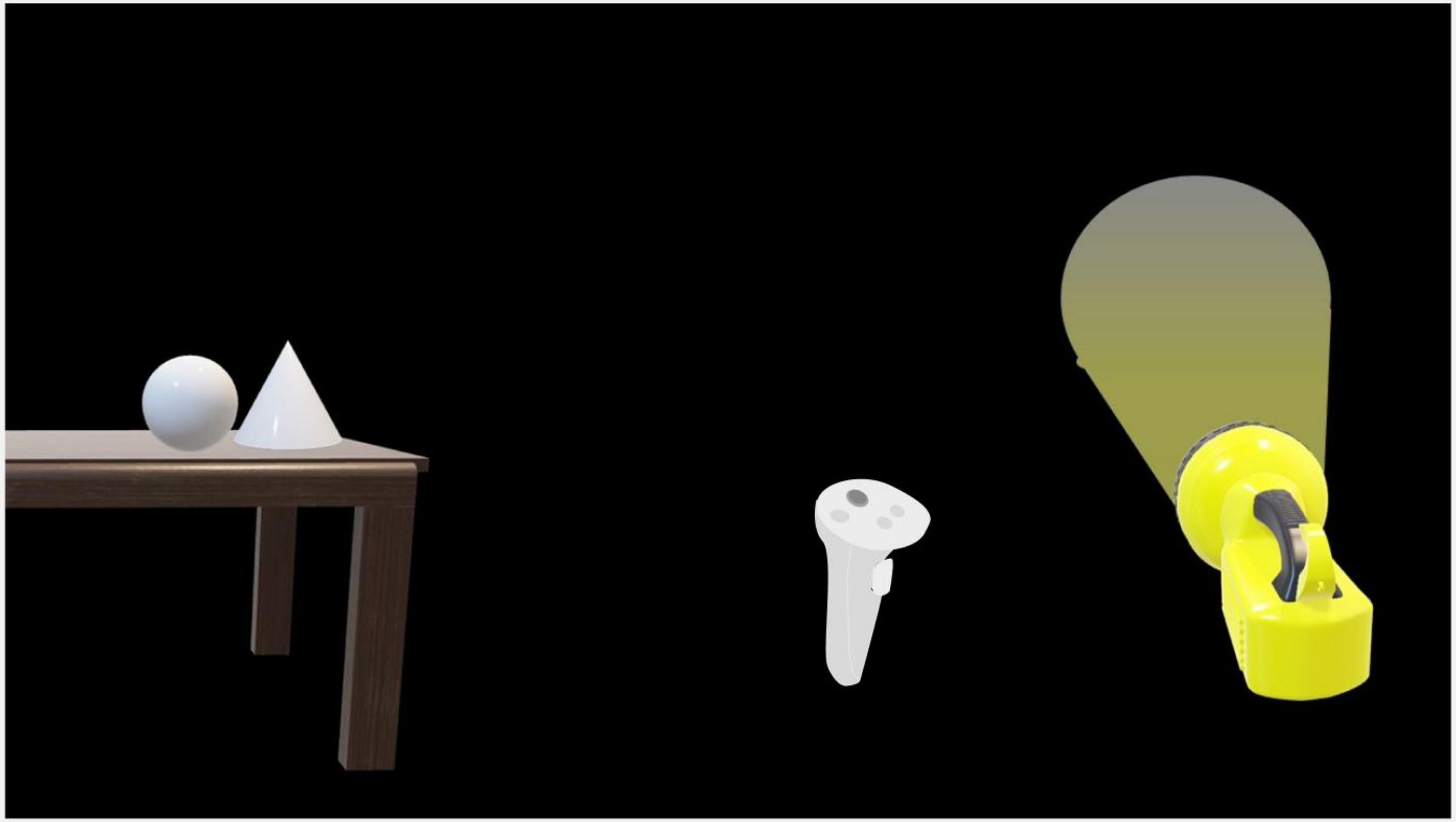
Moving around in the VR environment is quite simple, Users can also move around in the 2D space using the joystick similar to existing games. However, this mode of locomotion although fluid can lead to some nauseating side effects.

Teleportation

As mentioned earlier moving around using the joystick isn't the most comfortable experience for everyone in that case. Users need to point and click the joystick to teleport to the location.

Input mechanisms pressed or actuated

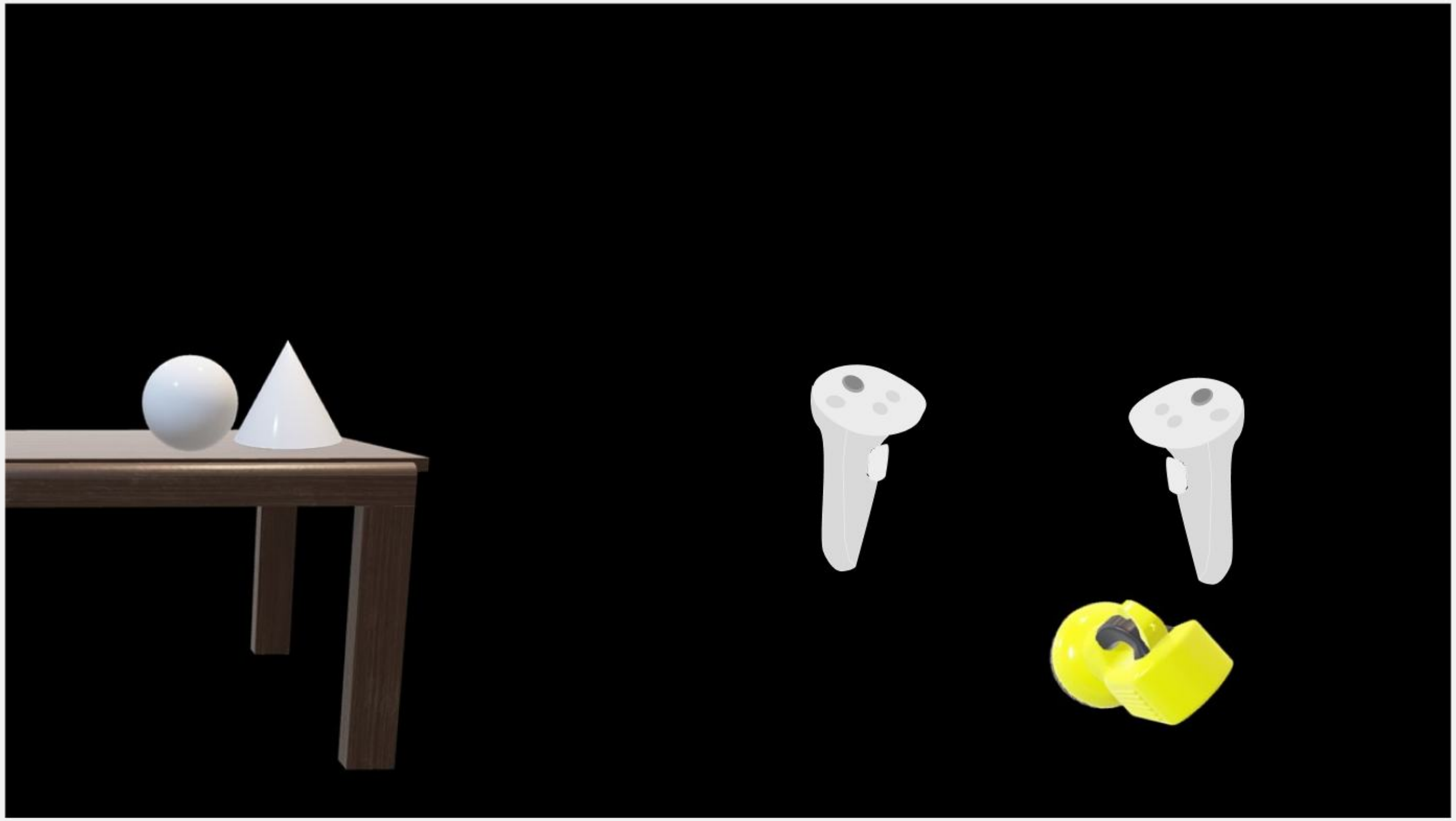




Input mechanisms pressed or actuated

Use an equipped tool

Users need to aim and hold the primary trigger button on the equipped hand.



Input mechanisms pressed or actuated

Unequip

This interaction depends on the software and the game. But in most cases one of the action buttons XYAB are used to unequip the object in hand.

Input mechanisms pressed or actuated

Pause Game

Dedicated menu buttons halt/pause your experience when actuated.

Accessibility and VR: The Present Scenario

Although much work needs to be done with accessibility (Creed et al., 2023), there are already products in the market that have accessibility features by default. Almost every smart electronic device now ships with its host of accessibility features. Every PC and Laptop now ships with a plethora of digital accessibility features. Most of these features address accessibility issues for users with visual or hearing impairments or who are having trouble interacting with their devices. Here are some of the accessibility options of two of the most popular VR headsets in the market, Quest 3 and Apple Vision Pro.

Despite these accessibility features, both headsets lack sufficient support for users with hand impairments, particularly those who have undergone hand amputations or have severely limited hand function. While hand tracking and voice commands provide some degree of accessibility, they may not be adequate for users who cannot perform the necessary hand gestures or who struggle with fine motor control. The reliance on hand gestures as a primary input method can be a significant barrier for users with hand impairments. For example, those with difficulty forming precise hand shapes or maintaining consistent hand movements may find it challenging to use hand-tracking features effectively.

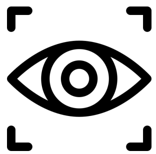
Common Accessibility Features

Hand Tracking: Both the Meta Quest 3 and Apple Vision Pro offer advanced hand-tracking technology. This feature allows users to interact with the VR environment using natural hand movements, eliminating the need for physical controllers. This can be particularly beneficial for users with limited hand dexterity.

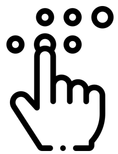
Voice Commands: Voice command functionality is available on both headsets, enabling users to perform tasks and navigate through menus using spoken commands. This feature is essential for users who may have difficulty using hand controls.

Spatial Audio: Both devices include spatial audio technology, which enhances the immersive experience by providing directional sound cues. This feature is important for visually impaired users, as it allows them to better orient themselves within the virtual space.

Uncommon Accessibility Features



Eye Tracking: The Apple Vision Pro utilizes advanced eye tracking to allow users to control the device and interact with the virtual environment simply by looking at specific elements. This is particularly helpful for users with severe physical impairments, as it minimizes the need for physical movement.



Customizable Braille Support: The Apple Vision Pro supports various braille displays and allows users to customize their braille experience. The device supports many international braille tables and refreshable braille displays.

Additionally, for users who have had hand amputations, the absence of alternative control methods that do not rely on hand movements severely limits their ability to interact with the virtual environment. Despite these accessibility features, both headsets lack sufficient support for users with hand impairments, particularly those who have undergone hand amputations or have severely limited hand function. While hand tracking and voice commands provide some degree of accessibility, they may not be adequate for users who cannot perform the necessary hand gestures or who struggle with fine motor control. The reliance on hand gestures as a primary input method can be a significant barrier for users with hand impairments. For example, those with difficulty forming precise hand shapes or maintaining consistent hand movements may find it challenging to use hand-tracking features effectively. Additionally, for users who have had hand amputations, the absence of alternative control methods that do not rely on hand movements severely limits their ability to interact with the virtual environment.

Conclusion and Key Takeaways - Virtual Reality

As Creed. et al. (2023) mention that VR/AR in its current state is not only not built for users with impairments, but at the moment, these users have no other alternative or avenues to experience them. So, at the moment, VR/AR is inaccessible to a vast sector of users with impairments.

Although physical hand and arm gestures have been successfully implemented into current systems, researchers have found that users do not prefer a hand/arm gesture-only mode of interaction and can get quite tiring over a prolonged duration (Johnson et al., 2023). Even the simplest of physical interactions could get tiring when using VR. Therefore, I cannot solely rely on one mode of physical interaction or the effect of physical interaction, no matter how simple and easy it may seem.

Giving users the freedom to choose their hardware does work. Allowing users to select the hardware and the location of the hardware can significantly improve users' comfort and experience(Malu & Findlater, 2015). In this case, the XAC approach also works for VR/AR. Allowing users to design their controllers. Having a Co-design workshop might prove valuable.

Key Takeaways

- **The c**urrent VR/AR Ecosystem is not built for users with impairments.
- No matter how simple, physical gestures can induce fatigue and discomfort when used for prolonged periods.
- Allowing users to build their control could allow the user to truly make the controller their own, suited for their needs**.**

Chapter 1

Users & Experts

In this chapter, we explore the critical insights gathered from both users and experts in the field of Virtual Reality and accessibility. The chapter will detail the methods used to engage with users who have hand impairments or amputations, highlighting their experiences, challenges, and specific needs when interacting with VR systems. Additionally, it will present expert opinions on current accessibility solutions and the gaps that remain unaddressed. This comprehensive analysis will serve as the foundation for the design decisions made later in the project, ensuring that the final product is both user-centric and informed by the latest industry knowledge.

Hand Amputees

The focus of this project involves users with hand amputations and other impairments. Hand amputation refers to the partial or complete loss of a limb. In addition, hand impairments encompass a wide range of conditions such as arthritis, carpal tunnel syndrome, Dupuytren's contracture, and nerve injuries. In both cases, the condition limits the user's ability to effectively use objects or devices that require their hands, fingers, or upper limb body features. This chapter provides information regarding the medical conditions relevant to this project, the nuances to consider when addressing them, and the rationale for their inclusion.

Amputation

Amputation is a surgical procedure that removes a part of the body, typically an arm or leg. While this project primarily considers medical amputations, it also includes congenital impairments where users are born with limb differences. Regardless of the cause, users in this project have experienced the loss of part of their arm. Other hand impairments, as considered in this project, focus specifically on conditions that result in limited mobility of the fingers or hands.

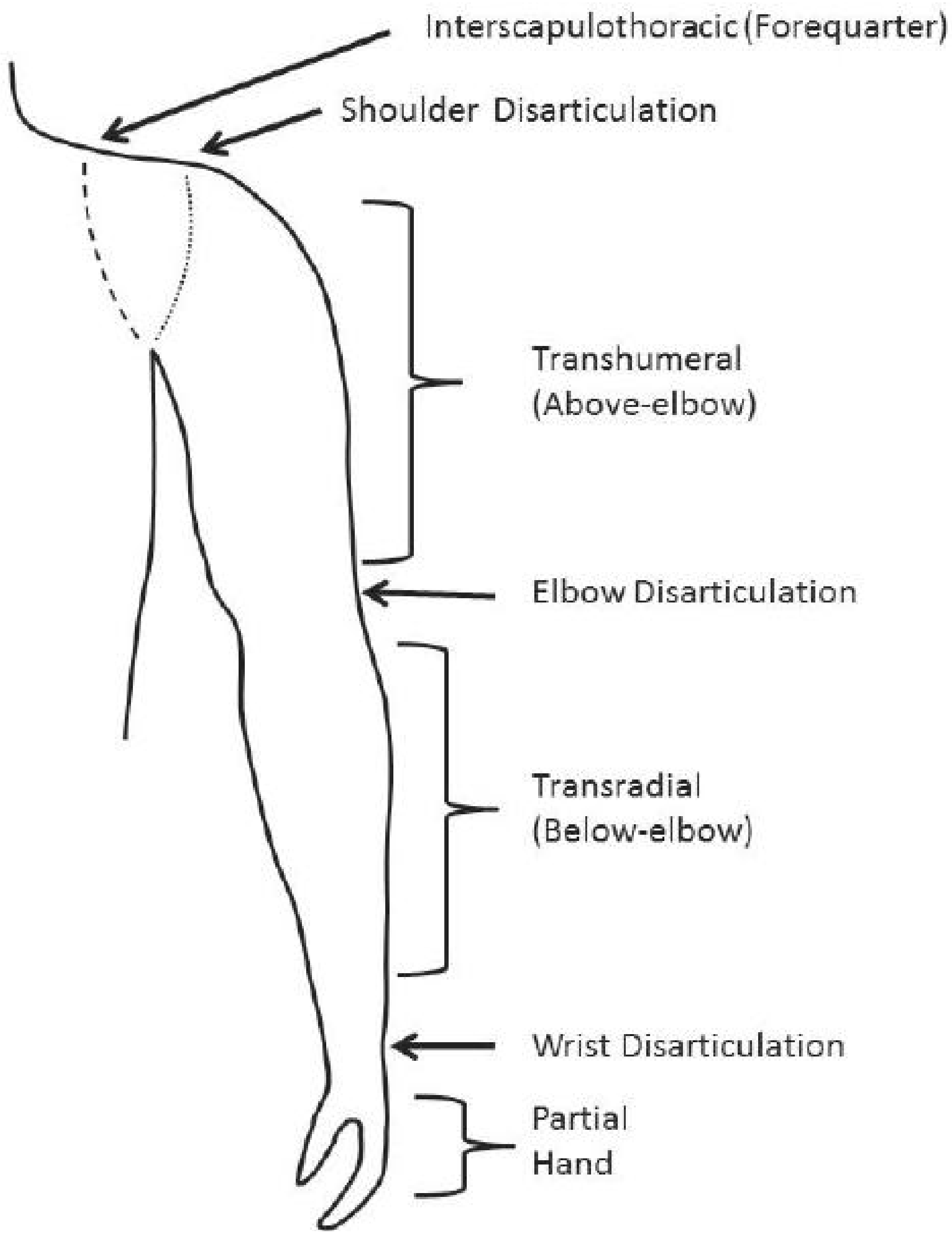


Figure 4.1: Levels of Hand amputation ("The Promise of Assistive Technology to Enhance Activity and Work Participation," 2017).

Anatomy

Stump or Residual Limb: This part of the limb remains after amputation. The condition and length of the residual stump are crucial for the fitting and function of a prosthesis.

Bone: The bone is often smoothed and rounded during surgery to prevent sharp edges from causing discomfort or damaging the surrounding tissue.

Soft Tissue: The soft tissues, including muscles, tendons, and skin, are typically sutured over the bone to provide padding and protection.

Nerves: The nerves that were once connected to the amputated part of the limb may continue to send signals to the brain. This can sometimes result in a phenomenon known as “phantom limb”, where the person feels sensations, including pain, in the amputated limb.

Blood Vessels: The blood vessels are sealed during surgery to prevent bleeding and to ensure proper circulation in the residual limb.

Skin: The skin is closed over the end of the limb, often involving techniques to minimise scarring and to create a good shape for fitting a prosthesis.

(Moore, n.d.)

Some unique conditions Experienced by Hand Amputees

Stump sensitivity: The stump is quite sensitive to the natural elements. Therefore, care must be taken to ensure full stump coverage when wearing any wearable.

Phantom Limb: The nerves that used to connect to the amputated limb continue to send signals to the brain.

Interview and Insights

When working on an inclusive design project, I realised that online ethnographic research could not give me the complete picture of what the user goes through. I had a general understanding of their problems but could never grasp the full extent of their challenges or lack thereof. Therefore, gaining insights from the users themselves was crucial to understanding their lives and how they face and overcome challenges. The interviews allowed me to truly understand how the users think, how they adapt to using everyday objects, what their preferences for games and entertainment are, etc. In the initial stages, users were only involved in interviews and filling out questionnaires. However, with time (as we will further discuss), users became very involved in the project's co-design sessions, activities, and interviews.

Aim and research questions

The initial interviews aimed to gain additional knowledge that the literature review and online ethnographic research could not answer or give user context-specific information. Therefore, the interview was structured and designed to gain insights into the user's lives. More specifically, I wanted to know about their experience working with everyday objects, tools, and devices and their preferences for these devices. How does their impairment affect their experience? Has their impairment affected their choice of hobbies or how they spend their time? And to understand the extent to which it hampers their everyday lives. The main purpose of this was to understand three things.

1. **Relationship with everyday objects:** How easily can they adapt to everyday devices never designed for them? Are there any objects that they are quite comfortable using? If so, why? Answering these questions could give many insights into the everyday objects that do or do not work and could help me understand and take inspiration (in terms of Form, design or technology) from everyday objects that do work and help me avoid design features to implement when designing my product/solution. It was also to understand their thinking and attitude to these tasks and scenarios. What can trigger frustration, anger, irritation or other negative experiences?
2. **Adaptability:** How do users adapt to their surroundings? Understanding this could lead to some interesting approaches. For example, suppose users prefer to modify and change everyday objects to suit their needs. In that case, handing them a rigid controller with fixed buttons, positions, forms, and mechanisms with minimal options to customize might be extremely annoying. In that case, a DIY solution might cater to their specific needs more accurately than a polished, well-designed, but restrictive (in terms of customizability and usage) product.
3. **Gaming Affinity:** It is also important to understand their affinity to gaming and familiarity with existing game controls and devices. Suppose users are not aware of or lack any gaming skills. In that case, some of the most obvious actions (managing inventory of items, choosing different weapons, game mechanics, etc) might seem completely foreign to them. Understanding this could help me maintain or change existing controls, button maps, frameworks, graphics, and symbols used in existing devices.

Questions to answer

- What is the participant's current situation? How do they currently Interact with everyday objects? When? How much?
- What is their Current Experience do they face problems?
- What are their efforts in trying to find solutions for their problems?
- Has it ever stopped them from achieving specific goals or having interactive events? (e.g., getting into the creative zone, online gaming, interacting with peers, etc.)
- What is their overall view of the technology industry and their access to it? How do they feel? Why? What do they think needs to improve?
- What do they think of Games? Have they ever gamed before? How? If not, then what was the setback? Was it purely an interaction roadblock, or are there other roadblocks for them?
- Their tastes and preferences? How do they want to play (alone/ together)?
- How do they interact with other objects in their everyday life? What are some of the common actions they can do? (If not specific, then I would list out some example actions)

Methodology

Mode: **Online**

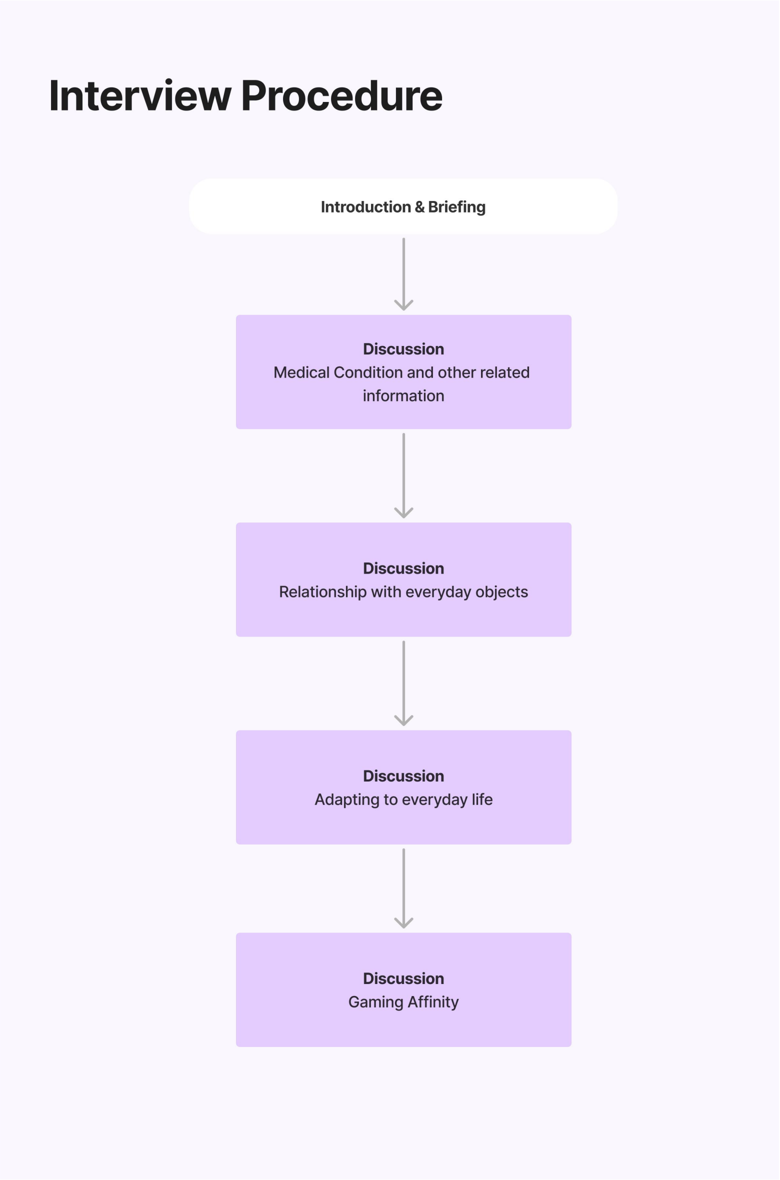


Figure 4.2: User Interview Process

About our Users

User number: 01

Age: 60

Gender: Male

Nature of Hand Impairment: Trans-Radial Amputee (Right Hand)

Since: Birth

Occupation: Distribution Driver (Currently), Senior Customer Manager (retired), Professional swimmer (retired)

Gaming Affinity: Low (Never plays Games)

User number: 02

Age: 40

Gender: Male

Nature of Hand Impairment: Limited Mobility (Right Hand)

Other Impairments: Impaired vision (right eye), trouble controlling the right side of his body.

Since: Past 10 years

1. 40 years old with a right arm impairment due to a cerebral haemorrhage 10 years ago.
2. Limited movement and reduced sensation in the right arm.

Occupation: Founder of Organisation for Disabled Gamers, Communication Manager (retired)

Gaming Affinity: High (Active Daily)

User number: 03

Age: 29

Gender: Female

Nature of Hand Impairment: Limited mobility (Left Arm)

Other Impairments: Impaired vision (left eye) and trouble controlling the left arm.

Since: Past 5 years

1. This condition is due to proprioceptive issues, where the brain doesn't accurately sense the position of body parts without visual input.
2. User 03 has fine motor skill impairment in her left arm.

Occupation: Occupational therapist.

Gaming Affinity: High (Active Daily)

User Interview Results

1. **Assistive Devices and Techniques**

User 1

- **Prosthetic Hand:** Used for everyday activities, driving, and biking to compensate for lost hand function (figure 4.3). Controlled using pronation and supination muscles.
- **Hook Prosthesis:** Utilised during biking to secure grip, with bike controls adapted for its use (figure 4.4).
- **Cooking Aids:** Employed in the kitchen to hold food steady while cutting.

User 2

- **Electric Toothbrush:** Aids in personal hygiene by simplifying brushing with limited hand function.
- **Modified Shoelace System:** Facilitates one-handed shoe tying (figure 4.5).
- **iPhone Mini:** Chosen for daily tasks due to its smaller, more manageable size

Figure 4.3: User 1 uses the I Limb prosthetic hand for a lot of everyday activities (Cornerstone Prosthetics and Orthotics, 2017).

Figure 4.4: Hook Prosthesis used to riding a bicycle (Cornerstone Prosthetics and Orthotics, 2017).

Figure 4.5: Adaptability is key: User 2 uses a single handed shoe lace tying technique for single handed use.

2. **Sports or other activities**

While Amputation might seem like an extreme impairment in many cases, when the amputated limb is healthy, it can still be used and adapted to accomplish everyday tasks, as mentioned earlier. Pushing it a little further, users can also actively participate and, in some cases, thrive in sports and physical activities. User 01 Participates in sports such as cycling and swimming with adaptations.

Figure 4.6: Users with amputation can in some cases even thrive in everyday activities, in this case user 1 (not in picture) was professional swimmer (Young Boy Who Does Swimming He Stock Photo 1147250576 | Shutterstock, n.d.).

3. **Transportation and Commute**

They could even drive cars, motorcycles (user 01) and modified bicycles to travel around. However, in some cases, hand impairments such as limited mobility or neurological impairments lead to restrictive access to many activities, even with a full limb. User 02 and User 03's impairments limit their ability to travel and move independently. While both could do some physical activities, their medical condition, however, prevents them from executing them daily. Therefore, they depend on public transportation or taxi services to move around.

"Using public transport, particularly taxis, is necessary since I can't drive due to my condition and vision impairment." - User 03

4. **Mindset & Dependence**

They are usually very independent and resilient but often too stubborn to receive assistance. Nevertheless, their view, mindsets and thinking rarely change due to their impairment, and they are more persistent in finding unconventional solutions and working around them to accomplish their tasks. However, User 03 was used to having a copilot (an assistive user) to play with them.

"It's a mindset, so it's not what you cannot do; it's what you can do that's the mindset." - User 01

"I always want to try things. I'm not every person is the same as the other ones." - User 02

"I ask help. That's something I don't feel bad about so it's easier for me to ask for help." - User 03

5. Gaming

User 01

- Early games with simple controls, like Pong and Wii sports (figure 4.7), were accessible.
- Faces challenges with modern game controllers designed for two-handed use.
- He was not motivated to try and use the VR controller.

User 02

- Uses a Gaming mouse with many buttons (figure 4.8) to replace keyboard buttons.
- Prefers PC gaming over console gaming due to the challenges posed by traditional game controllers.
- They also have a button near the leg of the table that can be accessed by foot.
- He did try to use VR but found it extremely difficult to use in his condition, and he hasn't found a solution for it since.

User 03

- Uses the Xbox Adaptive gaming controller to play games.
- Uses a Gaming mouse with many buttons to replace keyboard buttons.
- Using existing gaming peripherals like the Thrust master joystick (figure 4.10) to access games.
- Experimented with video gaming about four years ago and succeeded with adaptive setups.
- Uses a gaming mouse with multiple buttons for various functions.
- Utilises adaptive equipment like a joystick and additional input methods.
- Gaming remains a significant part of her life, and she has frequent sessions.
- Could not use/play the Nintendo Wii-U (figure 4.11) after the incident.

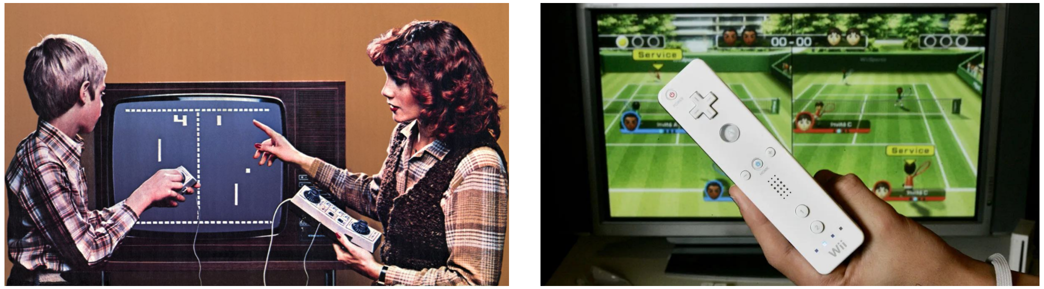


Figure 4.7: Pong home console (right), Nintendo Wii (Isenberg, 2022).

Figure 4.8: User 2's Gaming Mouse

Figure 4.9: User 3's Xbox adaptive controller.

Figure 4.10: User 3's Thrust master Joystick

Figure 4.11: Nintendo Wii-U (WiI U, n.d.).

User Discussion

Everyday Life is still possible

All users mentioned that most everyday tasks are manageable and executed without assistance. Since all users had full function of one of their hands, they heavily optimised and adapted the process and execution around it. While some tasks were easy on one hand, the others needed some workaround or an extra tool/apparatus to assist them. Users 01 and 02, however, showed a significant preference for executing their tasks independently without any assistance from others. And User 01 even executed trickier everyday chores such as electrical work, fixing bikes, etc.

Users who have had the time to accept their conditions/Impairment quickly move on to adapting to their new lifestyle. However, despite these efforts, there are some limitations; for all three users, any two-handed operation took much work and effort. For example, playing a musical instrument, games using a gaming controller, etc.

Gaming?

My three users at the moment were quite interesting as they are positioned on the extreme ends of the gaming experience spectrum. One of the users is an accomplished sportsman, and the other works in the gaming industry. I was curious about the inexperienced user's interest in games and gaming. To my surprise, he showed much interest and willingness to try gaming again if given the means and opportunity. He also mentioned playing the Nintendo Wii (also a motion capture-based system), which was relatively easy to use. On the other hand, users 2 and 3 had much more experience gaming the conventional way before their impairment. Therefore, they both implemented several workarounds and devices to overcome the roadblocks. For example, modern games require gamers to use many buttons for different actions and purposes. A one-handed user would find it difficult to operate the mouse and keyboard simultaneously. They, therefore, used a gaming mouse with up to 9 additional buttons on the side that the keys bound to play specific actions in the game. Since the device can be programmed differently with each game, they can effectively use their mouse to play even the most complex PC games. User 3 also uses the Xbox adaptive controller while user 2 uses foot pedals and buttons for additional input means.

However, although both users have unique ways of interacting with their innovative systems, they were still looking for a viable way to interact comfortably in VR. Nearly all VR systems require the user to use both their controllers to interact in the virtual world. Furthermore, there is no way for a two hand amputee to interact with a VR system.

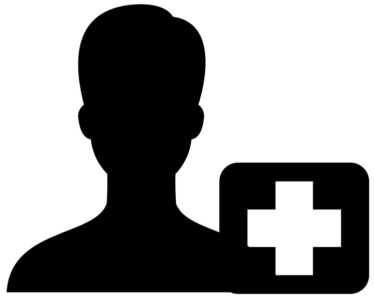
Expert interview and insights

While the user interviews proved invaluable, getting a better understanding of the user's physical abilities and limitations would help make sure that the users use these devices within their physical limitations and abilities. Moreover, making assumptions about a user's physical capabilities would prove extremely dangerous and negligible. Therefore, a medical expert in the field would prove to be an effective source of information, and their experience could provide insights regarding working with users with disabilities, experience designing custom game controllers for people with impairments, and key promising technologies to use and avoid could be invaluable to the project. It was also a good opportunity to clarify, confirm and verify my doubts and assumptions about my set of users. Just like the users, the expert were initially interviewed and then participated in a co-design session. However, the expert did not interact with the project users or participate in activities together.

Aim and research questions

1. **Learn from their experience helping disabled gamers:** To learn from their experiences working with disabled users and understand the nuances (if any) of working with such users.
2. **Methods, devices and approaches used to help gamers play:** How often were DIY solutions used and not? Understanding when to turn to unique technologies and solutions.
3. **Understanding the user's physical limitations:** To understand the physical limitations of users with hand impairments. Can repeated physical movements have physical repercussions? Like fatigue, muscle soreness, tissue sensitivity, etc.

About the expert



Gender: Male

Occupation: Paediatric Physiotherapist and Game Therapist

Experience: 10 Years

Details

- Physical therapist specialising in paediatric and rehabilitation centre work.
- Worked with several amputated gamers to help them access gaming.
- Part of a technical advisory team for mobility technology.
- Avid gamer who uses gaming to connect with friends.
- Works with gaming studios to make games more inclusive.
- Collaborates with engineers for custom adaptive gaming gear.
- Developed wheelchair gaming adapters to use the joystick on the wheelchair as a game controller.

Methodology.

Mode: **Online**

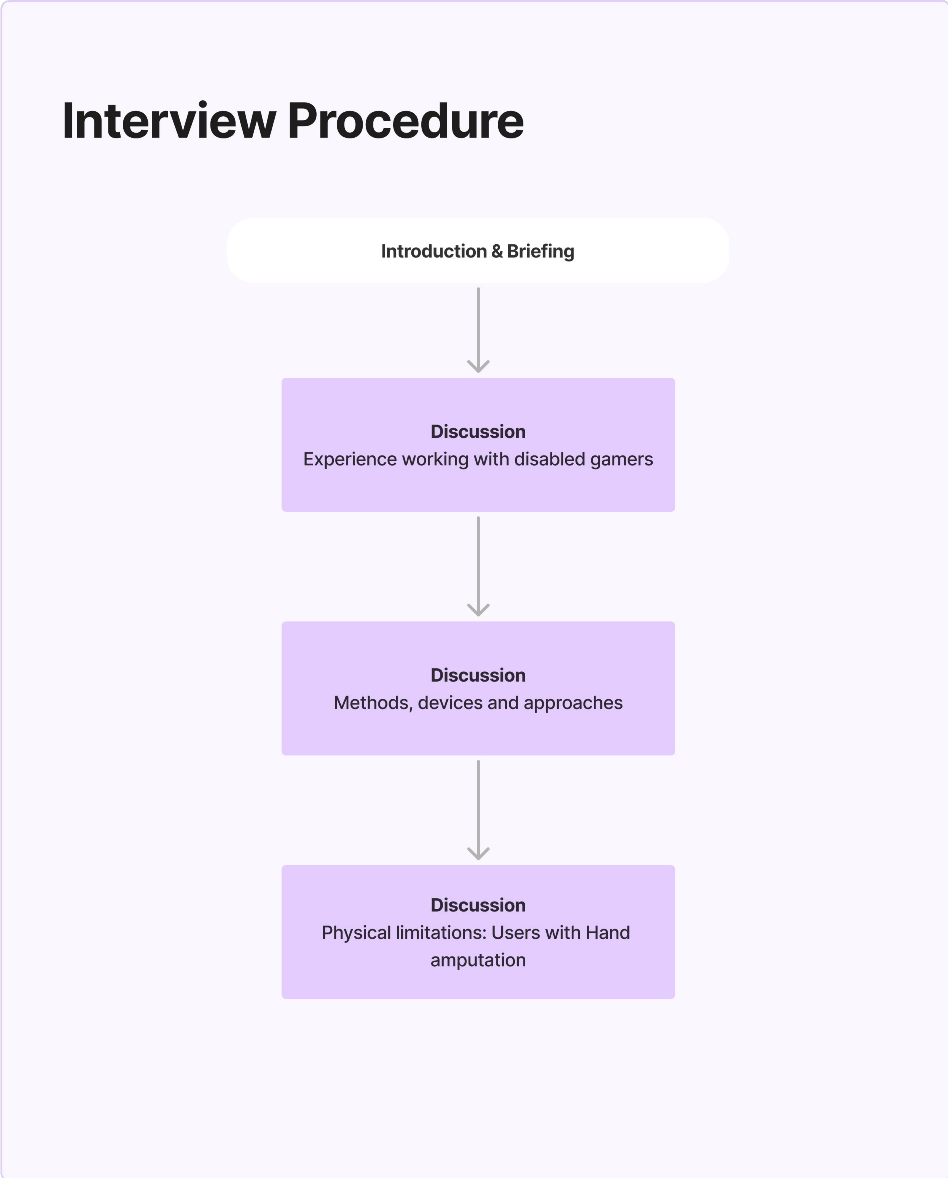


Figure 4.12: Expert Interview procedure.

Expert Discussion

Challenges and Adaptations

- Customization is often needed for individual needs.
- Emphasizes using available limbs or body parts to the fullest.
- Feet and mouth controls are viable options, but acceptance varies.

Using the Xbox adaptive controller
"Then a year later, that Xbox came with the adaptive controller, and then it just all opened up, and it made it so much easier."

Medical insights

- Adaptive gaming can aid rehabilitation by encouraging limb use and coordination.
- Advises gradual adaptation to new gaming methods and emphasizes good posture.

On using their impaired limbs
"The most important thing is if they're able to use their disabled hand and part, use it as much as you can because it's always better than not using it."

Conclusion and Key Takeaways - Users & Experts

The one key thing that stands out the most among users is their mindset. Their mindset is to not give up, and that caters for a capability to adapt to their environment. And because of this, every user interviewed had more than one way to adapt to their everyday lives.

Users were also very specific about the type of solution or workaround they used. These examples show us that when users are given the resources, with some guidance, they'll be able to find a solution that best suits their needs.

And that is important, as one of the other crucial things is just how different each of their lives were from each other. Catering to all of their needs and solving them completely all through one product will prove to be challenging. Therefore, it might be important to design a product that only partially solves problems out of the box but allows users to modify, customise and build their own controller. The product should give every user the freedom they need to build a controller on a platform/canvas.

On the other hand, it would also prove quite insightful to provide them with almost no restriction on building their own controller. Would they show a preference for technology or a mechanism? A layout?

Coming to their condition, every user found it difficult to do two-handed operations. Furthermore, VR controllers have a form that is built to be held and gripped by the hand. Their button, joystick, and triggers are fine-tuned and designed to be organic to hold and press or push down on. Users with hand impairments would need help to use these devices.

Key Takeaways

- Users can adapt, giving them the right resources and a versatile platform to build their controllers.
- Do not force users to use a certain mechanism, tech, or mode of physical interaction to have alternative solutions.
- Conduct Co-Design sessions with limited restrictions to build their own controller.

Chapter 5

Before we begin

A brief discussion about problems with current VR controllers, demands set for the product and Scope of the project.

Issues with current VR controllers for Users with hand impairments

Physical Design and Ergonomics

- **Grip and Holding:** VR controllers are designed to be held in the hand, with buttons and joysticks that require finger manipulation. Users with hand amputations may lack the necessary grip strength or finger dexterity to hold and operate these controllers effectively.
- **Button Accessibility:** Many VR controllers have multiple buttons, triggers, and joysticks that must be pressed or moved simultaneously. This can be difficult or impossible for someone with limited or no fingers.

Lack of Customization and Adaptability

- **Limited Customization:** Most VR systems do not offer extensive customisation options for users with disabilities. Few alternatives or modifications to the controller or input methods are available to make the controllers more accessible.

Software Limitations

- **Game Design:** Many VR games are designed assuming players fully use both hands. This can make it difficult for users with hand amputations to participate or enjoy the game fully.
- **Control Mapping:** While some VR systems allow for button remapping, this feature is not universally available and can be complex.
- **Lack of support for external hardware:** While the VR systems do support connectivity to some external hardware (For example, Quest system connecting to the Xbox controller). However, VR systems do not support devices that are accessible to them, such as the XAC. Furthermore, even if connected, the system would have no means to communicate with the device to receive the data from the hardware as it is now (Quest 3 Meta Quest Touch Plus Controller | Meta, n.d.).

To sit or to stand?

One of the key factors that I felt was important to consider was the mode of experiencing VR. Currently, users can choose to sit or stand and their VR experiences (depending on the application/game). Some experiences or games force the users to stand and experience, while some are more lenient in their play mode. Restricting these factors, however, makes it easier for developers to develop the game/experience that they want the users to experience. Regarding my project, I wondered if adding a restriction to sit and experience VR could be helpful. It was initially far simpler to have a varied number of table-based solutions. With different mode controls on the table and around it.

Disabilities and impairments are complex, and each user has a different experience with them; in many cases, users are not always only suffering from just hand impairments (similar to user 02). For example, a user, in many cases, would be suffering from some form of both-hand amputation combined with mobility issues with their lower limbs. Due to the obvious complexity of the project, I decided to exclude other impairments within the project. Therefore, for the case of this project, our users can live with some hand amputations (till trans-radial) on both arms or other hand impairments that do not impact mobility or dexterity. I decided to keep this feature to experience VR in both modes (sit and stand). Users should have the choice, just like a controller, to experience their VR environments by sitting on a chair or while standing and moving around. While the tabletop approach could be very helpful for people with limited mobility, I decided to focus on (as mentioned earlier) users with hand amputations (till transradial amputation) and other impairments.

Figure 5.1: VR systems being used both while standing up and sitting down (Chillingworth, 2024).

Demands

As is common in any project, limitations often significantly influence the approach and design aspects. While this may initially appear to be a drawback, it compelled me to thoroughly examine the core concept of the ideas and identify what was essential to the project's success. No Implementation of relatively new technologies.

- The controller should be usable while both standing and sitting down.
- The controller should allow the users to customise their inputs. (Button mapping, placement, mechanism etc)
- The controller should be usable by users with hand amputation (trans-radial) on both arms.
- Users should be able to execute Object-based interactions and Locomotion and graphic user interface interactions.

Some limitations (technology-related) are implemented purely as an inherent limitation of the project scope. However, this also forced me to think about the system and the interactions rather than just using an all-powerful technology (for example, Brain-computer interaction) to fill in the blanks. Others I felt were crucial for the nature of the product, as I wanted the solution to be a device that allowed the user to utilise the device the way they wanted freely and to be able to interact the same way as any other user would with an existing VR controller.

Scope

The scope of this project has been carefully defined to ensure a focused approach towards addressing the specific needs of users with hand impairments, particularly those with amputations. The design efforts are directed exclusively towards creating a VR controller for game-specific applications, intentionally excluding broader user groups without severe mobility or dexterity issues in the upper limb. By narrowing the scope, the project does not extend to considerations related to VR headsets, nor does it delve into quality-of-life features such as device accessibility, material durability, or mechanical stress testing. Furthermore, the development of a fully functioning prototype and the exploration of software-based solutions are outside the purview of this project. This concentrated focus allows for a more in-depth exploration of the challenges faced by this particular user group in the realm of VR gaming. Therefore, the scope of the project was:

- Not catering to users with no severe mobility or dexterity issues. This includes mobility issues for the entire arm and or joints in the upper limb.
- Designing a product only for VR game-specific applications.
- Will not be focusing on the VR headset.
- It does not include exploration of quality-of-life features like ease of accessing the device, durability of materials used, mechanical stress/load testing, etc.
- Does not involve a fully functioning prototype.
- The project will not deal with software-based solutions.

Chapter 6

Concept and Ideation

This chapter focuses on the creative process behind the development of accessible VR controllers. It will chronicle the journey from initial brainstorming sessions to the refinement of concepts, detailing the various ideas explored and the rationale behind each. The chapter will discuss how feedback from users and experts influenced the direction of the design, leading to the evolution of one of the concepts.

My approach to ideation with the project began in the very early stages. Existing DIY solutions inspired many designs online. However, what I did realise sooner and during my literature research was the influence of design on the gaming industry. It took work to implement a radical new design and concept with a completely different approach to the design that could be implemented and supported by every platform. The gaming industry and its users have evolved in a very different way. All users interviewed for the project are open to change in exchange for a significantly improved return, but if you change too much, you will receive resistance. This resistance to change makes sense as no user would like to buy a new controller only to realise they'd have to invest significant time learning and adapting to the technology. This is not the only problem; game studios and developers, too, have a hurdle of developing games that can support different hardware. By forcing developers to adapt and support different hardware, developers quickly receive many restrictions on their games and the type of experience they'd like the users to have. A good example was when game developers complained about making Xbox games compatible with the powerful Xbox series X console and the less powerful Xbox series S. The less capable series S put many restrictions on how the game looked and performed, leading to an inferior experience (Redden, 2023). So, with restrictions on both sides, it was crucial to have a design that would have elements of the current design while also serving the users.

Many designs were inspired by existing solutions used by users with impairments today. For example, many designs included foot controllers/foot-based interactions as input. Others included having existing peripherals (Joystick, D-Pad, Buttons, etc) on the table. It was far easier to ideate with the table in mind. Many modern peripherals could be used to fill in the missing input methods. But, after a while (as discussed in the previous chapter), I actively avoided a sit-only approach to this interaction.

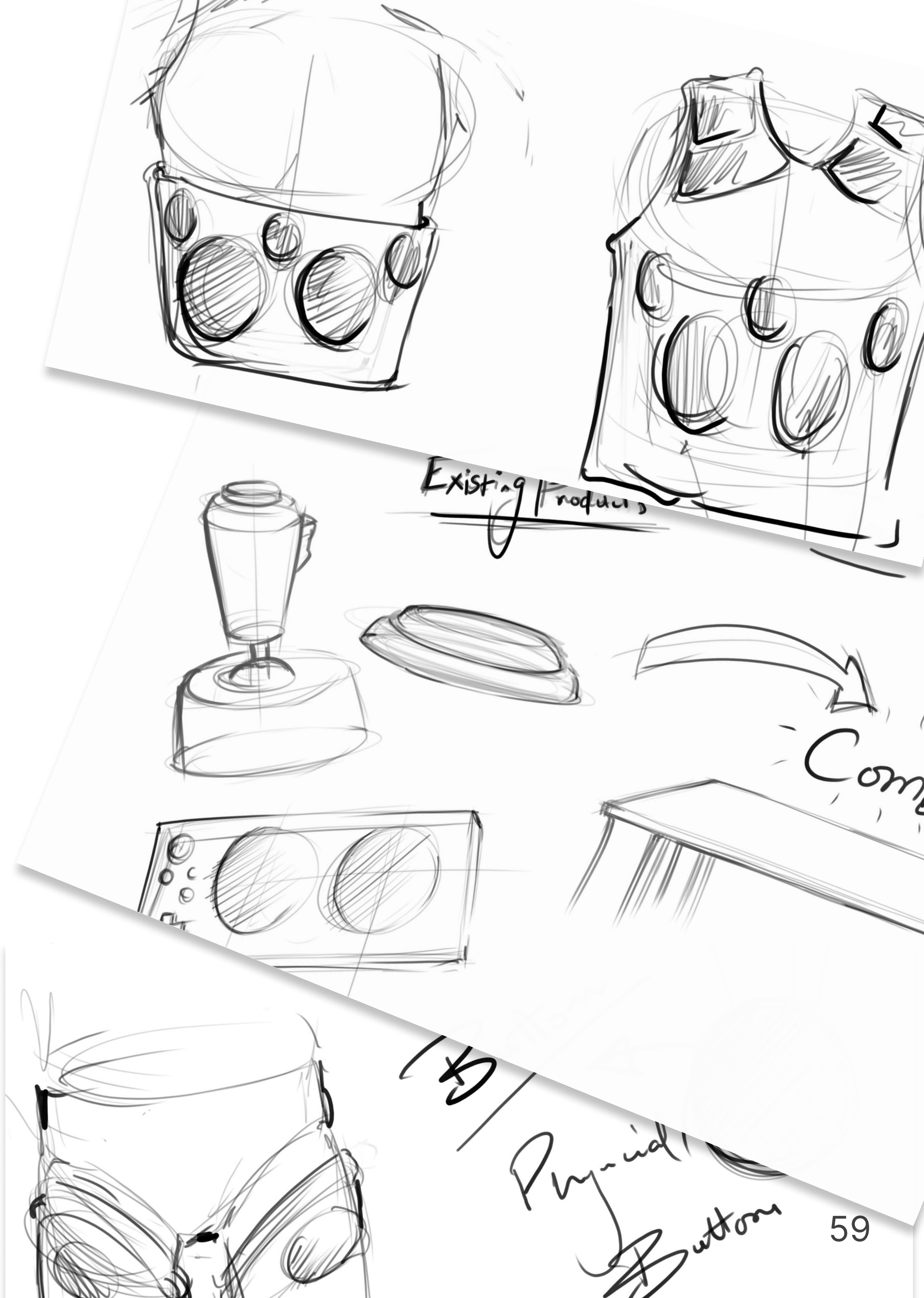


Figure 6.1: Ideation Sketches.

Technology and Mechanism in View

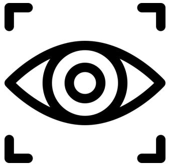
Technology has a huge impact on the product and its influence when in the real world. Use novel and expensive tech, and you have a product that could work very well but is far too expensive to manufacture. Use an old/well-established one, and you have a viable product that would not do what you want or, due to its age, might never be supported from the software side of things. Feasibility and viability are crucial for a product to succeed in the market. And the technology implemented has a huge impact on it.

While this is crucial, I kept an open mind during the initial ideation process. Therefore, as mentioned in the table below, you will see everything from novel technologies like eye tracking and muscle EMG sensors to mature, tried and tested ones like tactile buttons, analogue joystick, etc. As discussed earlier, some technologies in the list overlap with existing VR systems, such as infrared sensors, accelerometers, gyroscopes, and image recognition, as all these components serve one purpose (accurate motion tracking). This technology group has been listed as “Motion tracking”.

Figure 6.2: Modern prosthetic arms use EMG sensors to control the grip of their prosthetic limbs (Air Force Medical Service, 2015).

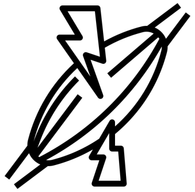
Voice Commands/Recognition

Technology that allows users to control devices or perform actions using spoken commands, enabling hands-free operation.



Eye Tracking

Technology that monitors where a user is looking on a screen, allowing control of devices or interfaces based on eye movement.

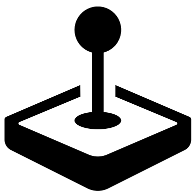


EMG Sensors

Sensors that detect electrical activity produced by skeletal muscles are used to control devices through muscle movements or tension.

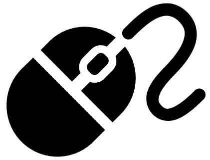
Tactile Buttons

Physical buttons that provide feedback (such as a click or vibration) when pressed offer a responsive and satisfying user interaction.



Joystick

A handheld device with a stick that can be moved in various directions to control movement or actions is commonly used in gaming and assistive technology.



Mouse

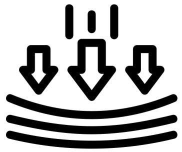
A pointing device that detects two-dimensional motion relative to a surface allowing users to interact with graphical user interfaces on a computer.

Motion Control Sensors

Sensors that detect and interpret physical movements, enabling control of devices through gestures or body movements.

Foot Pedals

Input devices operated by foot are often used to control specific gaming, music, or assistive technology functions.



Pressure Sensors

Sensors that detect the force exerted on a surface, used to trigger actions based on the amount of pressure applied, are often used in adaptive controls.

Some technologies/mechanisms have already been used in the gaming space; the joystick (existing controllers or as a stand-alone), physical buttons (PC peripherals and existing control), and foot pedals (racing simulator controls) have been used in existing controllers. Others were inspired by other devices, such as eye tracking from existing VR headsets, most notably the new Apple Vision Pro, and the EMG sensors from prosthetic hand sensors to control hand grip.

Co-Design Sessions

Before proceeding with the ideation process, I wanted to explore and understand participants' suggestions and recommendations for their custom VR controller. Designing for a physically impaired user is a very sensitive task, one that is made harder when the designer is not the intended user themselves. Therefore, involving users and experts in the design process through a co-design session could help me better understand their expectations of a product, their preferences for technologies, their method of access (To sit or stand), etc. While the users give much-needed insight into their personal opinions and suggestions, the experts' involvement should give me some insights from a medical perspective. Something that is much needed for a project of this nature.

Aim and research questions

To realise their affinity for hardware peripherals, layouts and position of their VR setup. While an interview would give me similar data, a co-design session allowed me to help the users visualise, interact and discuss more about their choices, reasoning and affinity in a much better way. The co-design activity also allowed me to help users focus and understand a specific part of VR interactions. With the list of technologies in hand, the next step was conducting co-design sessions with users and experts. The list of technologies and VR interactions (refer to Chapter 3) would be the basis for the co-design session.

Research Questions to be answered

Users
- Preference of Hardware/Technology or input mechanisms
- What is their preferred play mode, to stand or sit?
- What are some of the existing solutions used? Why and how do they use it?
- What is the user's preferred Gaming layout (position of hardware systems in their gaming setup/environment)?
- How do users implement and use Hardware and technologies in their controller?

Expert
- Which hardware/ technologies/ input mechanisms do experts suggest? And why?
- What is the physical impact of using VR controllers? How are they different from General users, and why?
- What are some Physical movements, Hardware, and technologies to avoid and why?

Why do we need this information?
Answering these questions would allow me to understand the user's preferences, gain their suggestions and also help me find common preferences of hardware, layout and input methods (if any) between them. It can also help me understand what to avoid, for example, positions of hardware systems that are out of reach for users, hard-to-use hardware systems or systems that they are used to and prefer. While users give me their personal preferences, it can also be the case that some of the interactive methods and choice of hardware/ technology preferred hurt their health in the long term. Therefore, medical insight would bridge the gap and shed some light on hardware systems/ technologies to avoid and even get some insights into a healthy way of using the system.

Methodology
The co-design sessions were held online and were individually conducted with each participant. Each session took an hour (roughly) and included an initial briefing, Activity – 01, Activity – 02 and Discussions.

The Co-Design session comprises two sets of activities. Both are identical, with some changes in the rules and tools available. My role during this entire session was:

- Brief participants
- Guide them through the activity
- Real-time discussion during the activity
- Clarify any doubts

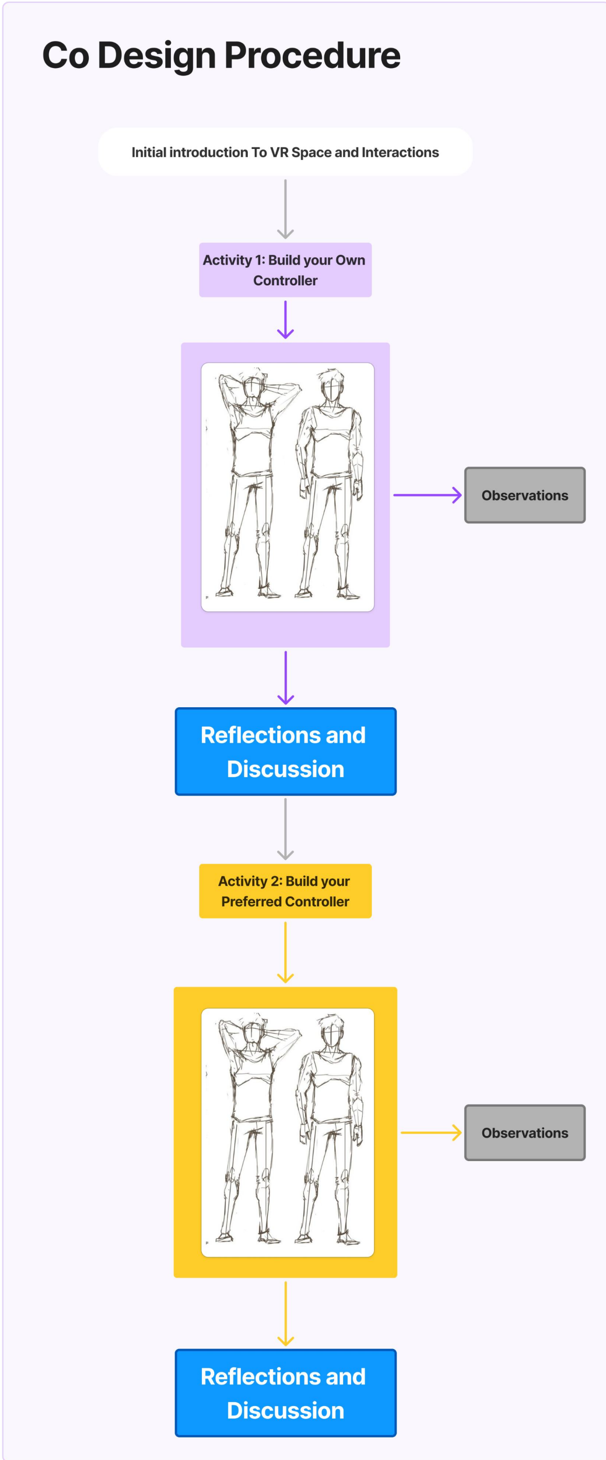


Figure 6.3: Co-Design Test Procedure.

Activity 01: Build your own VR controller

Duration: 20-25 mins

Users would be introduced to existing VR controllers and the framework. The entire interaction was divided into three simple parts: Object-based interaction, Locomotion and Graphic user interface interaction. As discussed earlier, VR interactions mainly comprise one or a combination of the three. Users are then given the technology list mentioned above to use and build their VR controller, and additional freedom is given to implement two of their technologies/ mechanisms/ interaction means. As shown in the figure, users would then drag and drop these technologies on the mannequin sketches, with additional freedom to place them on a tabletop or the floor.

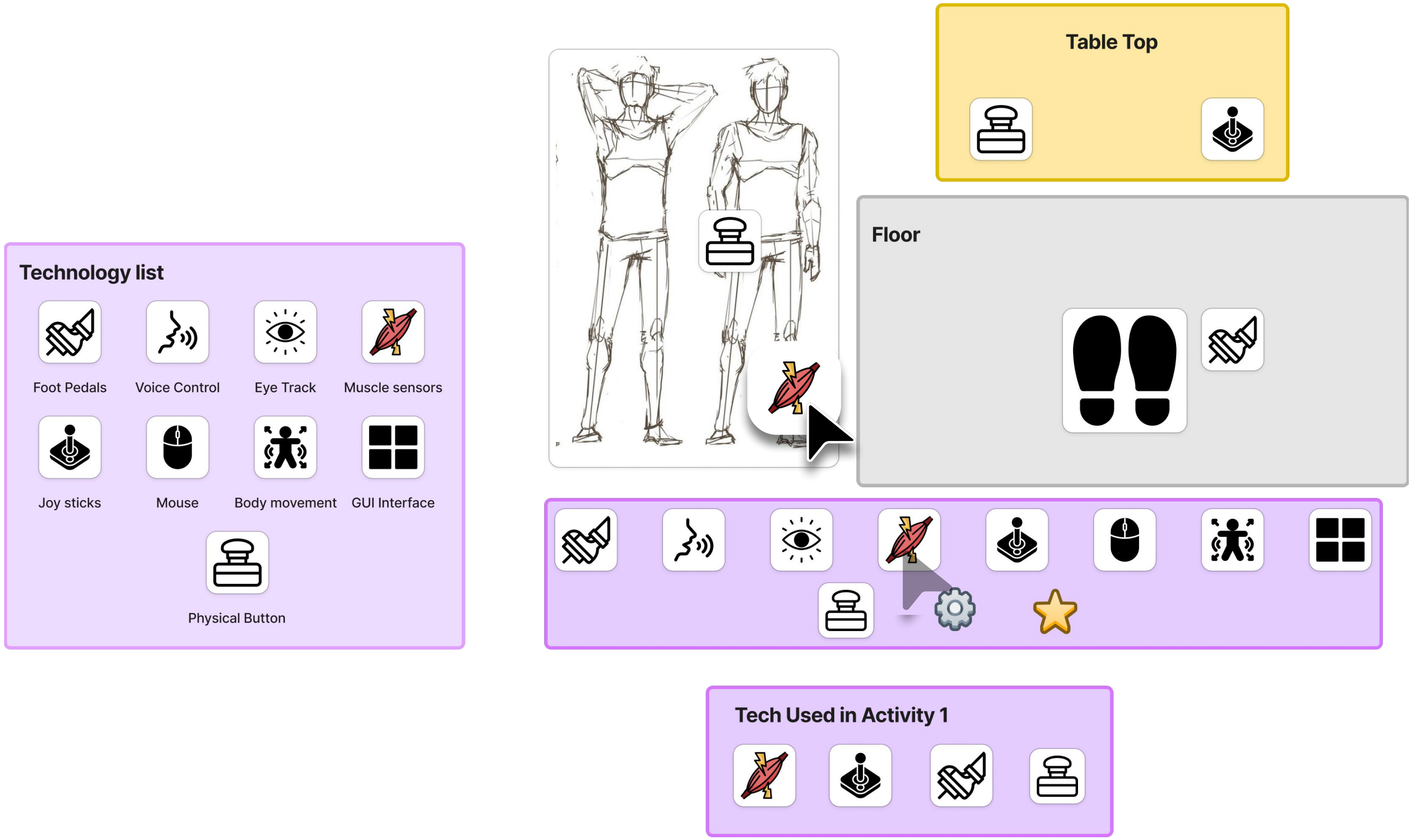


Figure 6.4: Activity one of Co-Design test.

Participants could create multiple layouts and configurations of their controllers in the first activity. This allowed them to expand and explore their options without choosing just one layout. This is in case users have more than one preference, want to experiment or have different layouts and positions of hardware for different games, applications, usage, etc.

Activity 02: Another round

Duration: 20-25 mins

The second stage is identical to the first, except for a few small changes. Users can use only two technologies used in stage 1, while the rest used before would be out of the list. Users were again free to make two new technologies for this round.

Participants in the second round were restricted to using limited technologies and layouts by choosing their preferred ones from the first round. This limitation of available technology and layout is hoped to force users to choose their preferred technology and layout. Although this would tell me a lot about their preference, it does not, however, mean that any of the layouts before were ignored. The purpose of the second round and the added limitation was to understand participants' preferences and another chance to redesign their controller after gaining some familiarity with the activity.

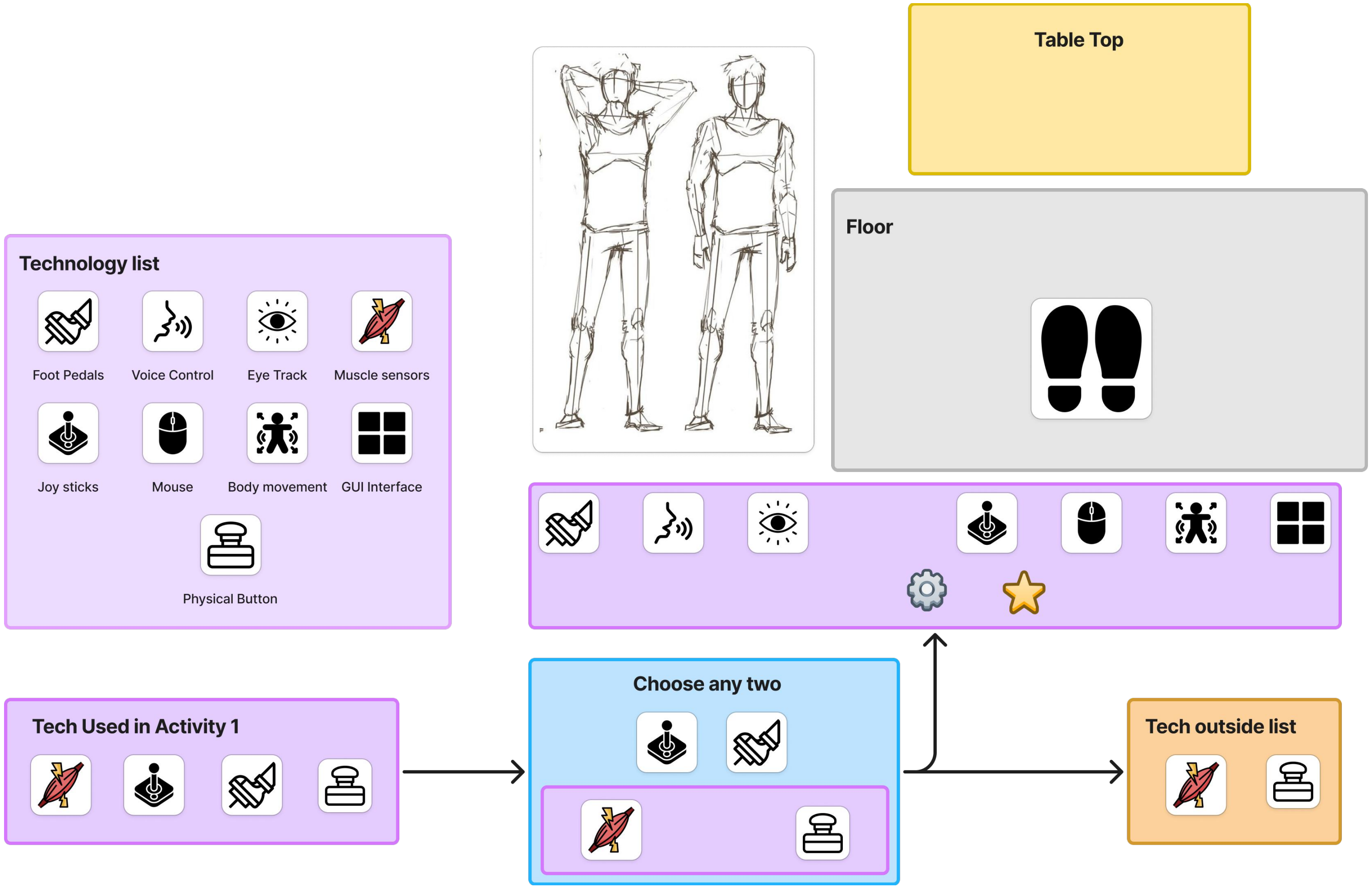


Figure 6.5: Activity two of co-design test.

Co-Design discussion & Key takeaways

Sitting down and standing up

Users 01 and 03 initially preferred to access VR while both were sitting in front of a table or standing like conventional VR. When asked to choose one, both chose to experience VR while standing up.

User 02's impairment restricts their interactions strictly to a sit-down approach and naturally chooses to design solutions for a sit-down approach during both activities. While this gives an idea of what the users preferred, the key takeaway is that users would like to access VR the way it's meant to (both standing up and sitting down) if they can due to their innate preference and their experience with observing conventional approach (of using VR).

Common mechanisms and techniques

Speech Recognition: Not so surprisingly, all users had some implementation of Speech recognition. User 01, with no gaming experience, used it to replace many key interactions (use, grab, select, etc).

User 02 and User 03, on the other hand, have a lot of gaming experience, and they use quite sparingly and, in some cases, prefer not to. They reason that, in many cases, game interactions and playthroughs are reaction, reaction-based, and speech recognition would not fit perfectly with many core interactions. For example, it is far easier to hold a button for 5 seconds to use a tool than utter the command "use *tool* for 5 seconds".

Eye Tracking: Eye tracking was one of the few frequently used technologies throughout the activity. However, every user used it sparingly. User 01 liked to have a blink of an eye mapped to selecting an object. Users 02 and 03, however, were quite restrictive in their usage, prompting user 02 to eventually let go of the technology.

User 03, on the other hand, used eye tracking in combination with speech recognition and GUI elements within the game, which was discussed later.

Conventional Buttons: All users used some form of a conventional button for various interactions. Many preferred to have at least one button near the foot for easy access to the button. User 02 used the buttons heavily through their designs by making nearly interaction mode through the button in the first activity. Both user 01 and user 02 also used the buttons on the table to have easy access while sitting down.

Motion tracking and Gestures: Users 01 and 03 often used motion gestures and movements quite effectively to execute different interaction methods. They used hand gestures to accomplish many primary interaction methods (using, grabbing, and moving objects). User 03 also liked the ability to customise and map different hand gestures and movements for each game.

Joysticks: All users used the joystick in at least one design to locomote and move around in their VR environments. User 2 even used it in his final design. As the joystick is widely known and used, it is quite logical that it is used heavily to move around within the environment.

Niche and interesting combination

Foot Pedals: User 01 liked to use the foot pedals in his design to play racing or other driving games.

EMG sensors: As User 01 was quite used to using the EMG sensor on his prosthetic limb, he used the sensors to search and grab objects.

Gaming mouse: For user 02, the gaming mouse proved to be a very good solution for executing the use-and-grab option in the world, all the while using the additional buttons on the mouse to customise other inputs and working well with his sit-down designs. This, however, was not preferred by the other users as they found other, more mobile ways to tackle this problem.

Translational Body Movements and Gestures: User 03 had an interesting approach to using body movements and gestures. They wanted the VR system to track their foot movements to move around, except by making just one simple move. For example, if the user wants to move left, they could look to their left while placing either foot by one step and then step back to stop moving.

Footpad with sensors: User 01 used a foot pad with sensors similar to a popular dance-based game, Dance Dance Revolution, that uses the same tech (figure 6.6) to sense his foot movements that can be used to either move around just like User 02, as mentioned earlier or use to interact with objects (use & grab).

Foot controls, on the other hand, while quite intuitive and preferred, have their limitations. Both users 01 and 03, who designed controllers while standing, realised that it would be a very useful way to execute some interactions like selecting, grabbing an object or pausing/resuming the game. But also acknowledged that freely moving around in the real world while wearing a headset could be challenging.

While eye tracking and speech recognition have obvious drawbacks, they are interesting ways of combining them to make them work much more effectively. This is seen in user 03’s implementation of the technologies. She wanted to pause/resume the game using voice commands. Further, they can use the voice command to access their backpack/inventory within the game and access different tools, weapons, or other objects. When faced with the inventory menu, she wanted the system to track her eyes so that she could select the right object on the screen.

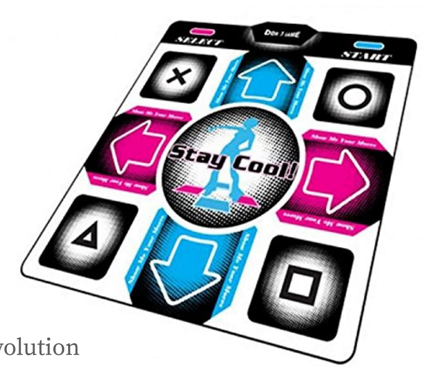


Figure 6.6: A Dance Dance revolution pad (Ubuy Netherlands, n.d.).

Expert
The Co-Design session with the expert gave me a lot of valuable insights. Unlike most users, every implementation of technology chosen by the expert was placed and positioned either in a person or near the foot on the ground. For example, while most users used the joystick on the table, the expert placed it near the waist so it could be easily accessed by the forearms. His reasoning is that speed will, in the end, be a huge factor in the quality of gameplay and interaction. Unlike every other user, users with an impairment will have to move their limbs quite a lot due to the position of different input methods. Therefore, having input mechanisms as close to each other as possible will, in the end, prove a lot more effective, less fatiguing, and provide a more immersive experience.
After the co-design session with the users, I was quite excited to see and implement the EMG sensors as it was effective, compact and perfectly suited for my user group; however, the expert did not prefer using them as the technology was not perfect, hard to get used to and quite expensive.
I was also advised to keep in mind of having some feedback to the users. Having the right kind of feedback system is the difference between a user hitting a button multiple times or confidently hitting it once and moving on to the next task.
While acknowledging the versatility of speech recognition, he also mentioned (just like the users) the difficulty of implementing it in multiplayer games.

On how speed is key

“I think speed is one of the most important problems because now you have vertices that are 1 centimetre apart. But if you have an empty, the buttons have to be like, let's say, 20 centimetres apart. Speed is speed is the biggest problem.”

On why EMG sensors are hard to work with

“I see muscle sensors immediately. I'm very intrigued with it. I think you mean by using EMG signals and stuff like that. Yeah. I don't think it's gonna work. Not in the next coming years. I think it's too difficult. It's too hard. Of course, people with amputation use it as well, have it for the prosthesis or something like that. But that's it. It needs a lot of practise, and lots of training and equipment is quite expensive.”

On Speech recognition

“Yeah, and and the problem is the social component. If you play with friends online, then it's not that it's not an option anymore. And the most of the people game for the social interaction.”

Morphological Chart

The literature review, user interviews, expert interviews, and the technology list provided me with a palette to start my ideation process. Key expected sub-functions were defined using the literature review and the VR interaction Framework. The technology list acted as the boundary condition with which I ideated and created ideas. This restriction made sure that I wouldn't stray too far away from the Program of requirements defined earlier (refer chapter XX).

With key sub-functions defined, the morphological chart (figure 6.7) proved to be a logical method to ideate. The chart allowed me to visualise and compare the solutions with each other to form ideas.

Sub-functions/ Solutions					
Primary Posture	Sitting	Standing	Sit &/or stand	Sleep	
Primary Action/ Select	Arms/Hands	Foot control	Voice command	Eye gaze & Muscle movements	
Secondary Action/ Grab	Arms/Hands	Foot control	Voice Command	Eye gaze & Muscle movements	
Traversing	Arm movements	Foot control	Joy sticks		
Rotational Movement (sight)	Head movements	Joy sticks	Mouse		
Menu Interactions	Interactive GUI	Physical button	voice command	motion control	
Actions 1					
Actions 2					
Actions 3					
Actions 4					

Figure 6.7: Morphological chart used during the ideation process.

Table-Top only Solutions

Many of the initial ideation sessions were just all about tabletop solutions. Or using the table in some way to assist the user. Most of the Accessible gaming solutions are on a t to help users get access to the hardware.

Therefore, many of the solutions were based on using existing hardware and utilising them to provide users with a full VR experience.

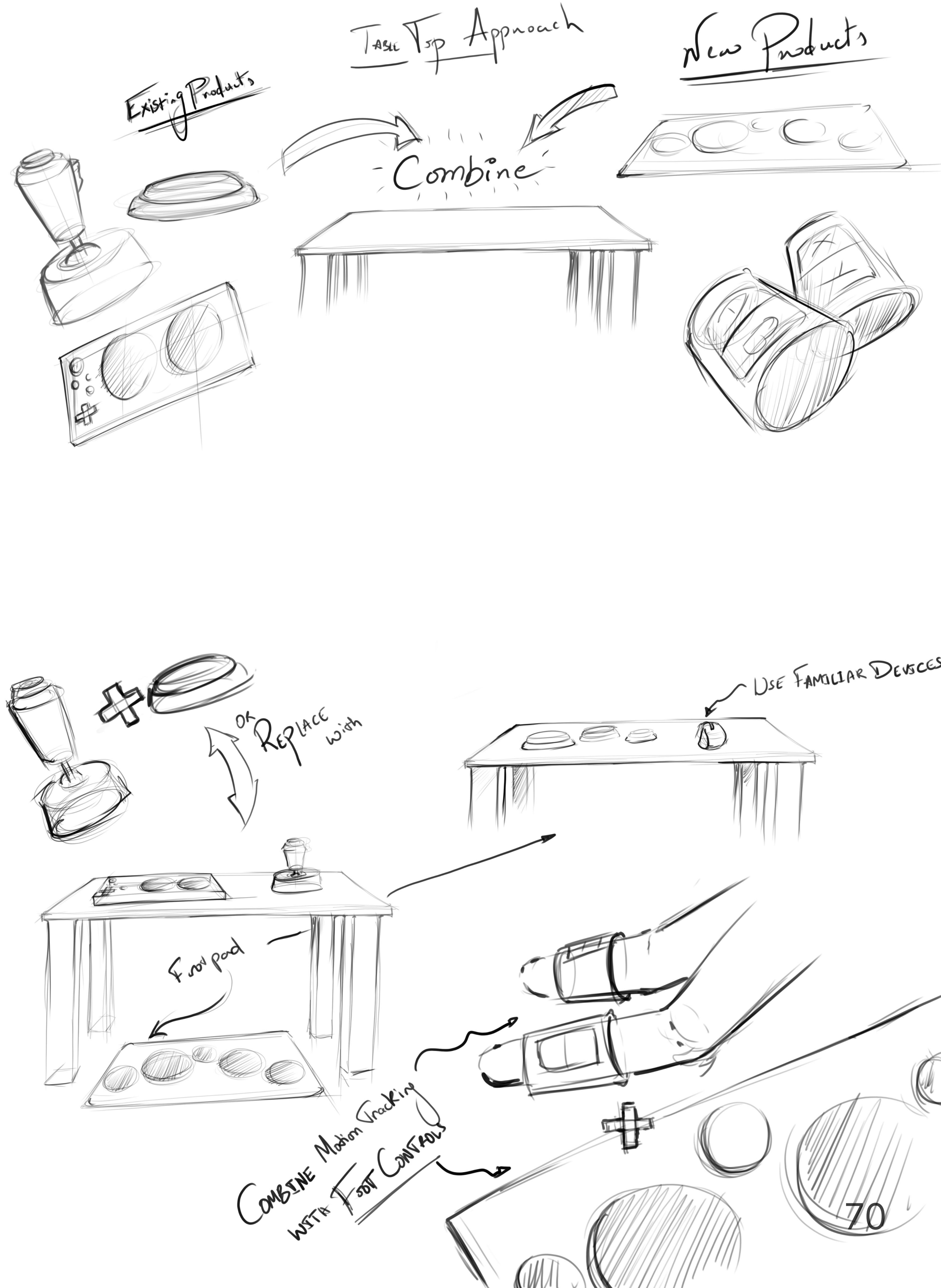


Figure 6.8: Ideation sketches for table top solutions.

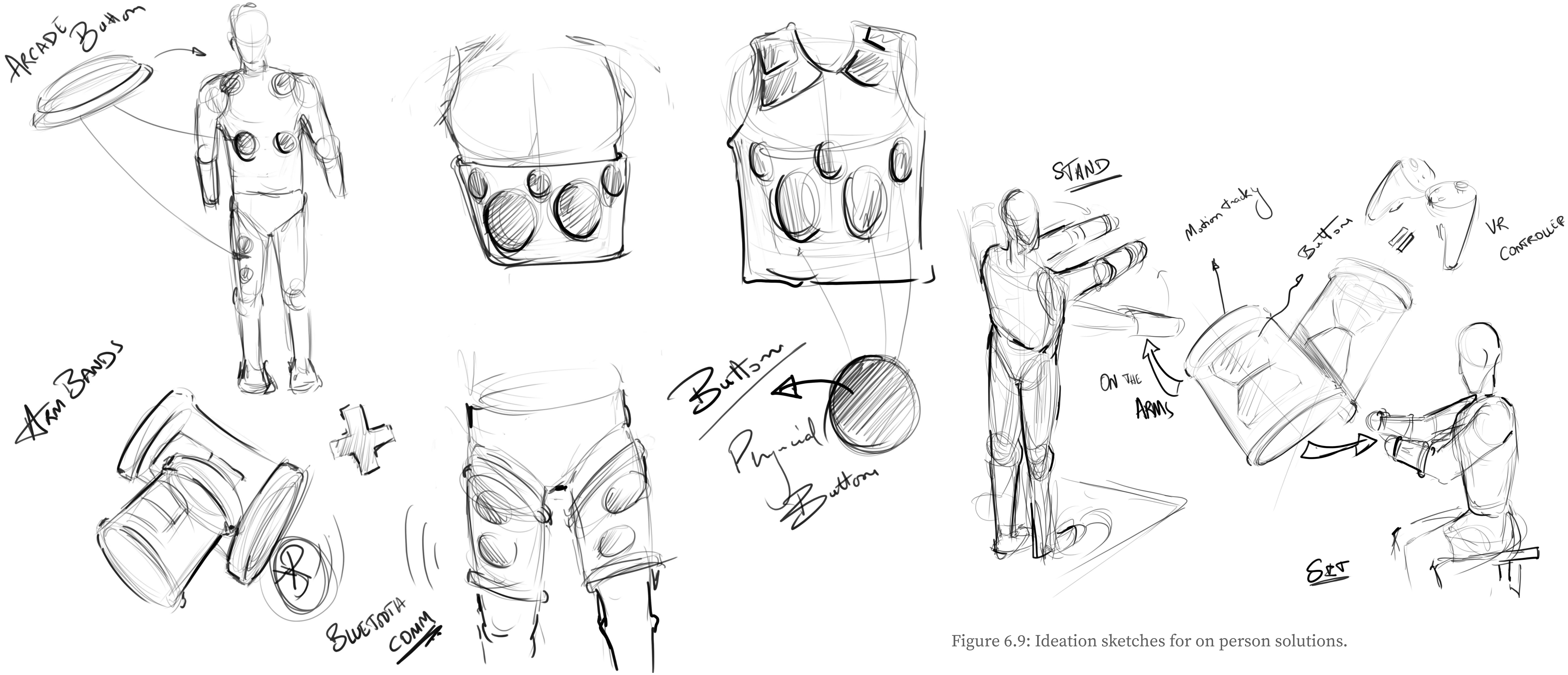


Figure 6.9: Ideation sketches for on person solutions.

On-Person Input Solutions

I started to diverge from the tabletop solutions when I tried to maintain the stand-play aspect of VR. By forcing myself to ideate on a couple of ideas, it was much easier to diverge and expand on the concepts. This is also where niche and more recent technologies, such as voice control, EMG sensors, and motion capture, came into the picture.

In most cases, however, users could access VR not just while standing but while being seated as well. There was a combination of using both feet and arm-based mechanisms as inputs here.

Concepts

Arm Bands

The Arm Bands were the first major component of the VR controller system to be finalised. The Armbands solve the motion tracking and Additional Action Buttons (XYAB) on the VR controllers. The design comprises a breathable polymer-based (neoprene) Armband that can easily conform to the user's arm profile. With the discussion of the concepts in the upcoming chapters, they all utilise the Armbands as a means to bridge the motion tracking and provide users access to the Actions buttons.

Components and Working

Motions Sensing Module: The plastic encasing within the armband includes all the conventional tracking sensors used in current VR controllers, infrared sensors, an accelerometer, and a gyroscope for dynamic information about the user's movements.

Wireless Communications Module: A Bluetooth or similar wireless module in the sensor housing (figure 6.10), used to communicate with the VR headset.

Action Buttons (XYAB): The Armbands also house the action buttons. The buttons and their implementation are similar to conventional controllers; this means that two action buttons, X, Y and A, B, are split between the two armbands.

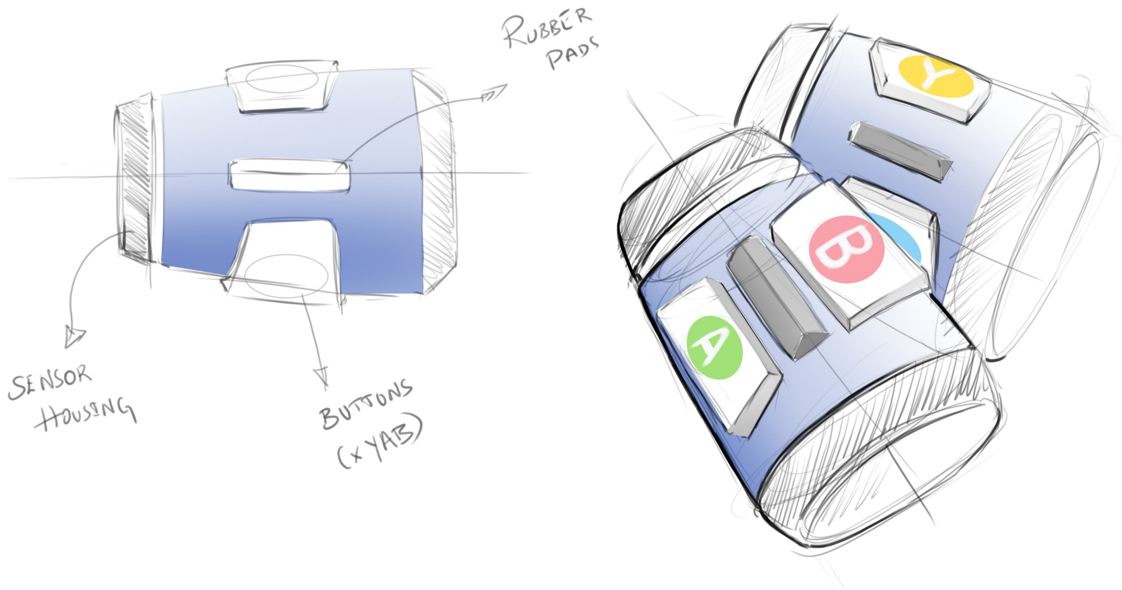


Figure 6.10: Arm Band concept.

Why Armbands?

According to the literature review and expert insights, amputation users do not have a significant issue moving the rest of their limbs as long as there is no significant damage to their elbow joint (Understanding Upper Limb Amputation | OSSUR, n.d.). Hence, Users can still make the required Arm motions, which are predominantly used in VR. We can, therefore, use this to our advantage by translating the user's Arm movements as done in conventional VR controllers. The Arm Bands are, therefore, one of the constant devices to accompany the rest of the concepts.

The Effect of Severity of Amputation on the Design of the Arm Bands

Initial designs of the arm took advantage of the Armband's entire geometry and form to enclose the needed sensors. However, another factor had to be considered for the design: the severity of the amputation. As the severity of the Amputation increases, the length of the user's limb decreases. One factor that changes here is the Linear dynamic properties of the Arm. This would include Position, Velocity and acceleration.

Let us take two individuals, A and B, With the right lengths 70cm and 65cm. Both users are tasked with moving their right limbs from positions 1 to 2. Assuming both users move at the same angular velocity (10 rad/s), user A's linear velocity would be higher by 0.5 m/s.

While a part of the issue can be resolved through software, it was also clear to extract and gain every bit of dynamic leverage available. To do so would mean that the sensor housing must be positioned at the very end of the Arm Band.

How to Use it

1. Press any of the Action Buttons (Unequip, Pause & Resume)

   1.1 Method 1: Using the Torso/other parts of the body.

   1.2 Method 2: Using the other Arm.
2. Motion tracking
3. Optional* Grab interaction

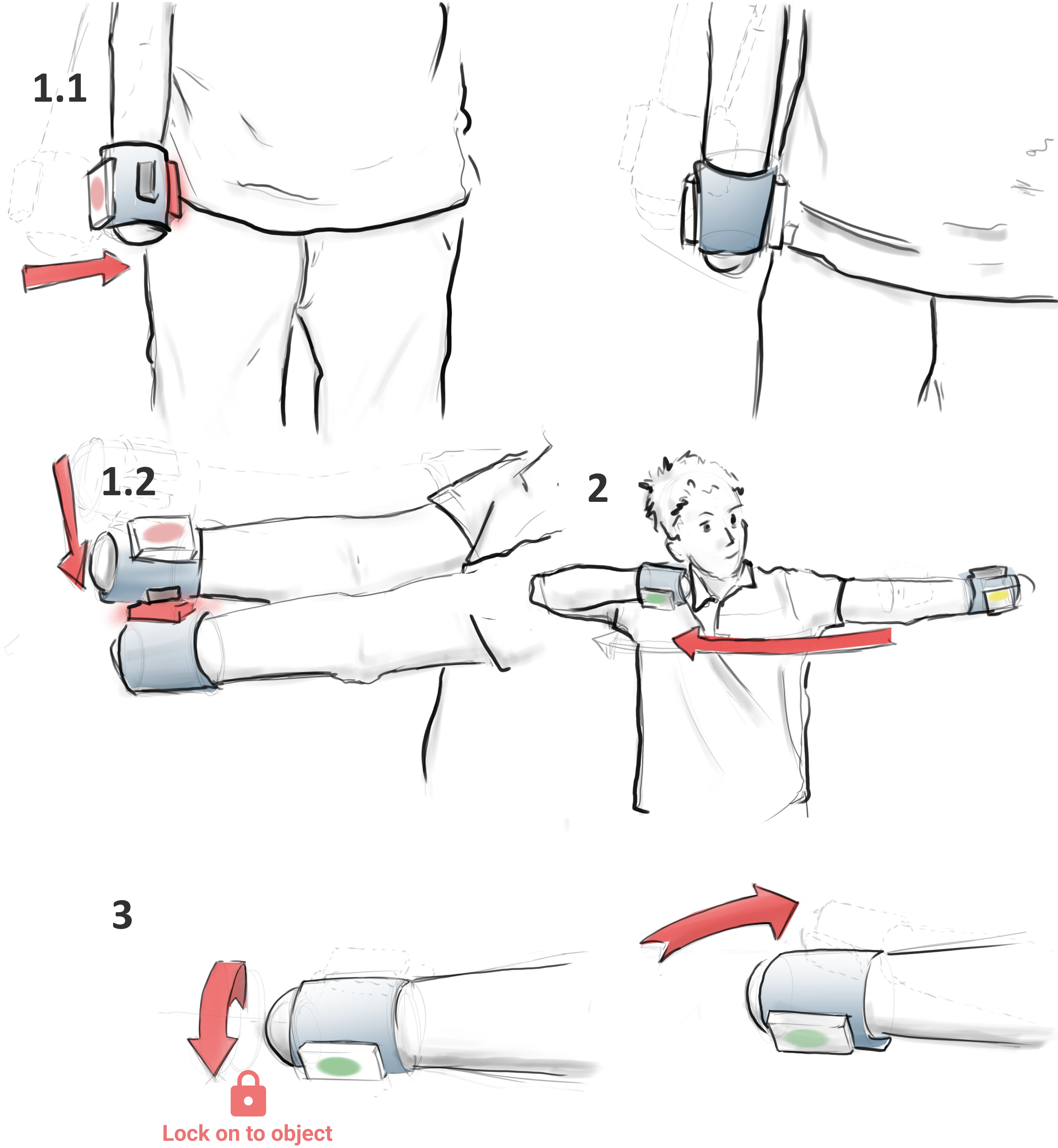
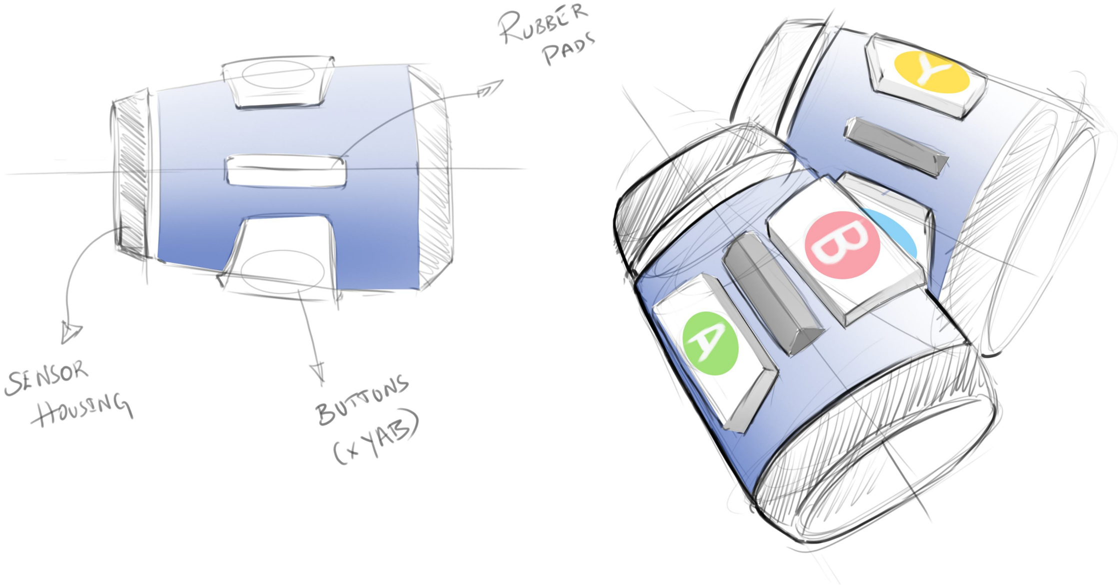


Figure 6.11: On using the Arm band and pressing the buttons.

Feedback and reactions from users

- Overall, feedback on the Armbands was positive.
- All Users (trans-radial amputation) found the usage quite intuitive and easy.
- Users also liked the idea of gesture-based control.
- User 01 also mentioned he might find it difficult to actuate buttons on the Arm Bands.



Concept 1 – Rockwell

With Rockwell, the design aims to solve and provide a solution to the primary and secondary triggers and the locomotion (Joystick). Rockwell solves the problem using an input method already used by gamers with hand impairments, making it a beautiful solution for our users. The primary mode of interaction with the device is through the foot, where the user places and steps on the desired button. Rockwell consists of a Footpad with buttons/actuation spots on the pad, similar to the "Just Dance" pad. Motion control of the arms is maintained through the Armbands, which host the XYAB action buttons. The Footpad houses the Use, Grab and Teleport buttons. While the design shown here is simple, the layout can be adapted to various possibilities.

Main Components

Foot Pad: The Footpad is a flat polymer-based pad with graphics and symbols to indicate the location of the inputs/sensors. As VR is a predominantly active method of interaction, devices that use the foot for inputs have to be carefully designed to ensure it does not harm the user, either by protrusions in the form or through wires and cables. Therefore, unless these devices are used wholly seated, the design should have no features that can disturb the user's movements or come in the way.

Pressure Sensors: A pressure-based sensor would pick up the user's movements and inputs through the mat. Using a pressure sensor can allow users to modify the sensor sensitivity and customise each

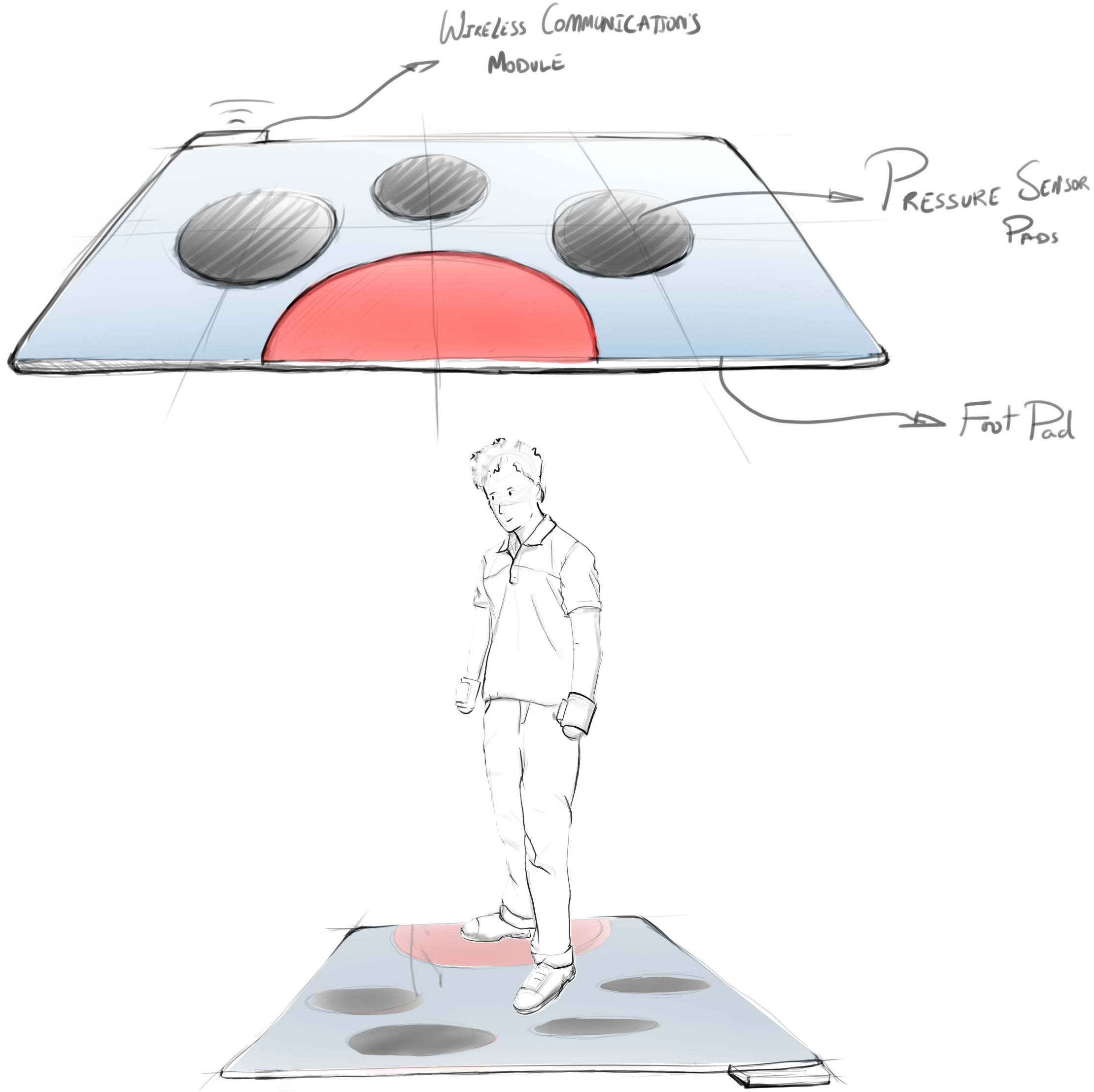


Figure 6.12: Concept Rockwell.

Button and its sensitivity. For example, users could program the grab button to be sensitive enough to be actuated by a small flick; this would mean that users wouldn't have to worry too much about putting the right amount of pressure on the button. However, users would want the opposite for locomotion buttons and have low sensitivity (high pressure needed to activate the button) to avoid accidentally teleporting themselves throughout the environment.

Wireless communications module: As discussed above, wired communication could be quite an inconvenient experience for users. Therefore, just like most VR systems, the footpad would utilise Bluetooth wireless communication to the headset.

Design Discussion

The concept's inception resulted from online accessibility solutions, insights, and takeaways from user and expert interviews using foot-based input methods to play games. And it makes total sense why. A person's legs and feet are the next logical interaction mode for anyone with a hand impairment. Many Xbox Adaptive controller layouts involve foot-based controls, and with users already using them, it should also be easier to adapt to “Rockwell”.

How to Use it

1. To press a button
2. To press a button and Motion track
3. To press a button and two-arm motion track

Feedback and reactions from users

Accessibility

- User 01: Concept is accessible.
- User 03: The concept is liked, but suggests click-up buttons for the foot for less energy.

Multi-tasking

- User 01: It is difficult to do two things (foot controls and arm movements) simultaneously.

Preferred Areas for Control

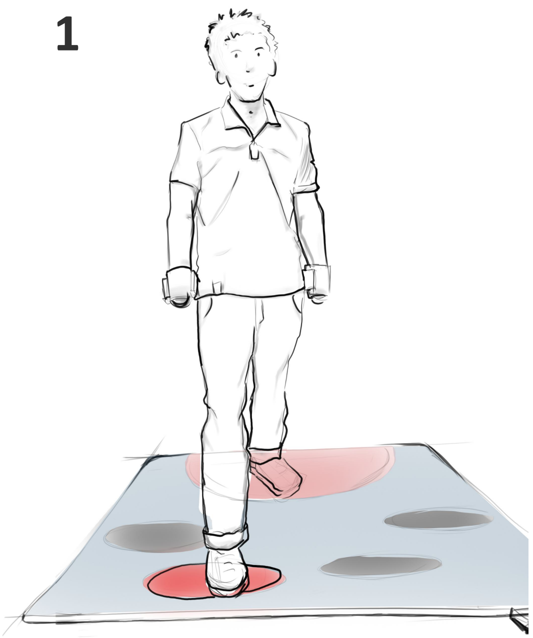
- User 01: Prefers using the arm (upper half) or upper/lower body.

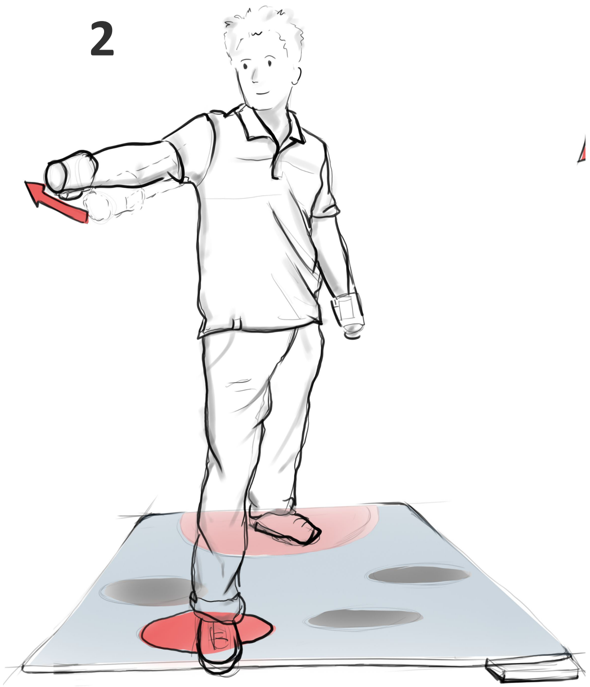
Usage Position

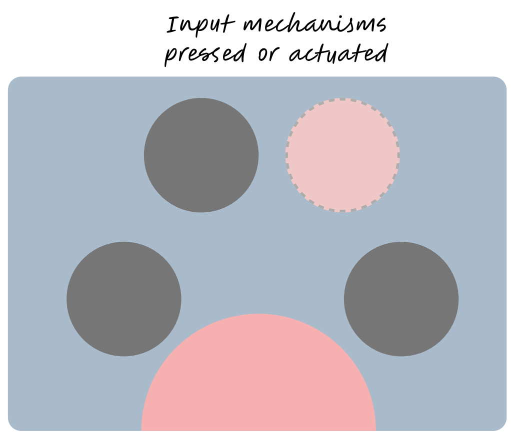
- User 02: Prefers using it sitting down, possibly attached to the chair.

Specific Features

- User 01: Preferred to do all with the arm.
- User 02: Really likes the grab button option.







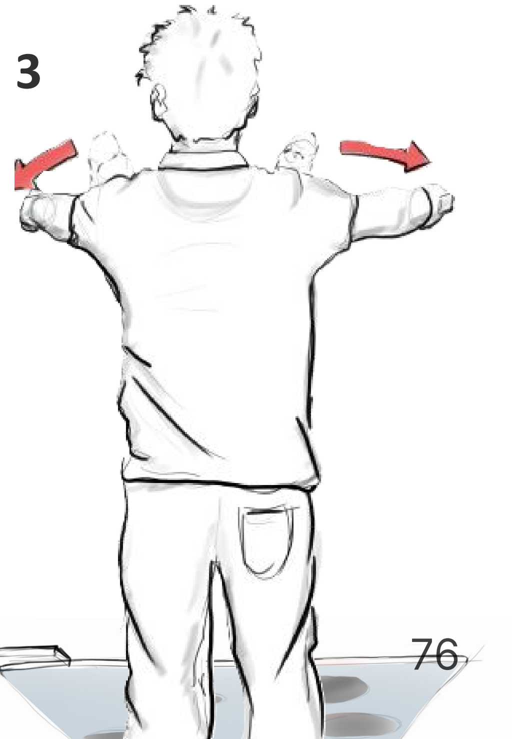


Figure 6.13: On using and pressing the buttons.

Concept 2 – Django

The second concept to be worked on, Django, involves the same Armbands for motion tracking and XYAB buttons. Django aims to solve and provide a solution to the primary, secondary and locomotion buttons. The rest of the interactions take place on the gaming belt.

Main Components

Belt: A combination of cloth and polymer, the belt consists of layers of soft foam and polymer while also housing the Velcro layer (loop side) on the outer layer of the belt.

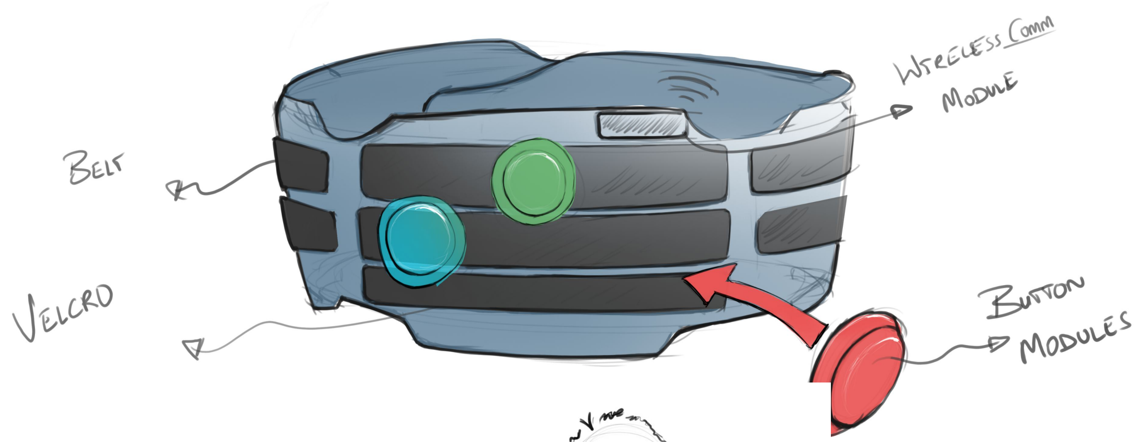
Detachable Buttons: These buttons include the button cap and the housing. The button housing contains the mechanism to deliver tactile feedback when the user acts. The housing also has a layer of Velcro (Hook side) that attaches the buttons to the belt.

Bluetooth Module: The module could be placed in every sensor or only one in the belt. Having a means for all buttons to communicate with the belt allows the belt alone to communicate and transfer information to the headset.

Working

The belt holds Velcro's blank canvas, allowing users to place the buttons where they seem fit and comfortable. The belt houses the use, grab and teleport buttons. Just like Rockwell, Django can also be modified using a combination of buttons of different sizes. The belt could host a plethora of layout and button mapping combinations.

Users would have to press/actuate buttons on the belt with one arm while they point with the other. This would, however, make almost all interactions a single-handed one. In many cases, some use scenarios for dual-handed use are limited.



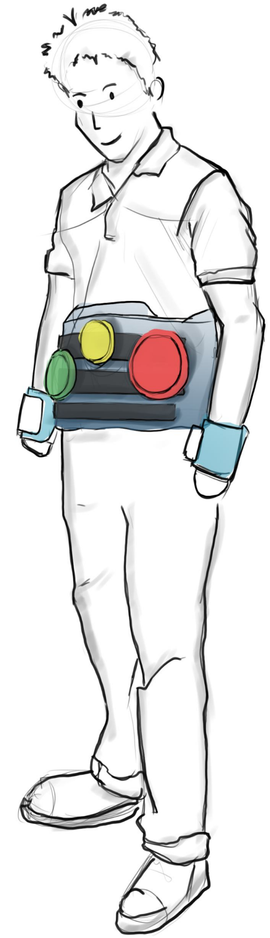


Figure 6.14: Concept Djando.

Design Discussion

Django's design resulted from trying to keep the controller inputs as close to the users as possible. This would mean that the buttons would have to be positioned on the torso of the body. While Action buttons (XYAB) were already on the armbands, populating the armbands further with the remaining inputs felt too crowded. Therefore, the next best option was to change the position of the controller inputs to the torso, specifically on the abdominal portion. This felt like an optimal location for the users to comfortably reach the buttons or input methods while keeping the controller space manageable. However, the design, therefore, must allow for customizability of the positions of the buttons on the belt, allowing each user to customise and map their layout based on their needs. Django solves this issue by bringing the buttons and input methods close to the arms while keeping the layout less crowded and allowing for custom positions and button maps.

How to Use it

1. Pressing a button on the belt.
2. Point and press a button.
3. Press and hold the button while moving the Arm.

Feedback and reactions from users

Elbow Limitation and Reach

- User 01: Has some issues due to the limited reach of the arms. Therefore, buttons close to the arms are preferred in the neutral position on the side.

Overall Combination

- User 02: The combination of Armbands and the Belt is good.
- User 03: Liked having a customised button layout for each game.

Button Placement and Usability

- User 03: Likes the idea of buttons closer to the arms.
- User 03: Concerned about finding too many buttons (5 buttons).

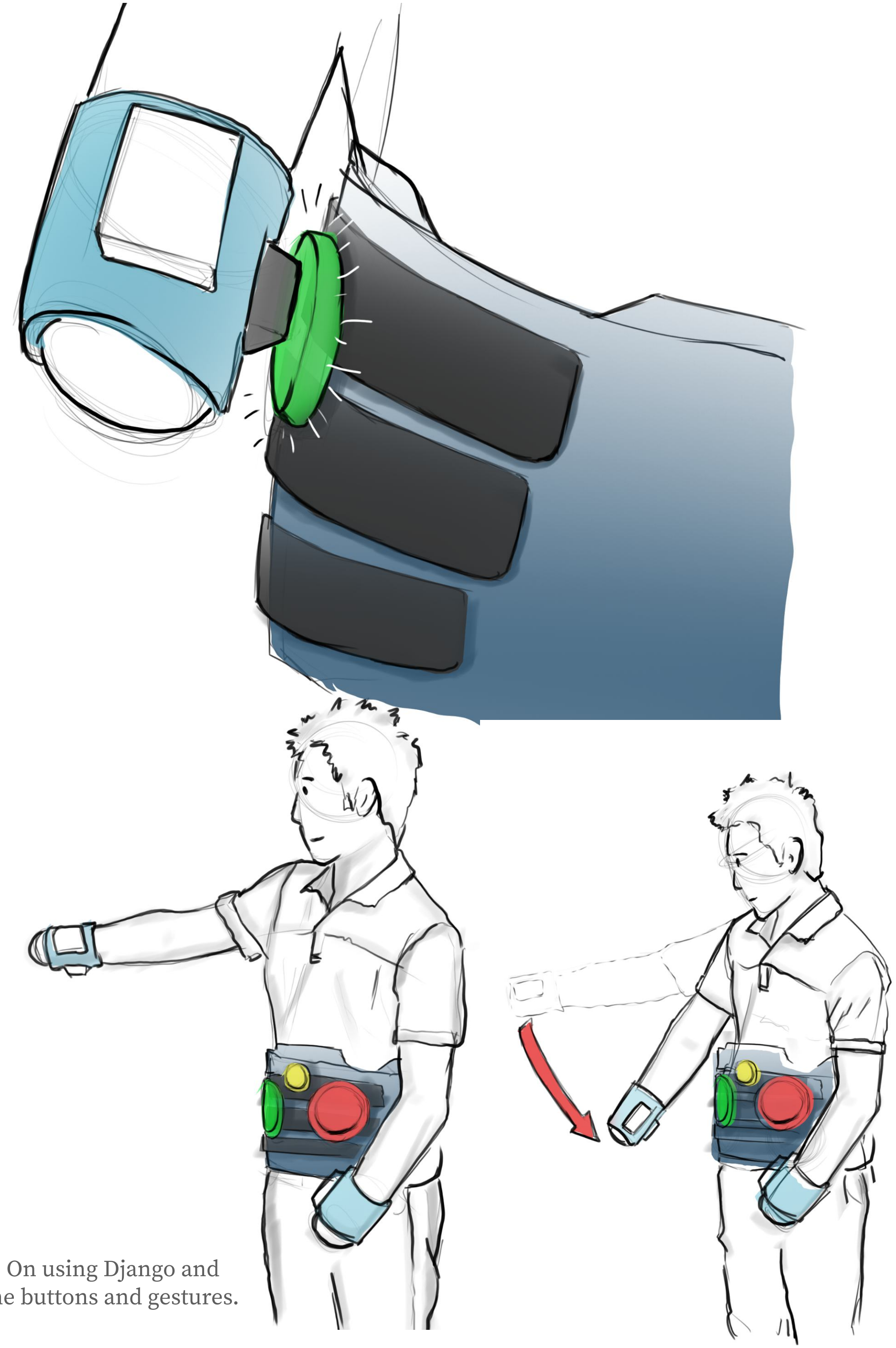


Figure 6.15: On using Django and actuating the buttons and gestures.

Concept 3 – Mithril

Think Django, but a vest. It is similar to Django but with buttons on the shoulder regions and the abdomen. With more real estate, users can choose the positions of the buttons over a larger surface area. The controller is wearable, acting like a gaming vest.

Main Components

Vest: The vest is similar to the belt. A combination of cloth and polymer, the vest consists of soft foam and polymer layers while also housing the Velcro layer (loop side) on the outer layer of the vest. The vest covers nearly the entire torso, providing ample space and options for users to place and choose their button layouts.

Detachable Buttons: These buttons include the button cap and the housing. The button housing contains the mechanism to deliver tactile feedback when the user acts. The housing also has a layer of Velcro (Hook side) that attaches the buttons to the belt.

Bluetooth Module: With more space than the belt, the vest can house one Bluetooth module for all the detachable buttons for the controller.

Working

Like Django, the vest has a Velcro layer to allow users to place the buttons and design their layouts and mapping. With the additional space available, users can use many buttons for niche actions (for example, a button mapped to execute a certain type of magical spell). With the available space, users can position the buttons to their liking by positioning frequently used buttons closer to the neutral positions of their arms and the less frequent ones in other less comfortable spots.

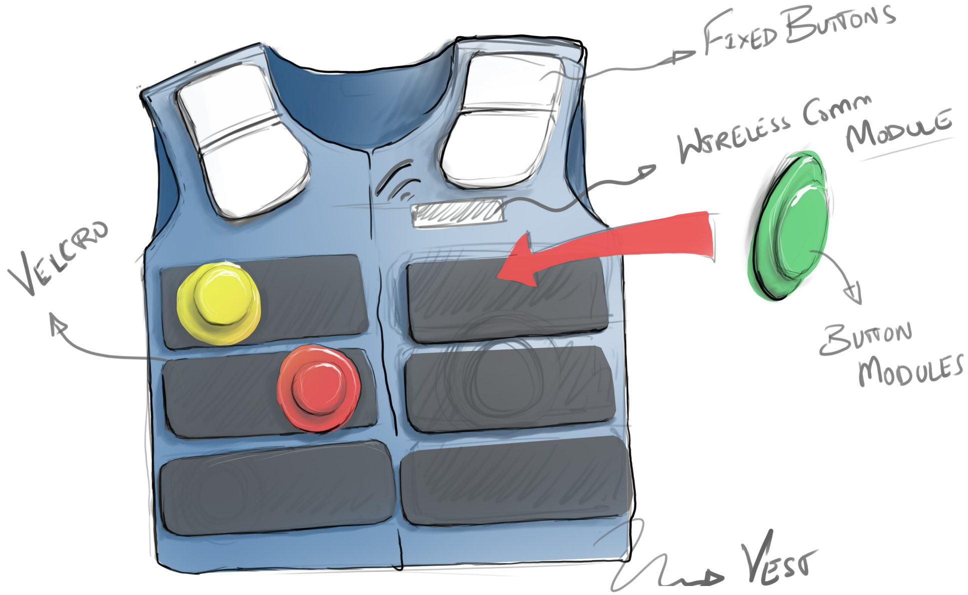


Figure 6.16: Concept Mthril.

Design Discussion

The design for Mithril was a natural successor to Django. Both concepts use the same mechanics and technology. The only difference is the type of wearable used. With Mithril, however, I was curious to know how users would probably use the extra space and under what circumstances they would use it.

How to Use it

1. Pressing a shoulder button on the Vest.
2. Pressing a Button module on the Vest.
3. Point and press a button.

Feedback and reactions from users

Button Reach and Accessibility

- User 01: Vest makes it difficult to reach buttons; suggests eye tracking.

Button Placement and Differentiation

- User 02: Suggest placing the button in the middle for single-handed users.

Comfort and Practicality

- User 03: Prefers not to wear a vest due to potential warmth and discomfort.

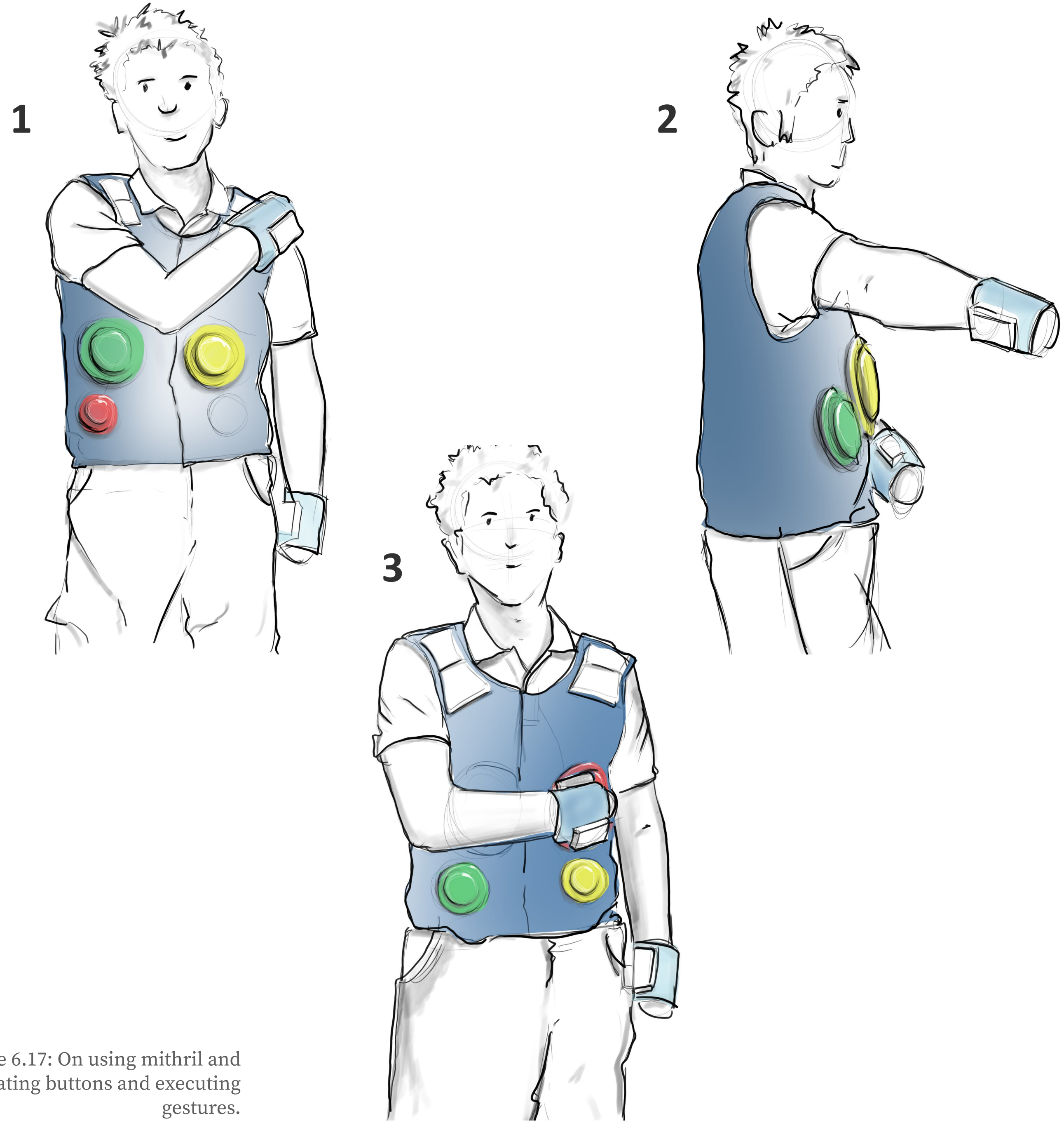


Figure 6.17: On using mithril and actuating buttons and executing gestures.

Expert’s Overall Feedback

Arm Bands: Motion Tracking:

- Supported motion tracking with armbands as a practical solution, utilising simple sensors on the arms for effective interaction.

Concept 1: Foot Controls:

- Considered foot pads for controls a viable option, particularly for actions like grabbing and teleporting, but stressed the necessity of user testing to determine effectiveness.

Concept 2: Button Placement:

- Discussed the feasibility of placing buttons on different body parts, such as thighs or a belt, emphasizing the need for user testing to avoid interference with in-game movements.

Software and Hardware Balance:

- Emphasized balancing software development with physical hardware support to prevent unintended in-game interactions.

Additional Control Methods:

- Acknowledged the potential of voice and eye tracking for interaction but noted limitations in social gaming settings and the importance of tactile feedback.

Pressure Sensors and Sticky Buttons:

- Suggested using pressure sensors in objects for nuanced control and highlighted the benefits of sticky buttons for users with limited fine motor skills, ensuring accurate and consistent interactions.

Decision and Reasoning

Choice of Concept to test: Concept 2 - Django

I received much valuable feedback from users and experts; User 1 (trans-radial Amputation) gave me much feedback and insights into the effect of amputation on the device, how it can be used, and the challenges that come with it. Both users 1 and 2 (limited mobility on the right side of their body) preferred Django 1 for different reasons. While User 1 liked Rockwell for its compatibility with racing games, User 2 (who also has difficulty moving around) preferred Rockwell for its ease of use while sitting down.

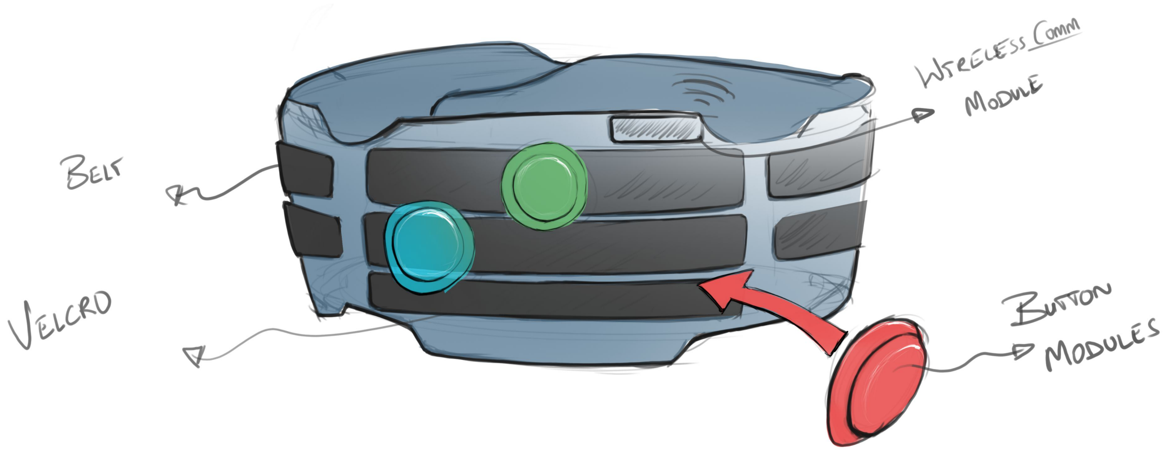
While user 3 liked to experience VR standing up, they also liked the freedom to choose their button layout for each game. User 1 also liked Django and would prefer it over foot-based controls to access VR games (non-racing) while having all the controls on the upper part of the body.

Mithril, on the other hand, showed many drawbacks ranging from being perceived as uncomfortable to wear to having buttons out of reach for some users.

Therefore, ultimately, I had to choose between Rockwell and Django. Both had their advantages and disadvantages, but there were a couple of factors that eventually led to a choice

VR is a very active way of interacting and experiencing games. User 1 (who uses a foot-based button) also pointed out that moving the foot frequently would cause fatigue.

Nearly all users pointed out that Django would be interesting and would prefer Django for a conventional (stand-up) VR-based experience.



Furthermore, both users 1 and 3, during the co-design session, discussed that although foot controls are a good solution to have an input, freely moving around in the real world and executing it while wearing a headset could be challenging.

Ultimately, the most logical concept to choose was “Django”.

However, Rockwell is, I think, a very effective way of making VR accessible to any user who is either wheelchair-bound or has similar impairments. Furthermore, the concept with some software-based solutions (in-game representation of foot pads, using motion capture for inputs, etc.) can still be a very effective solution to replace conventional controllers.

Technology Limitations

It is quite evident now that all three concepts mentioned before (including the Armbands) do not include some of the niche, experimental or latest technologies. And this is for quite a few reasons.

- As discussed earlier, some niche tech, like EMG sensors, were quite well suited for the device. But, with the Expert's advice, it was deemed too difficult to get used to and expensive to include.
- On the other hand, the design could easily implement something as mature as voice recognition. However, the users and the experts mentioned its lack of suitability for social-based gaming or interactive sessions.

Eye tracking also fails in the same way. Although relatively mature and already in use in current VR systems. It is, however, cannot replace all physical-based interactions.

These technologies are good enablers and enhance existing systems by making them more accurate. For example,

- The Apple Vision Pro uses hand movements and eye tracking to recognise where the user is looking and the object they are trying to interact with.
- Similarly, smartphone voice recognition allows users to carry out tasks efficiently and easily with digital assistants.

Furthermore, with the current restrictions (time and funding) of this project, it is also hard to test and verify these concepts effectively through lo-fi prototypes. Therefore, while implementation is possible, it cannot fill all the gaps or solve every problem. The implementation of these technologies in the concept has been avoided.

Conclusion and Key Takeaways - Concept and Ideation

In conclusion, Rockwell and Django received the most positive feedback from users. Reasonings vary, but both seemed to be well suited for the job. Django, however, proved to be quite well-suited for a stand-up VR experience.

However, both expert and user one individually mentioned concerns about Django. The expert emphasised the need to test and verify the button layouts and interaction while in a VR environment to ensure that the layout mapping does not end up in uninterrupted game interactions; for example, a gesture involving moving the arms clockwise could be linked to an action however, through the course of the VR experience Users might accidentally perform the gesture inadvertently executing an action that they didn’t intend to make.

During the co-design sessions, all users used novel and modern tech (speech recognition/voice control, eye tracking) to build their controllers. However, Every user, given enough time, realised that over-utilizing this tech could lead to unintentional consequences.

Key Takeaways

- If users have the opportunity, they physically can, and then they will choose to experience VR the conventional way if they can.
- Every user was open to trying Rockwell (foot pad) as well, and it could be an interesting research mode for future work.
- Speech recognition and eye tracking tech can not be the sole mode of interacting with VR environments.

Chapter 7

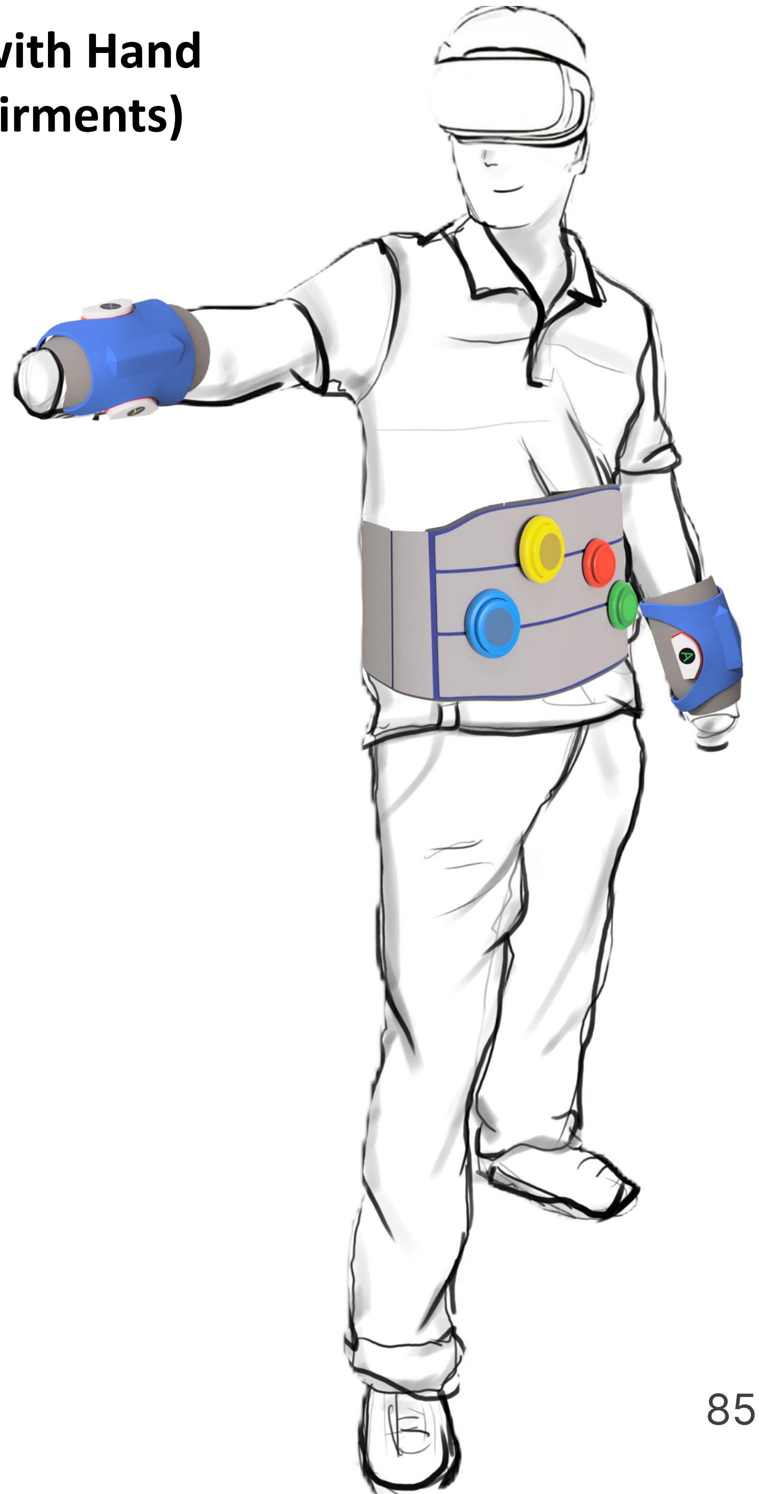
Final Design

In this chapter, the culmination of the design process is presented in the form of the final VR controller. The chapter will provide a detailed overview of the final design, including its features, functionality, and how it meets the specific needs of users with hand impairments. The chapter will also discuss how the final design was validated through testing and user feedback, demonstrating its effectiveness in providing an accessible and immersive VR experience.

Django
VR Controller

A VR controller for Gamers with Hand amputation (and other impairments)

Figure 7.1: Django VR controller.



Belt

A combination of cloth and polymer, the belt consists of layers of soft foam and polymer while also housing the Velcro layer (loop side/soft side) on the outer layer of the belt. This component of the VR controller does not have a any electronic modules within (unlike the concept). The belts sole purpose therefore is to provide users additional space for the button modules and a way to keep them in place once positioned.

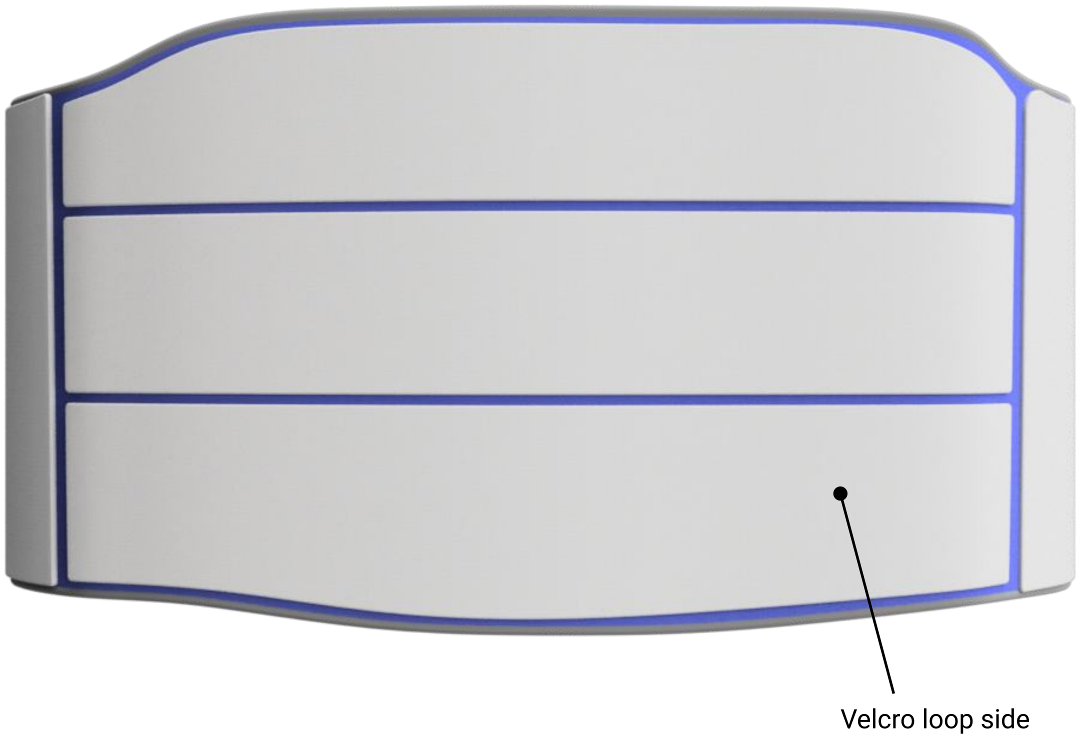


Figure 7.2: Django Belt with Velcro on the front.

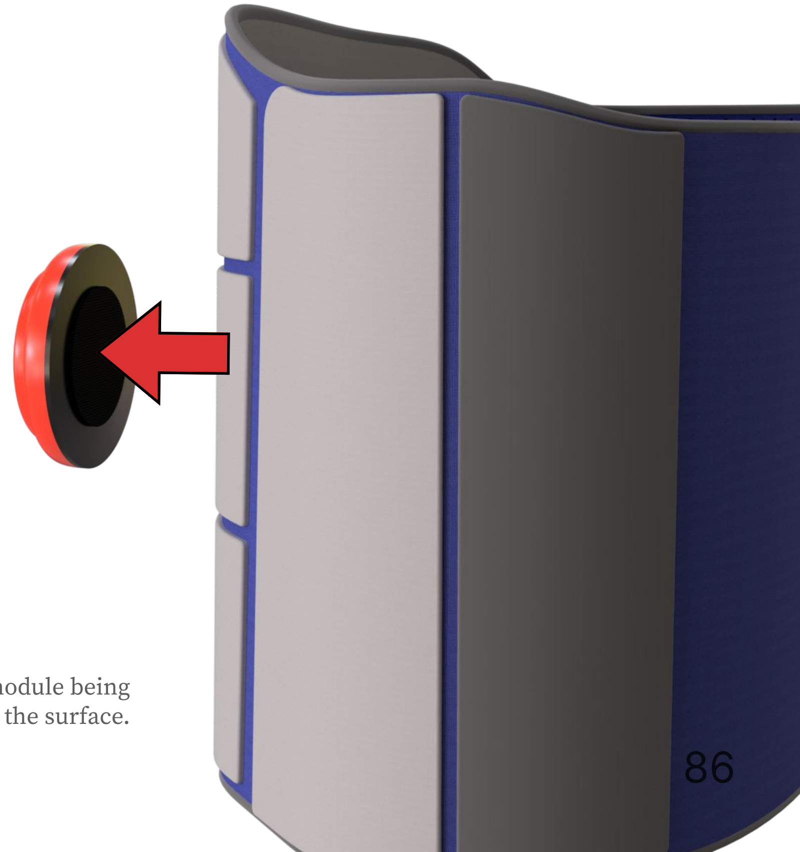


Figure 7.3: A button module being removed from the surface.

Button Module

The button modules are plastic-encased switches that are very similar to conventional buttons available on the market today. The buttons also house the Battery and the Wireless communications module. Doing so helps the switches/buttons communicate directly to the VR headset.

The Button modules effectively replace the primary trigger, the secondary trigger and the joystick on the conventional VR controllers (figure 7.4).

The modules come in two sizes: a small diameter of 6 cm and a Large diameter of 8 cm (figure 7.5). Each module has a Velcro patch (figure 7.6) on the back (hook side of the Velcro). This allows the module to adhere to the belt. Every module can be custom-mapped to the user's desired mapping scheme.

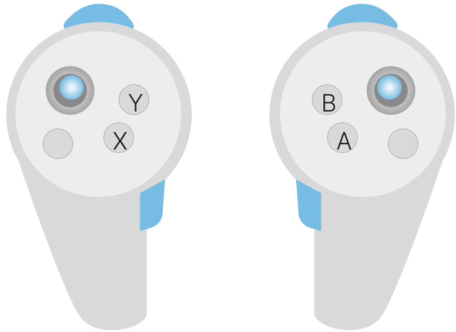


Figure 7.4: VR buttons being replaced by the buttons.

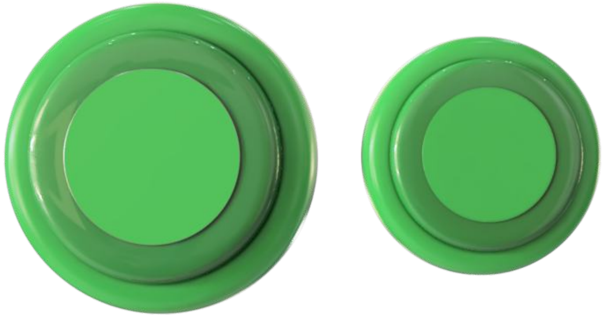


Figure 7.5: Modules come in two sizes Large, 8 cm and small, 6 cm.

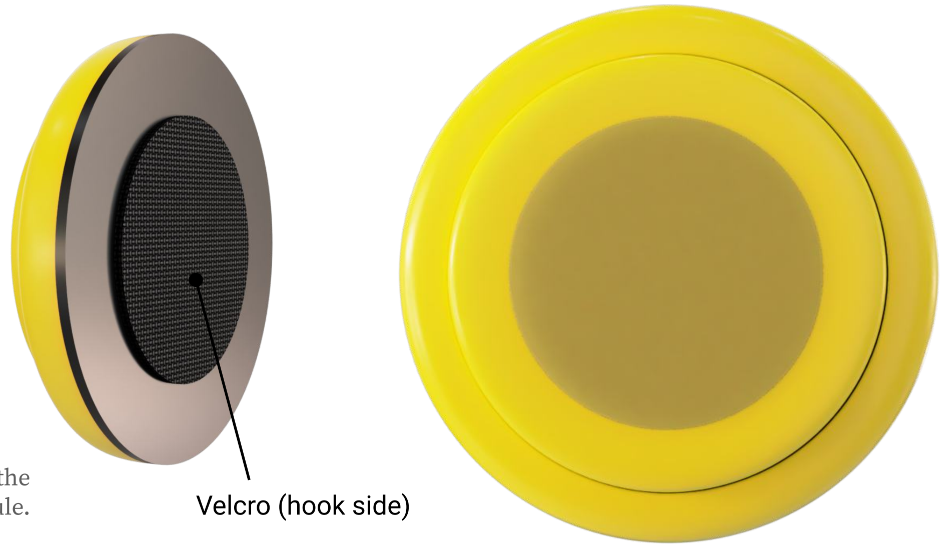


Figure 7.6: Velcro on the back of each module.

Arm Bands

The Armbands are comprised of 3 main sub-components. The silicone outer cover, the inner fabric lining, and the button module house the action buttons (XYAB) (figure 7.6). Each armband has its own set of motion capture sensors (gyroscope, accelerometer, etc.) (figure 7.7). Allowing the armbands to accurately translate the user's real-life movements into the virtual world.

The inner fabric lining is made up of breathable fabric (figure 7.8) material that ensures comfort for the users wearing the armband for prolonged periods of time.

The Button module is a simple module that has tactile feedback. Users can actuate the button by either pressing it against any part of their bodies or by using the Rubber pad (a part of the silicone casing) to hit the buttons.

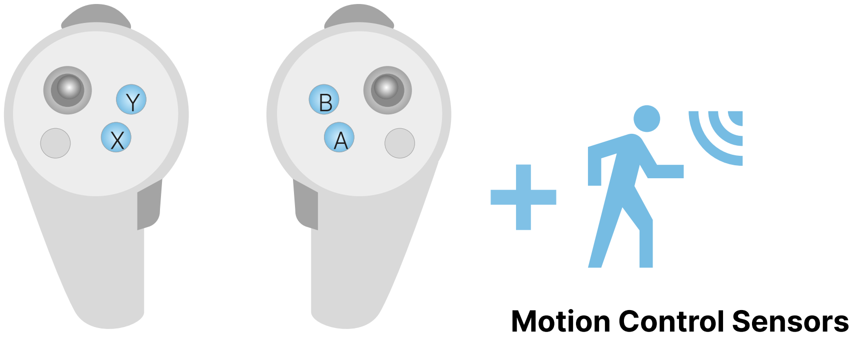


Figure 7.8: VR systems being used both while standing up and sitting down (Chillingworth, 2024).

Action Buttons

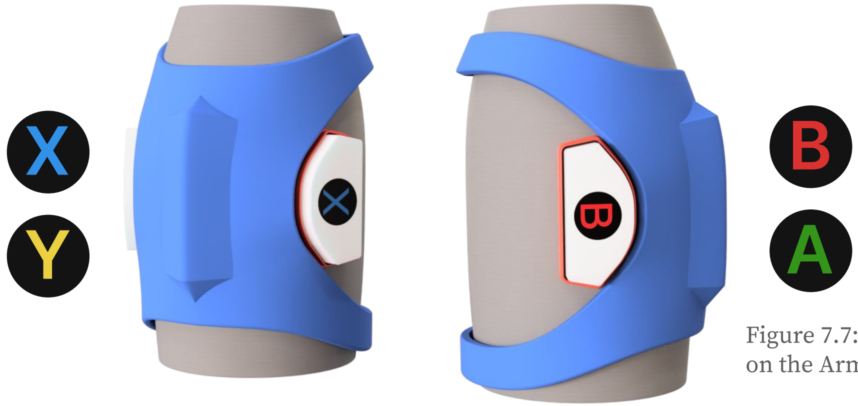


Figure 7.7: Action buttons on the Arm bands

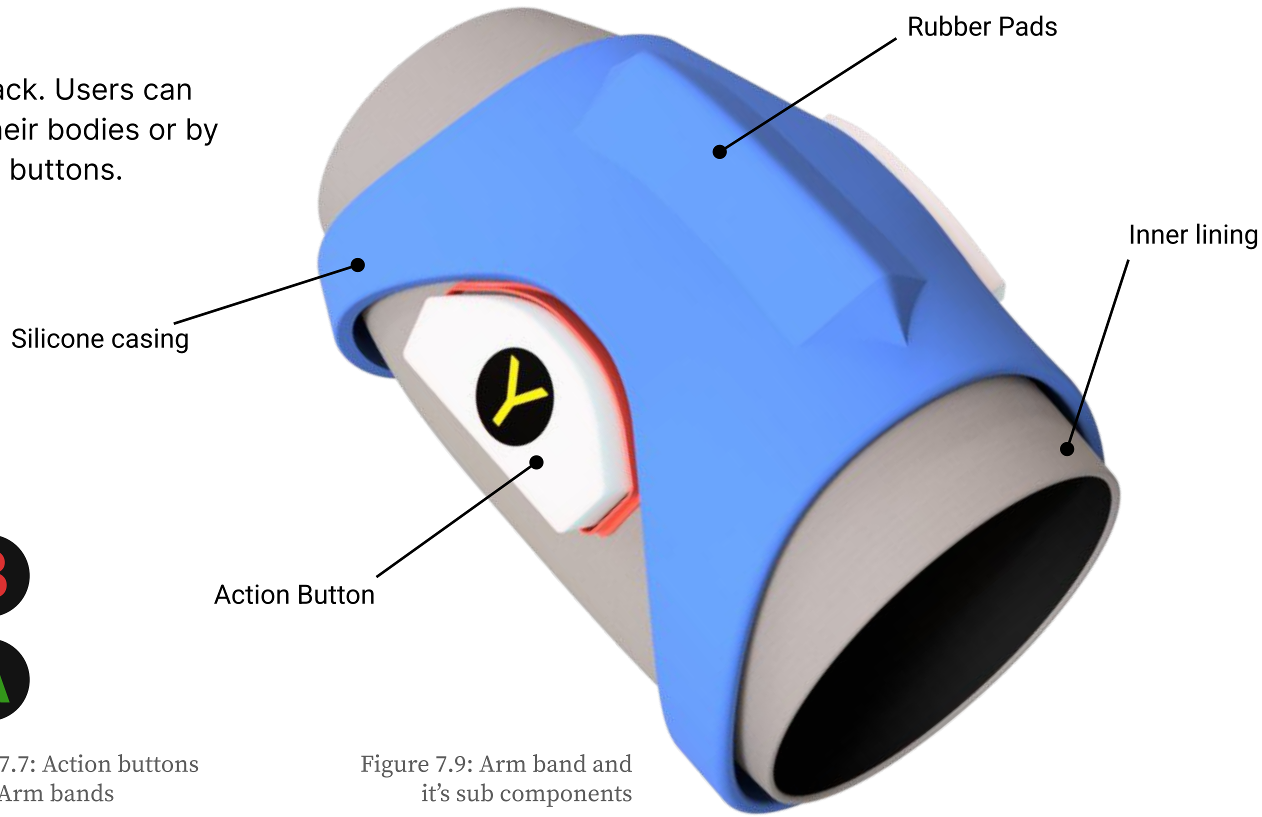
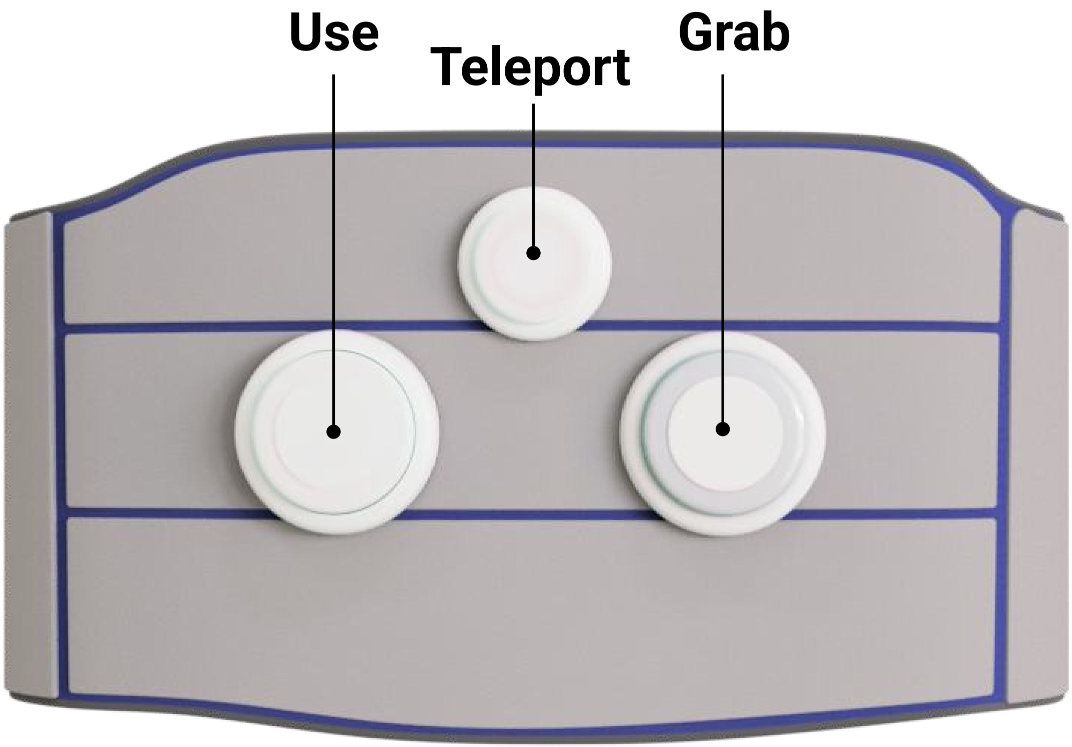
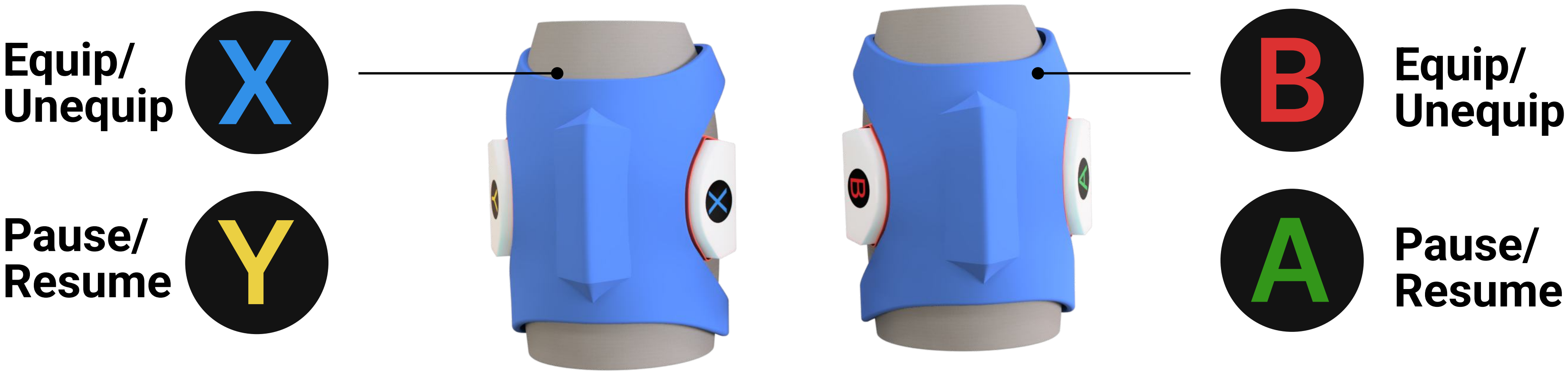
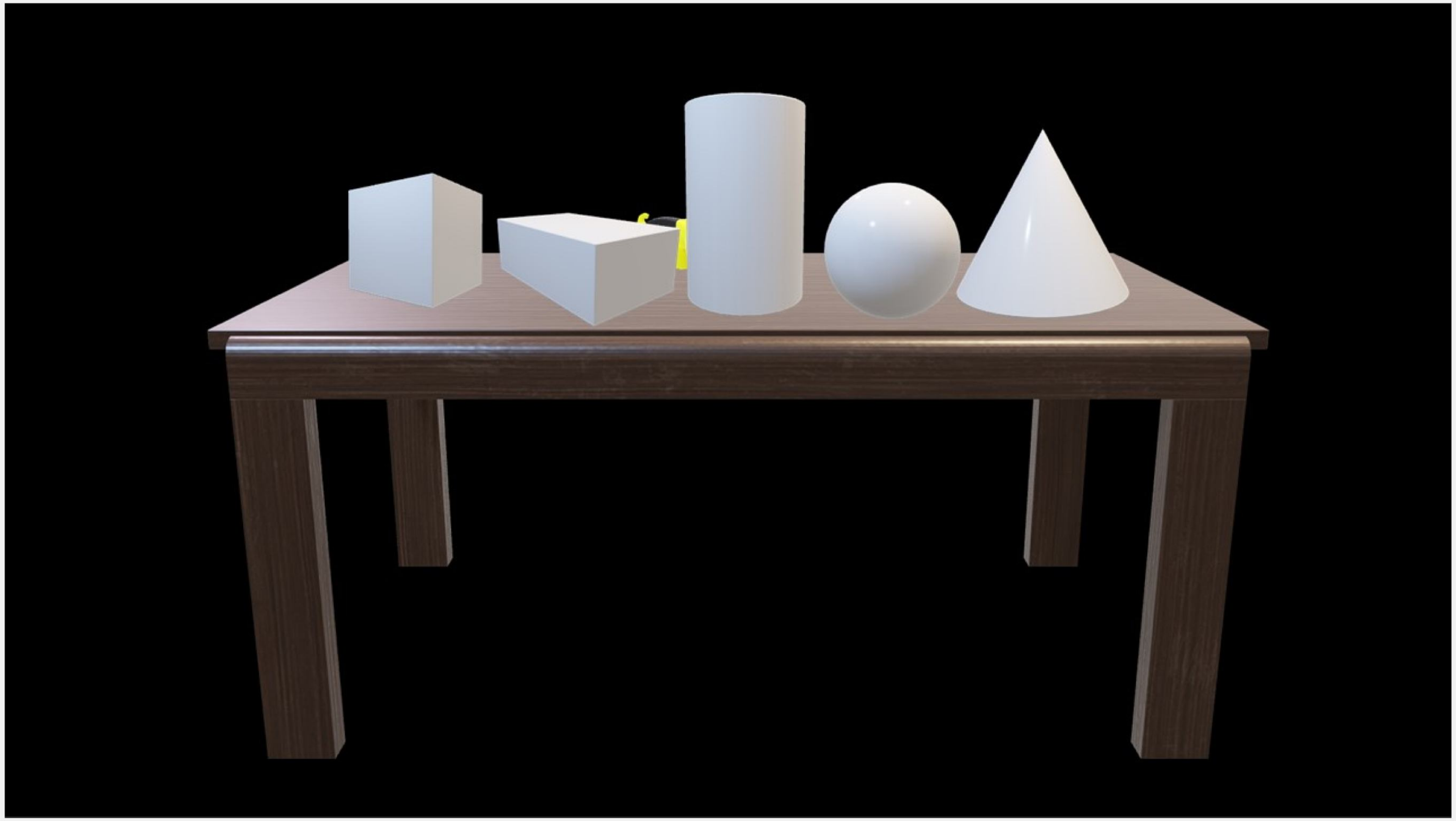


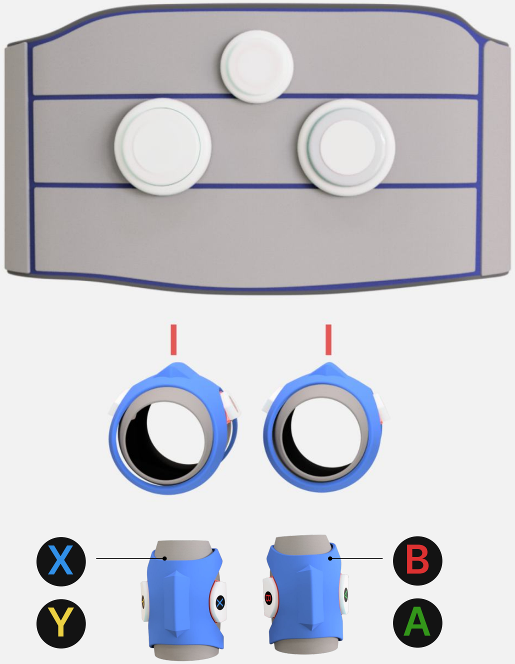
Figure 7.9: Arm band and it's sub components

How do we use it?





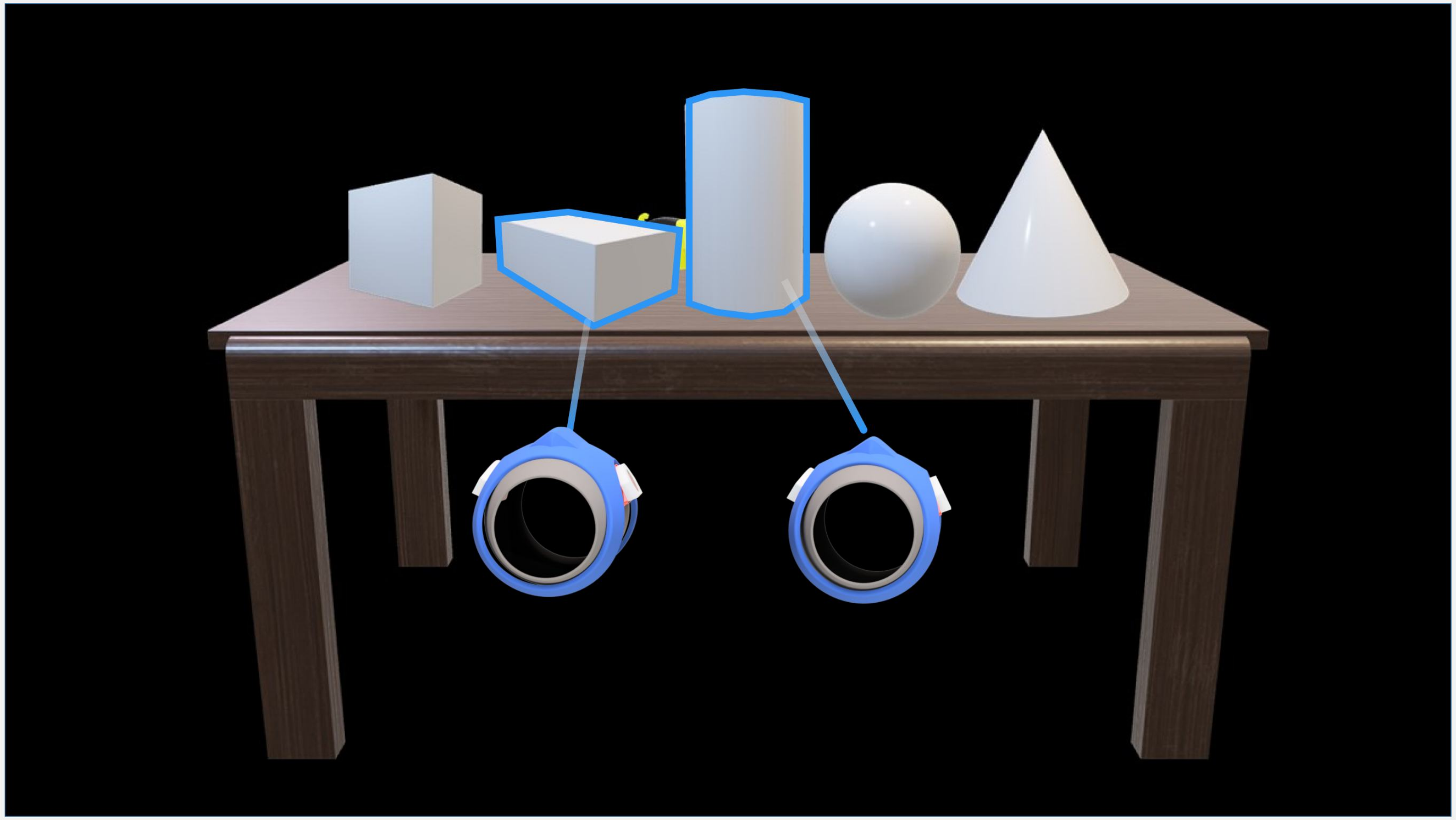


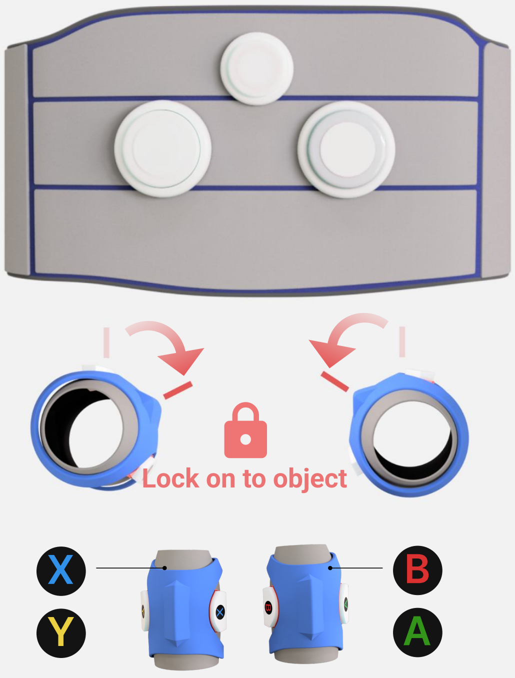


Input mechanisms actuated

The Scene

A table with a bunch of random 3D objects on the table. Users need to grab and move the objects out of the way to fully uncover the torch.

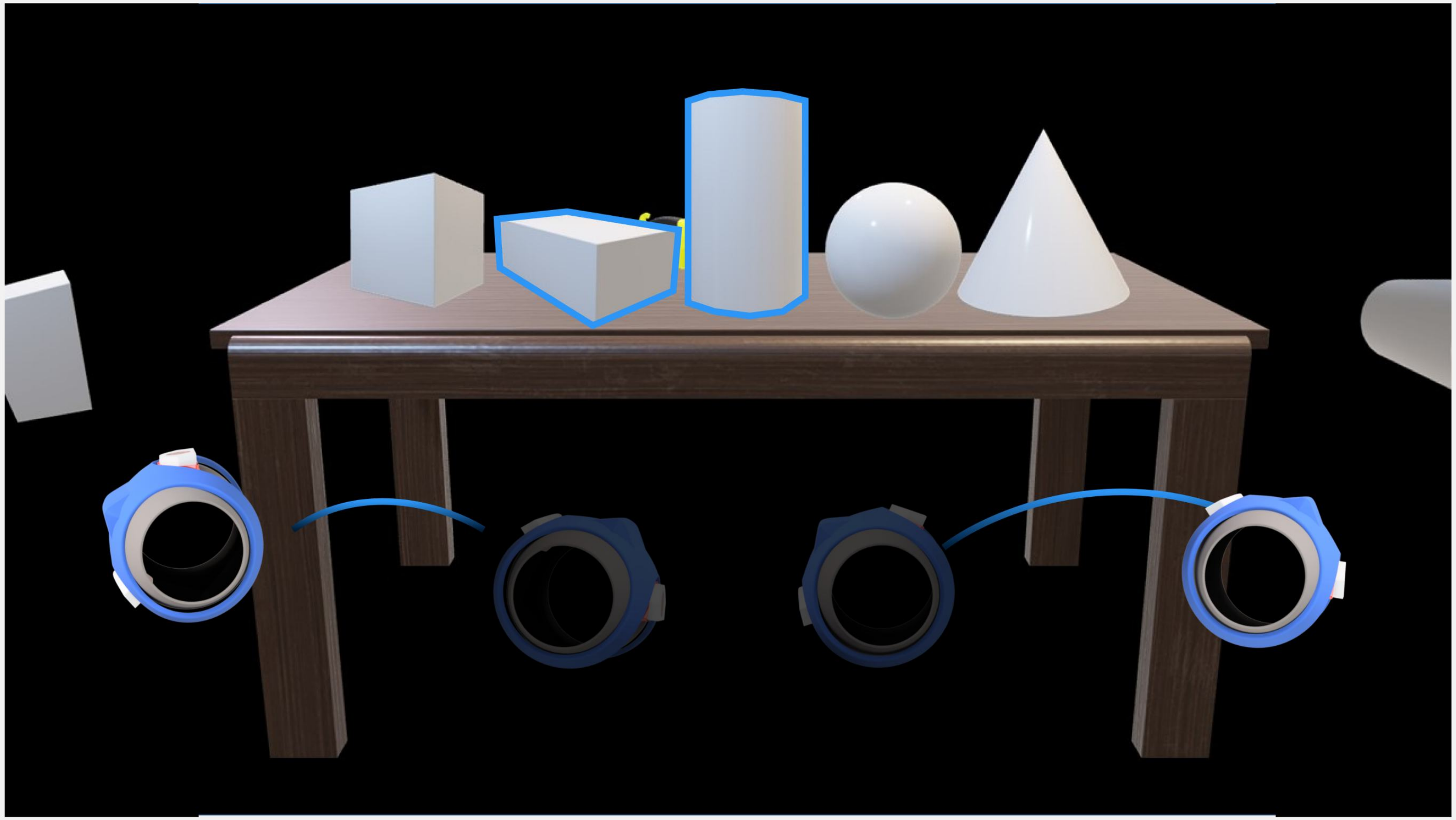


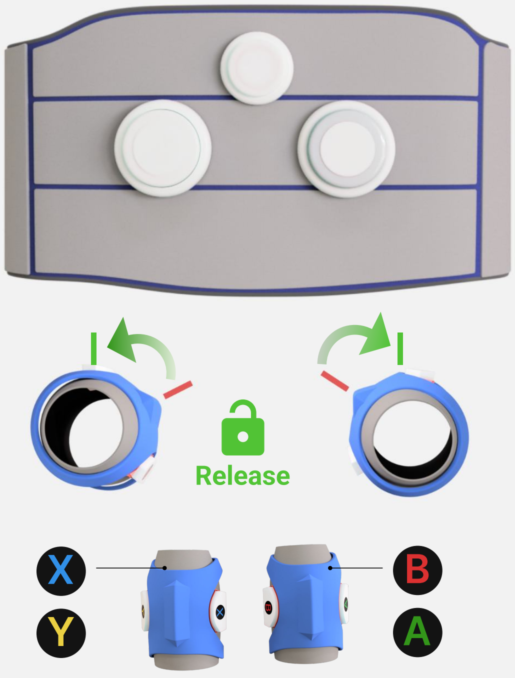


Input mechanisms actuated

Grabbing two objects simultaneously

Use the grab gesture to lock on to objects.

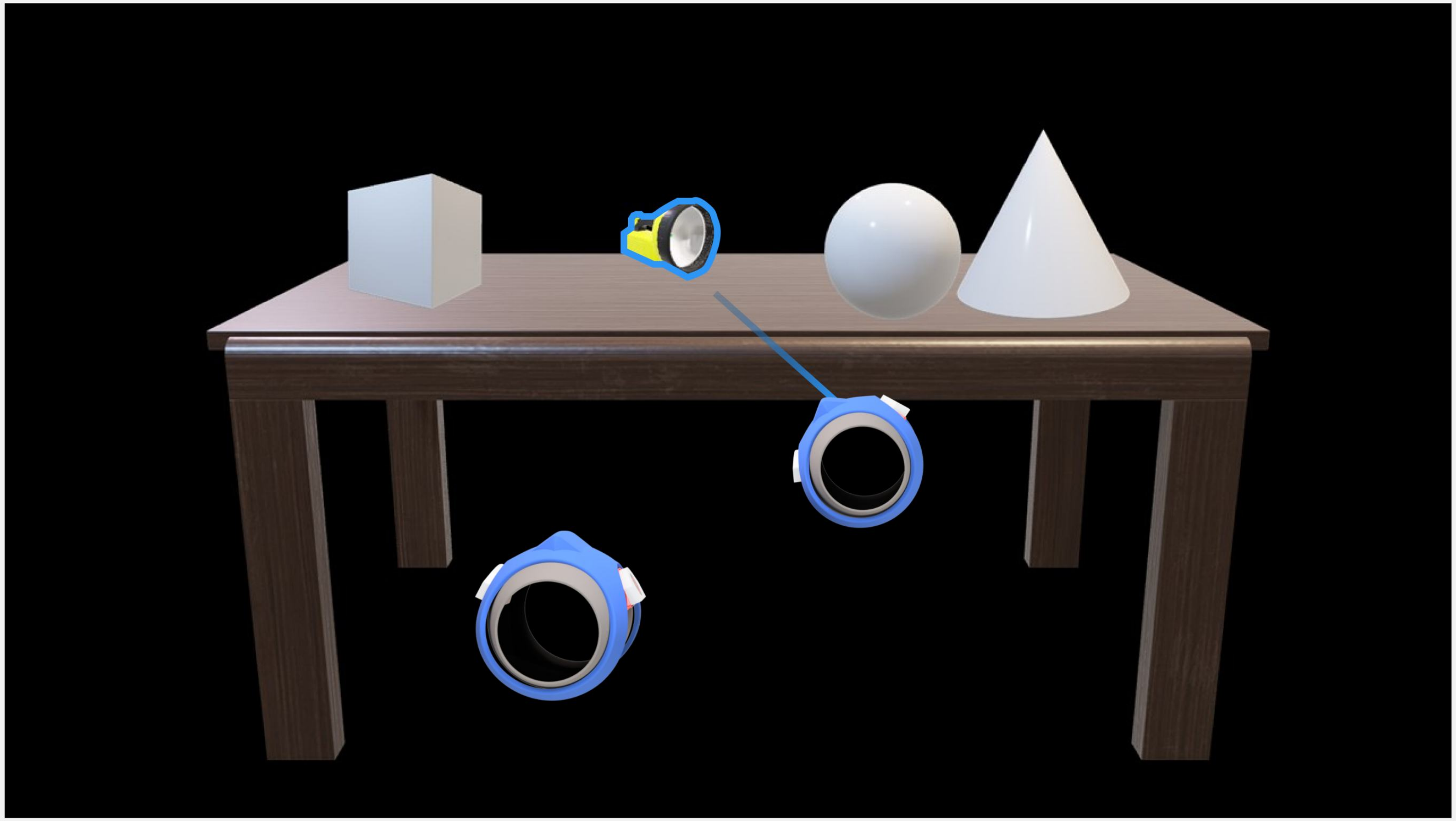


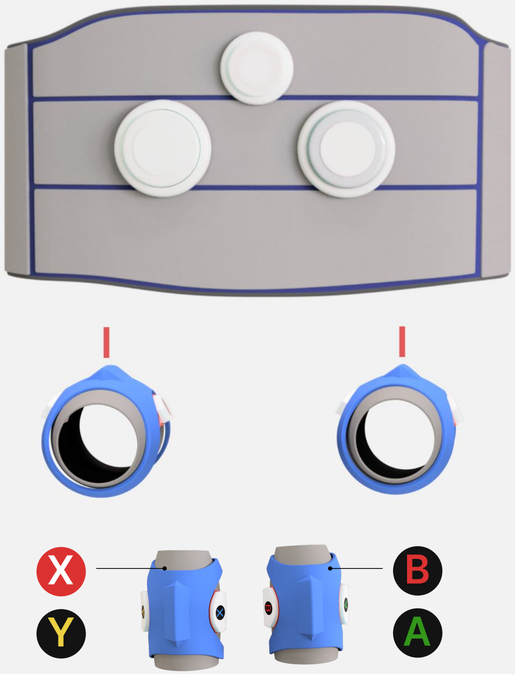


Input mechanisms actuated

Moving two objects simultaneously

Once locked on to the object, users can then manipulate and move from it's initial position by physically moving their hands. All while maintaining the grab position.

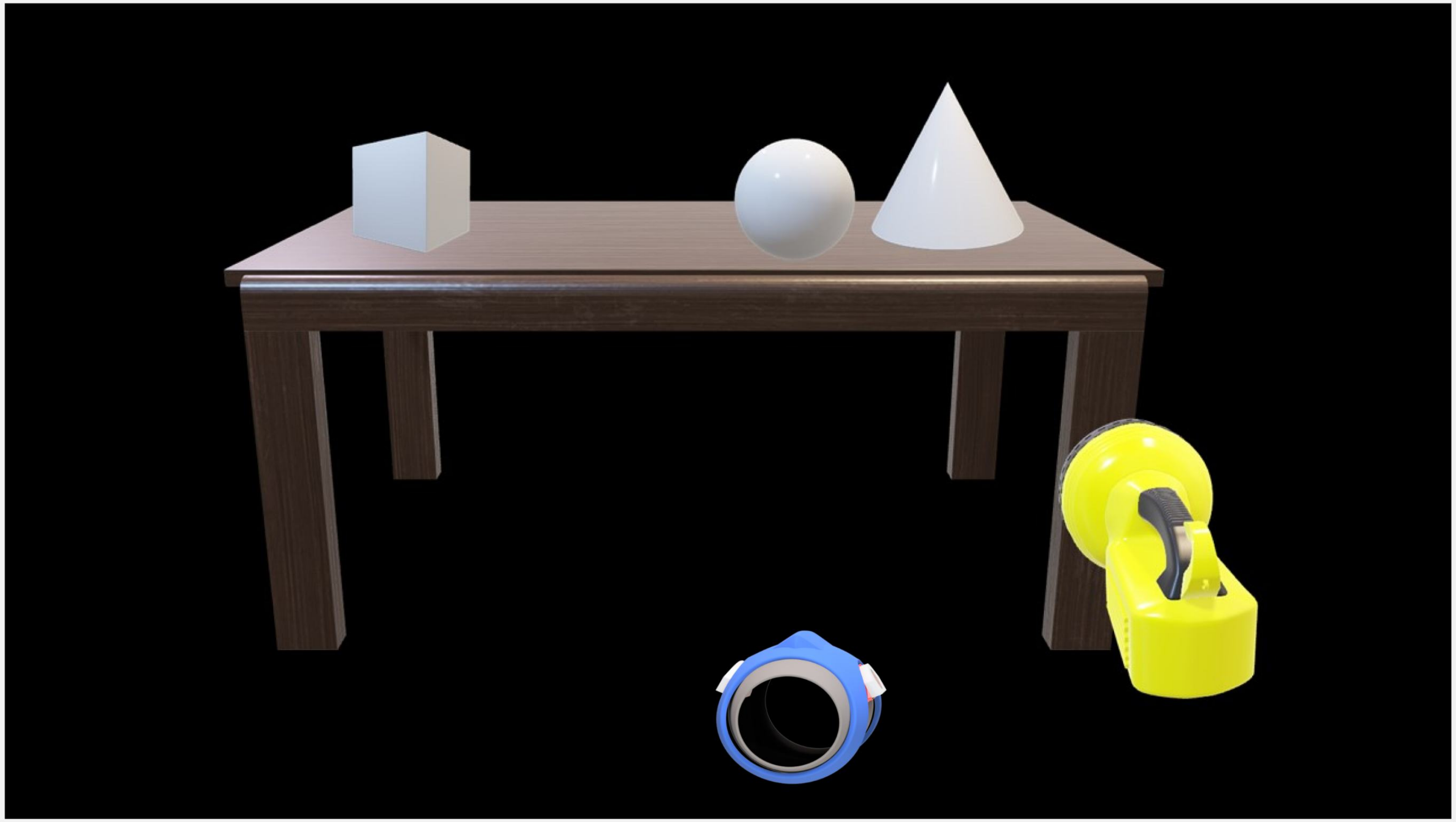


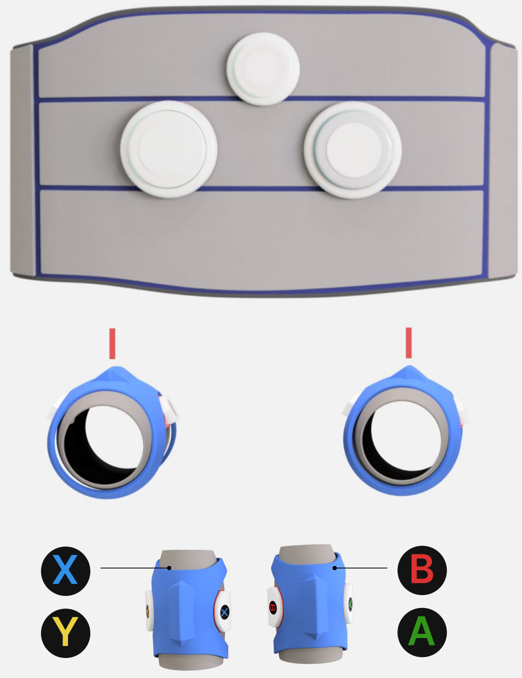


Input mechanisms actuated

Equipping a tool

Equipping or holding an object is executed differently with each game/application. Some application just ask the users to select the object by aiming and pressing the select button while others require users to press the grab button (as shown here) and combine it with a physical motion. Both work and its implementation depends on the user, game and the developer. In this case we press the Equip/Unequip button the Arm bands.

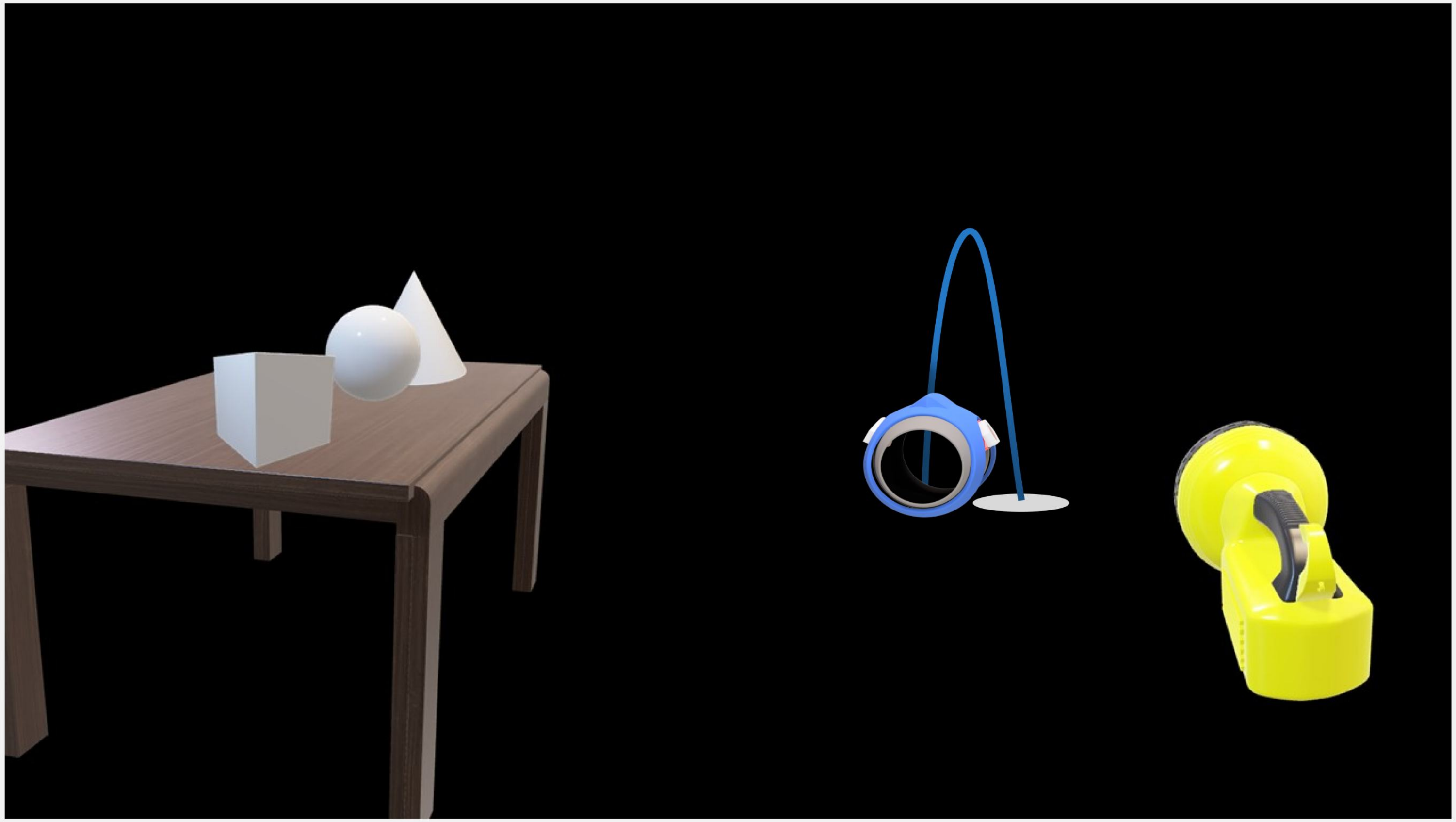


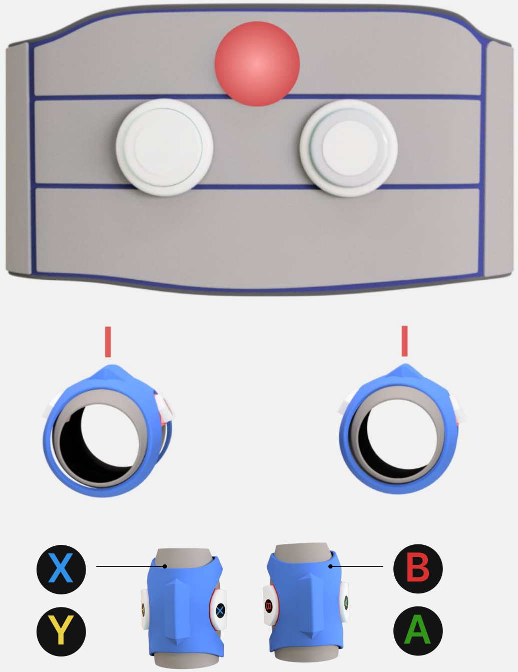


Input mechanisms actuated

Object Equipped

In this case while the right arm is equipped with the object, the left arm is free to manipulate and move around in the environment.

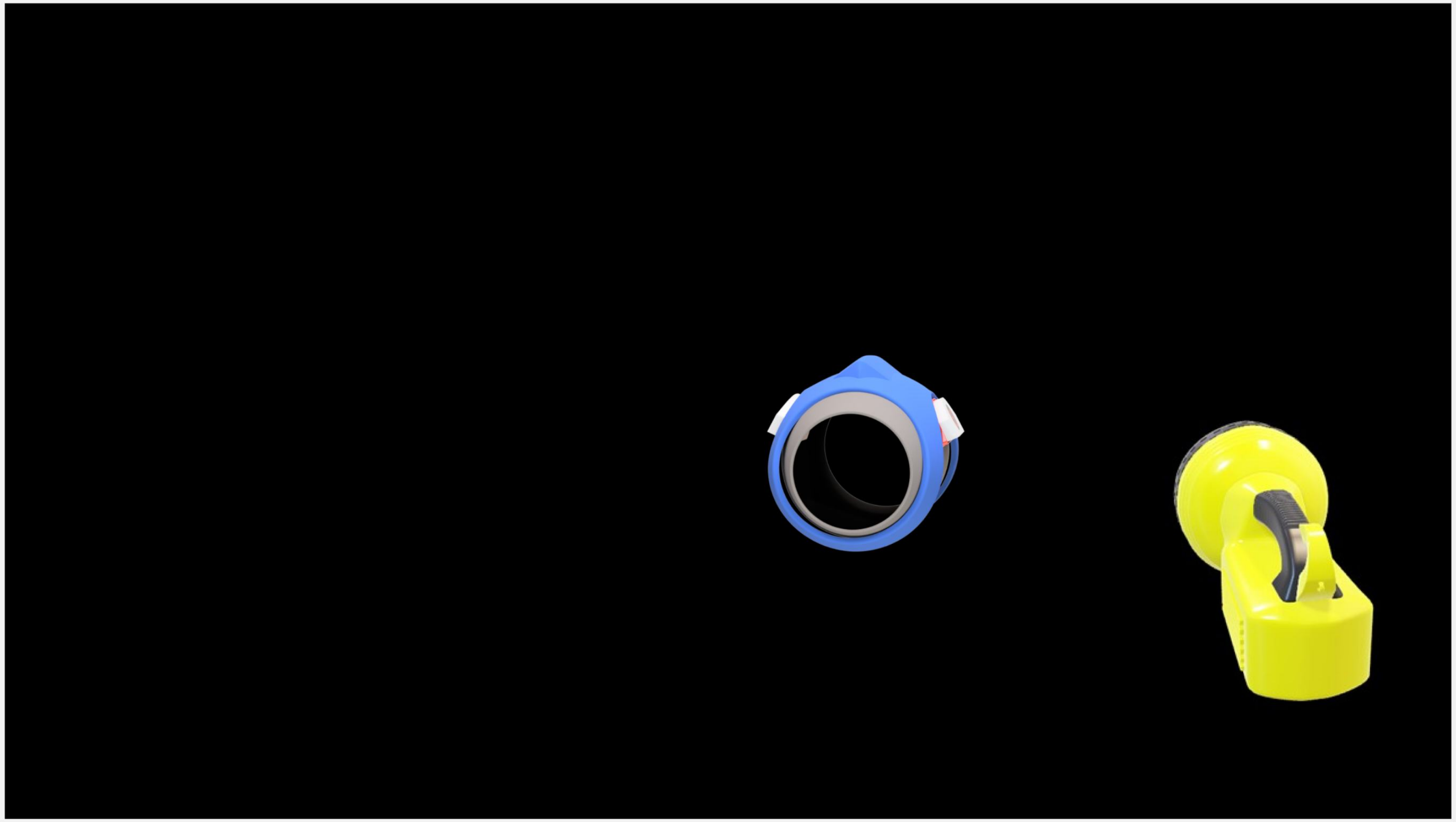


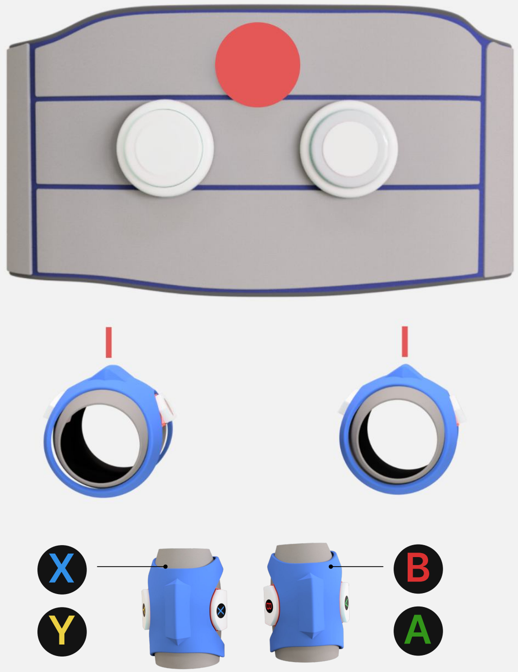


Input mechanisms actuated

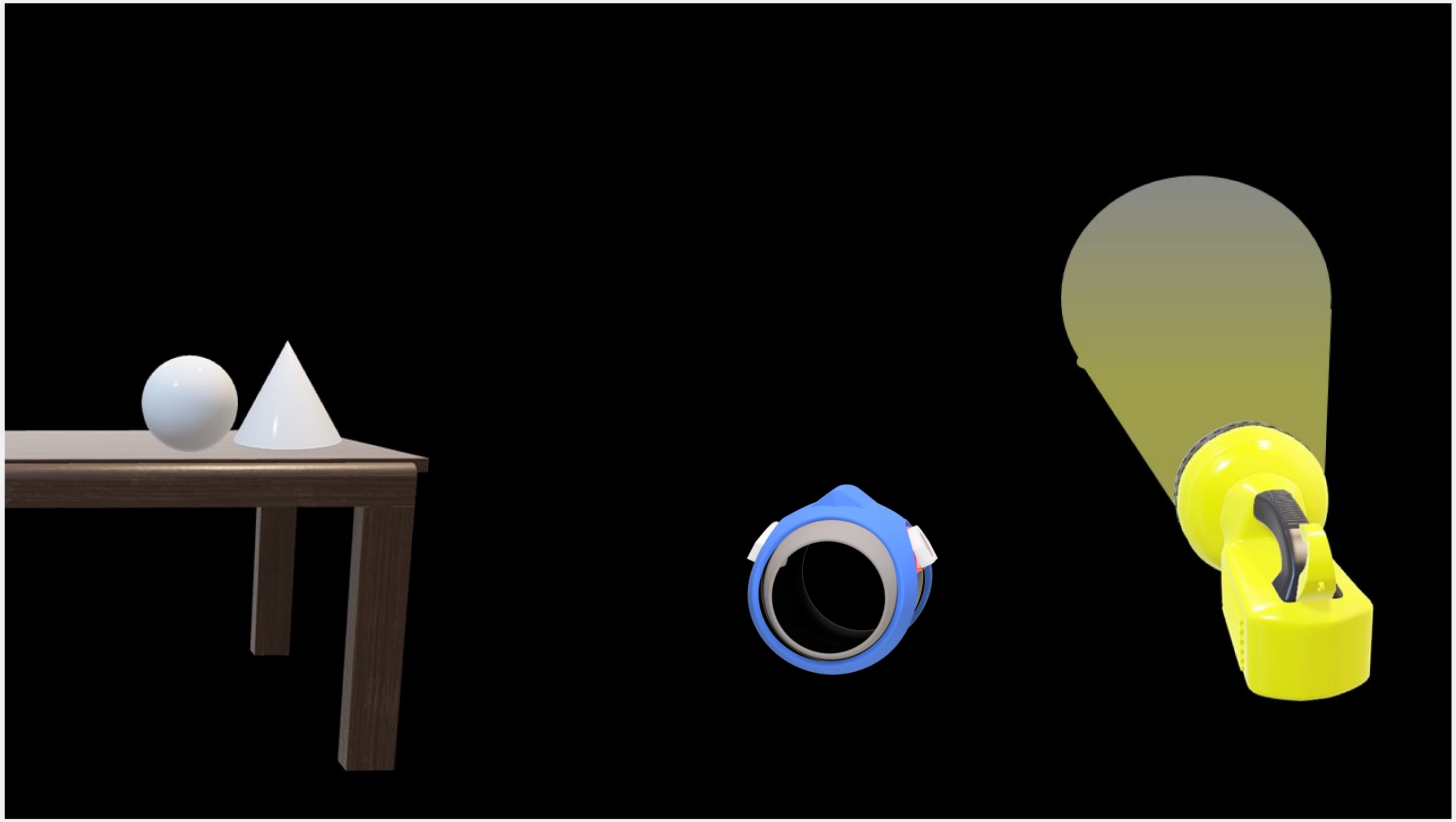
Teleportation

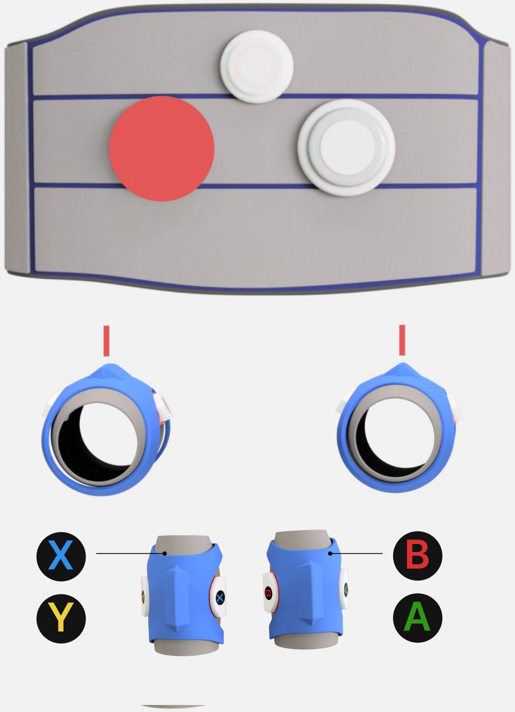
Moving around using Django is quite simple, point to the location you want to teleport to with your unequipped hand and and press the teleport button using the other arm.





Input mechanisms actuated

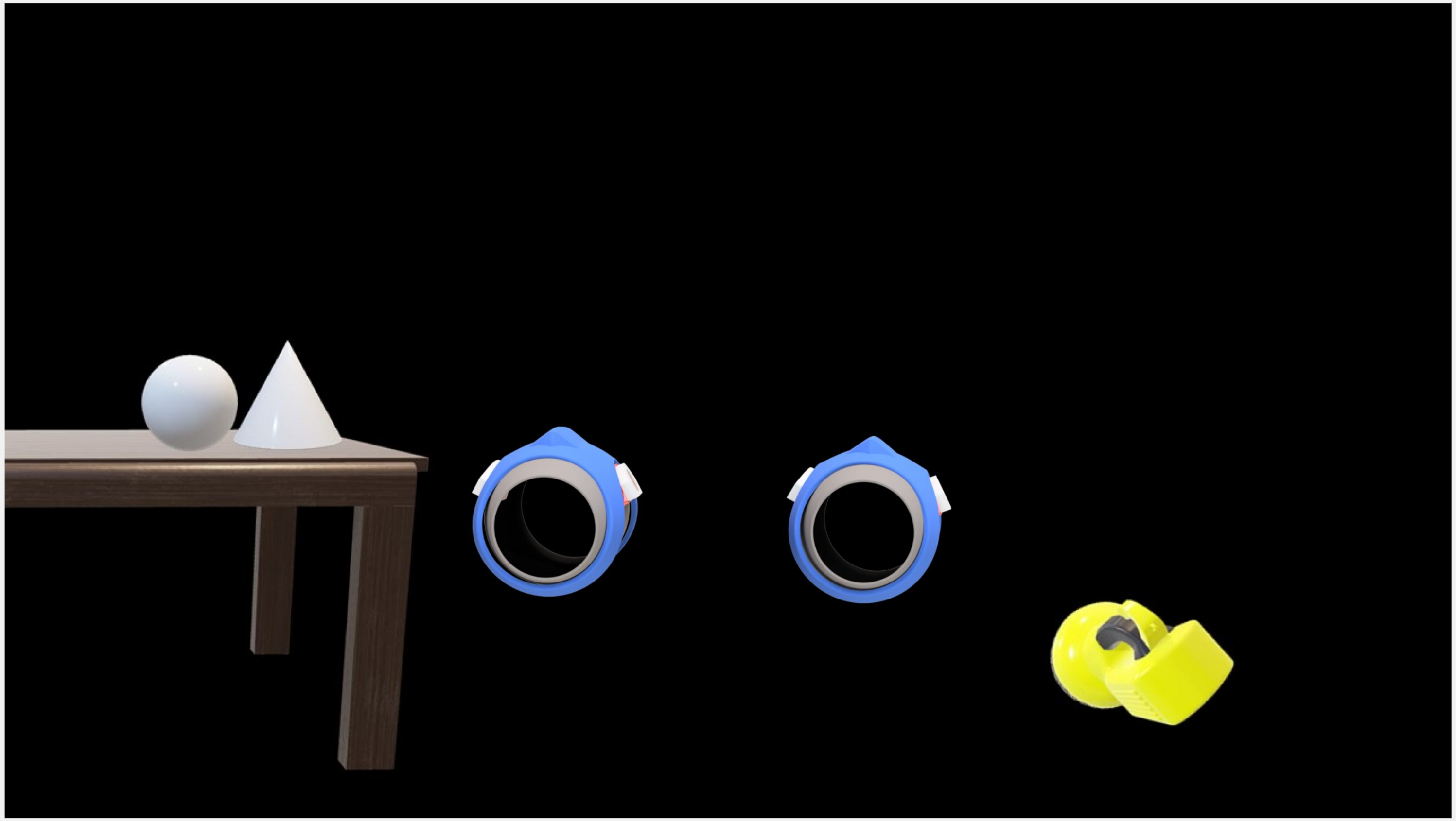


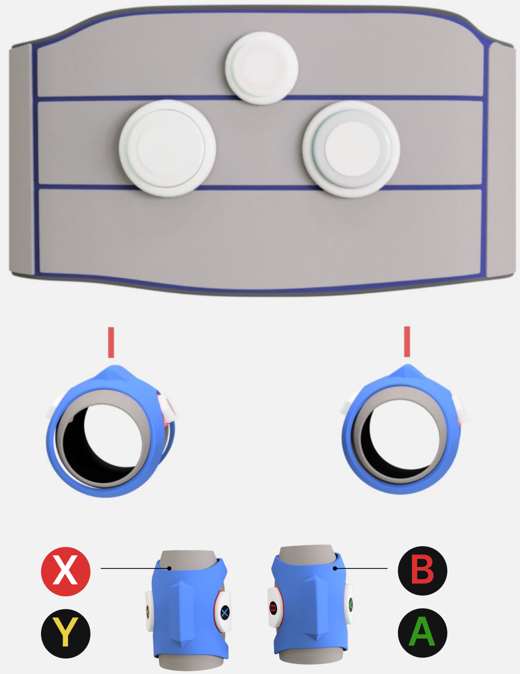


Input mechanisms actuated

Use an equipped tool

Users need to aim and hold the Use button with the unequipped arm.

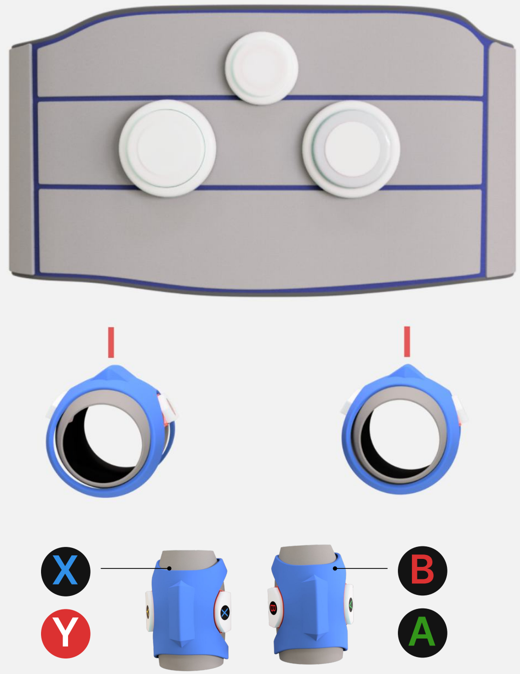




Input mechanisms actuated

Unequip

This interaction depends on the software and the game. But in most cases one of the action buttons XYAB are used to unequip the object in hand/arm. In this case users can again press the equip/unequip button on the arm bands.



Input mechanisms actuated

Pause Game

In case of the arm bands the other two action buttons are used to Pause/Resume your experience.

Button layout and possibilities

In the final design, users have full freedom to add more buttons to the controller; we have taken two scenarios/layouts of button maps and layouts in this project, and a user testing scenario. gives the users a clear option between a complex button layout with fewer buttons or a simple button layout with more buttons (in this case, five).

Three Button Layout: A complex button mapping but simple layout. Having one for each (Use, Grab, Locomote/Teleport). The Three-button configuration is a simple layout, but it restricts each arm's reach to all three buttons (depending on its position). If all three buttons are positioned on the right side of the body, the user would have trouble reaching them with the left arm, making it a one-handed operation. However, are the buttons uniformly positioned in the centre (Figure 7.9)? Then, each arm would have trouble reaching the buttons on the far side of each other.

Five Button Layout: A simple button mapping but complex layout. With Five Buttons, users are dealing with many more buttons than before. The same area (the belt) now has two more buttons. While this might not seem like a lot, users are technically blind to their environments (due to the VR Headset). Which might make it significantly harder to find the right buttons. On the other hand, with more buttons, each arm gets its own pair of Use and Grabs buttons. Furthermore, with the right button mapping, users could even choose to invert the button mapping (the right pair of Use & grab controls the left arm, and the left pair of Use/Grab controls the right arm).

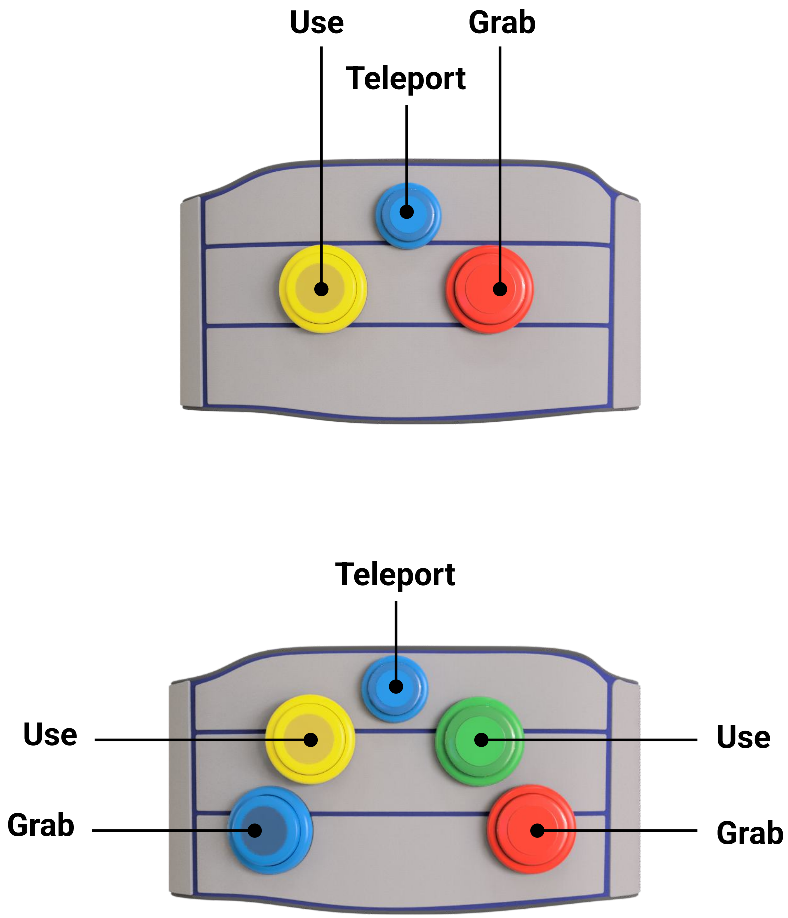


Figure 7.10: Three button layout (top) and Five button layout (bottom).

User Testing

Aim

User testing aims to test out and verify key concepts of the product's final design. In the end, I wanted to understand:

1. Does this input mode, regarding position and feedback, help users interact in a VR environment?
2. Does the Button layout impact the user's performance while wearing a VR headset?
3. Do users prefer gesture-based interactions or conventional button-based inputs?
4. How well can the users perform with and without the headset?
5. What kind of button positions do users prefer on the armband? do they want the action buttons closer to each other or farther away?
6. Do users have a preference for a button layout?
7. Do users find the Armband and the rubber pad useful while pressing the buttons?
8. How does the severity of the impairment affect the user's preference for button layouts, location and Button sizes?

Users

Total no of Participants **Male: Female**

In an ideal scenario, users with Hand impairments would have tested the prototype. However, due to the nature of the project and some logistics and resources (Travel and transportation, Funding, and time), it took a lot of work to test it with users with hand impairments. According to the expert, In most cases, users with hand amputees and their ability to move around do not differ from a general user. Therefore, volunteers (students) from the faculty were chosen to test the prototype for final user testing. Since all users had no impairment, they were requested to wear socks on their hands to prevent them from accessing and using the prototype with their hands and fingers.

Taking this approach, however, is that the results, in the end, could give us much information about the new interaction framework and how cohesively they work with the controller without using any hands. However, it does not provide us (with absolute certainty) whether the controller and the interactions work for users with hand impairments. For example, while an abled user might find the smaller button module easy to use, users with impairments might need help to reach, press, or actively hit/actuate on the belt due to their small size. Therefore, the user testing will only be able to give us some of the information we are looking for, but what it can provide can be used as a stepping stone for future work.

Procedure

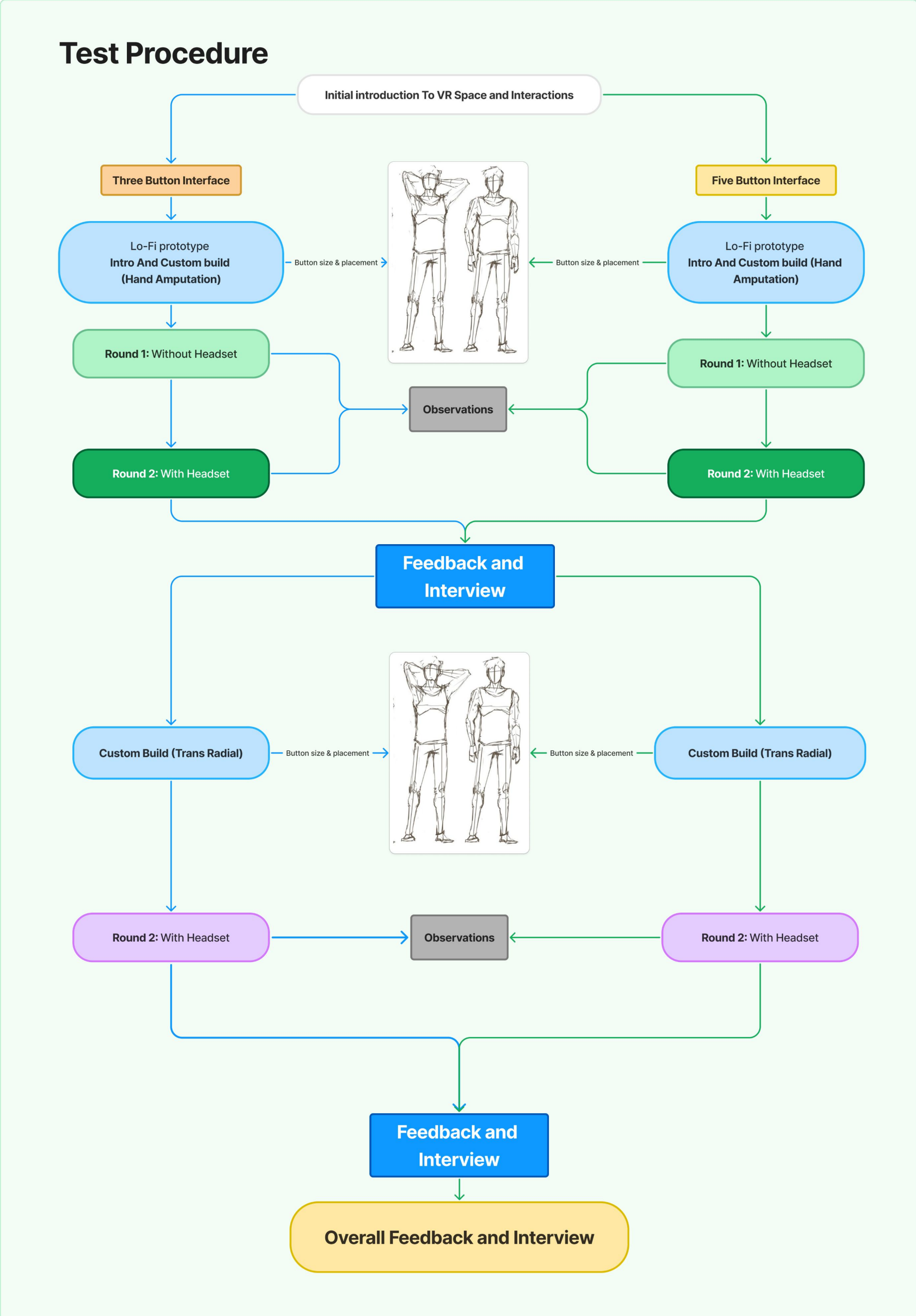


Figure 7.11: Prototype user testing procedure.

Activity 1: Practice Session

Duration: 10 mins

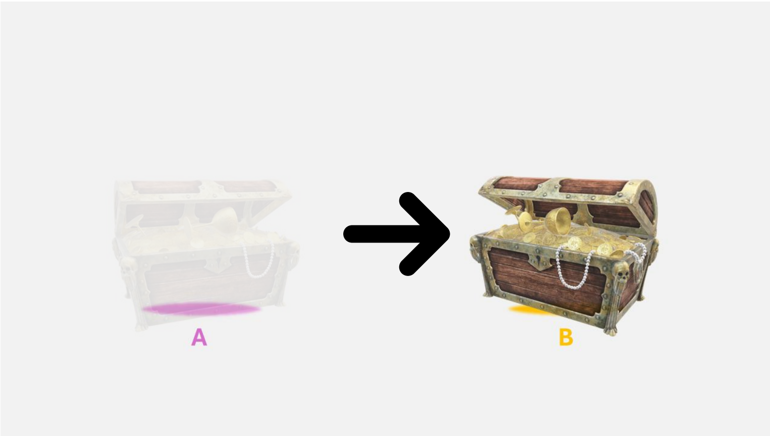
Mode: Without VR

The users are introduced to the product, and they will test the layout. They are also briefed on the Device's function and guided on how to use it. After the brief introduction, Users can wear the Belt and Choose the Buttons (Small or Big) and their position on the belt. The buttons are then stuck to the belt using Velcro.
The initial stage of the User testing was all about getting used to the device and verifying the layouts and the comfort of those layouts. For this, a TV display prompted the users to complete different tasks. Users were then asked to execute the tasks on the screen. The entire test (including activity 2) was conducted using a Wizard of Oz approach, using Powerpoint.

Why this activity?

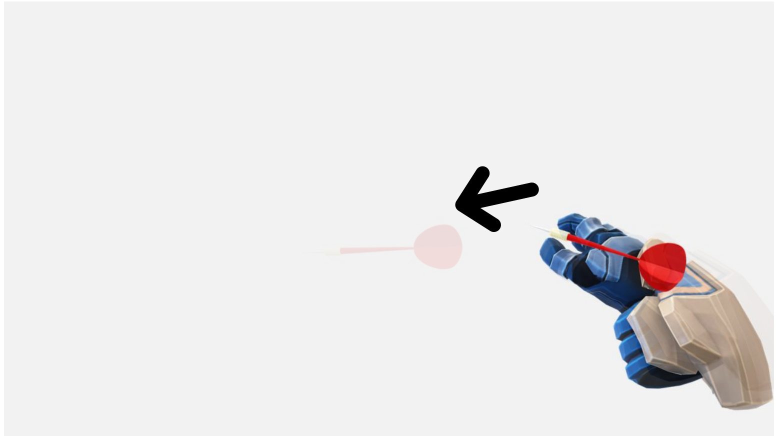
The practice session was designed to allow the user to interact and use the product to execute all the basic interactions of the framework. In the end, users should have a good idea of how to use the device and their preference for button layouts on the belt. If found uncomfortable, users then had the opportunity to change the positions of the buttons on the belt for a more comfortable one before moving to the next stage of the user testing.

Example of tasks and prompts:



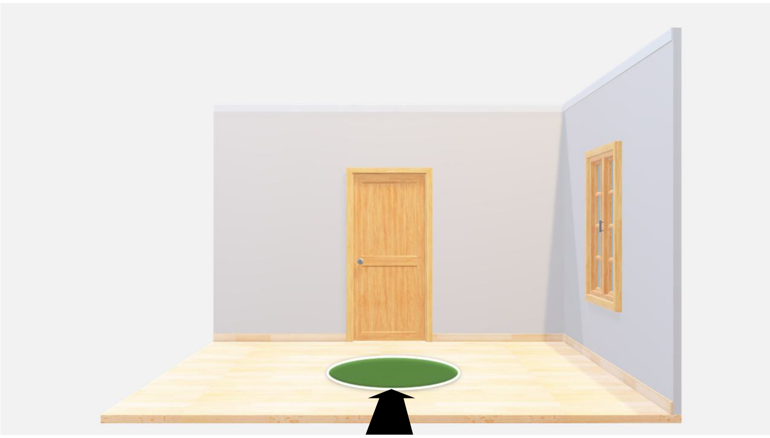
To test moving a single object

Prompt: Move the object from position A to B



To test Equip & Use

Prompt: Pick up the Pickaxe tool and use it to mine the Ore



To test Locomotion

Prompt: Move to the location (highlighted) in Green

To Move two simultaneous objects

Prompt: Help the Person and the Dog: Move them close to each other together.

Activity 2: Interaction Framework (Torch Scenario)

Duration: 20 mins

Mode: Without VR Headset

Users should now have a button layout that they are comfortable with. Unlike in previous activities, users will not be assisted during any part of the activity. I would, therefore, observe their performance (successful task completion), their behaviour, and the audio and visual cues for discomfort or annoyance and adaptation to the device.

Why this activity?

As discussed earlier, the “Find the torch” scenario is used here for the activity. The activity covers all types of interaction discussed at least once. This allows me to observe and discover flaws within the products (Belt and Arm Bands), Layouts (three and 5 Button layouts), and Hardware (Size of the buttons). And to answer the key research questions mentioned below:

1. How well can users adapt to new hardware and layouts and perform the tasks?
2. Does the interaction framework have any flaws?
3. Are the users confident in using the device? (Through Questionnaire/Interview)

Action to be conducted

1. Grabbing & Moving two objects simultaneously
2. Equipping a tool
3. Locomotion
4. Teleportation
5. Use an equipped tool
6. Unequip
7. Pause Game

Activity 3: Interacting in a Scenario in VR

Duration: 20 mins

Mode: With VR Headset

Hardware: Quest 3 - Headset and VR controller(tracking only)

Application: Rec-Room

Users would've used the prototype twice by now, executing all possible interactions. Users are now moving on to the next stage and executing tasks while wearing a VR headset. Users wear the headset and are placed in a Virtual environment. Users also wear the VR and controllers but do not use the controller in any way during the activity. The VR controllers help users visually represent their hands, which could help them navigate their arms more accurately. Without this, users are essentially blind to their environment and their movements.

Why this activity?

During these activities, users react and perform tasks on objects in a virtual world that do not interact with the user. The whole point of the activity is to understand how well the user can use the device to accomplish and execute tasks and to answer the key research questions mentioned below:

- Does this input mode, regarding position and feedback, help users interact in a VR environment?
- Does the design have any flaws?
- Does the Button layout impact the user's performance while wearing a VR headset?
- Do users prefer gesture-based interactions or conventional button-based inputs?
- How well can the users perform with and without the headset?

About the environment

There are two scenes (one for a Three-button layout and the other for a five-button layout). Both scenes are held in the same Virtual room. Users then execute tasks that cover all the interactions in a random order within the environment. The prompts cover all the basic interactions at least once.

Figure 7.12: Rec room living room.

Scene – 1 (Table)

For the first scene, users are placed in a room. Much of the activity occurs in front of a table within the room (figure 7.12). On the tabletop are various objects, water bottles, darts, and a radio. In the first scene, users interact and execute tasks using these objects (figure 7.13).

Actions to Execute (example)

Grabbing and moving two objects simultaneously

- Grab two darts simultaneously on the table and move them near the radio.

Equipping a tool

- Equip the dart and throw it near the basketball on the ground.

Locomotion/Teleportation

- Move to the adjacent side of the table.

Use an equipped tool

- Equip the radio and switch it on (use it).

Unequip

- Unequip the radio and place it back on the table.

Pause Game

- Pause/Resume the Game.

Figure 7.13: Table.

Figure 7.14: Objects on the table top.

Scene – 2 (Whiteboard)

For the second scene, users are placed in front of a whiteboard within the same room (figure 7.14). Beneath the whiteboard and to its side are a bunch of coloured markers and an eraser on the ground (figure 7.15). In the second scene, users interact and execute tasks using these objects.

Actions to Execute (example)

Grabbing and moving two objects simultaneously

- Grab a red and black marker and move them away from each other simultaneously.

Equipping a tool

- Equip the eraser on your right hand.

Locomotion/Teleportation

- Move to the right of the whiteboard.

Use an equipped tool

- Equip the eraser and use it on the whiteboard.

Unequip

- Unequip the eraser and place it on the side of the board.

Pause Game

- Resume/Pause your game.

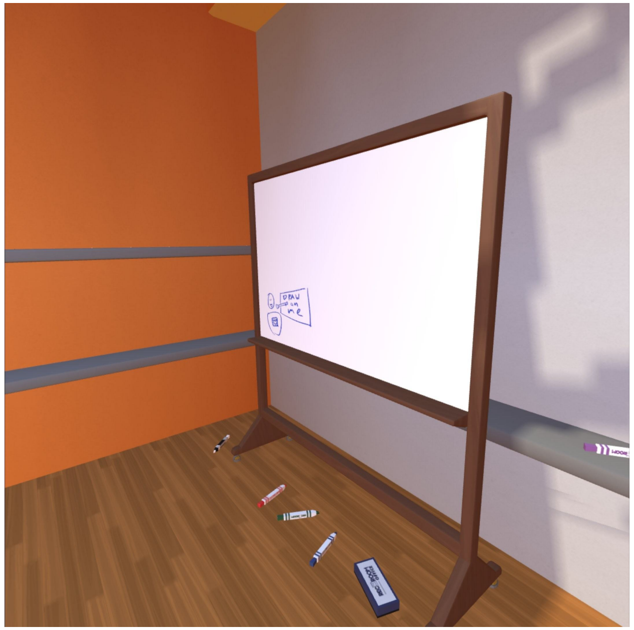


Figure 7.15: Morphological chart used during the ideation process.

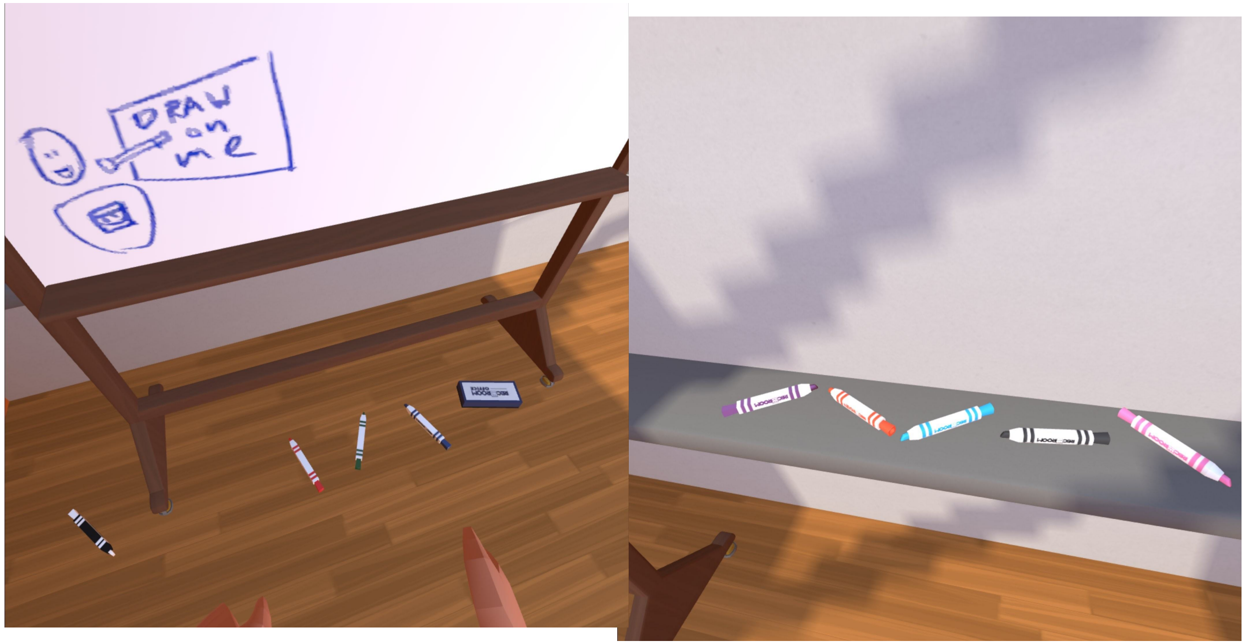


Figure 7.16: Markers and duster around the white board.

Severity of Amputation – Additional tests

If presented with enough time, the users will perform Activity 3 with the armbands positioned near the elbow in a very extreme case of Trans-Radial Amputation. The users can then test both layouts (three and Five-button layouts) again and choose their new buttons and positions.

Why this activity?

This activity can give further insights into how the severity of the amputation would affect the users' preferences for:

- Button sizes
- Button positions
- Button Layouts

Furthermore, it can also show the design flaws within the armbands and the belt when used by users with extreme cases of trans-radial amputation.

Prototype

The function of the prototype for user testing was to allow users not only to wear it but also to have the freedom to design their controller using the components given to them. Ultimately, I needed a prototype that could help me answer the critical research questions mentioned earlier and satisfy the following needs.

- Finding fatal flaws within the Design or approach (Belt and armbands).
- Help users position buttons on their belts.
- Should give some form of tactile and audio-based feedback.
- Impact of (tactile and audio) feedback on the user's performance and confidence.
- It should fit users of varying body dimensions, such as waist dimensions 80cm - 120cm.
- It Should be easy and relatively inexpensive to fabricate using materials that can be easily modified and cut while also being cheap to procure.

Figure 7.17: Prototype, hardware and equipment for user testing.

Fabrication

The design and fabrication of the prototype were relatively straightforward once the prototype's functions were realised. Cardboard was the predominant material used to build the prototype (figure 7.17). It was chosen for its versatility, ease of use and durability. While Foam and other more novel materials (polymer-based fabrics Foam and breathable fabrics) could've been used, the lack of resources (time and funding) proved that cardboard was the ultimate material to work with. Some custom components (Armband Action buttons, Hitting pad, Button caps) had to be fabricated using conventional 3D printing. These components would undergo more physical loads and use and, therefore, needed more rigid and strong material to be built on. There were two sizes of buttons to make, small of 6 cm diameter and large of 8cm diameter. To test out the tactile function of the buttons, keyboard key switches (figure 7.18) were used to produce the necessary reaction force for the tactile effect.

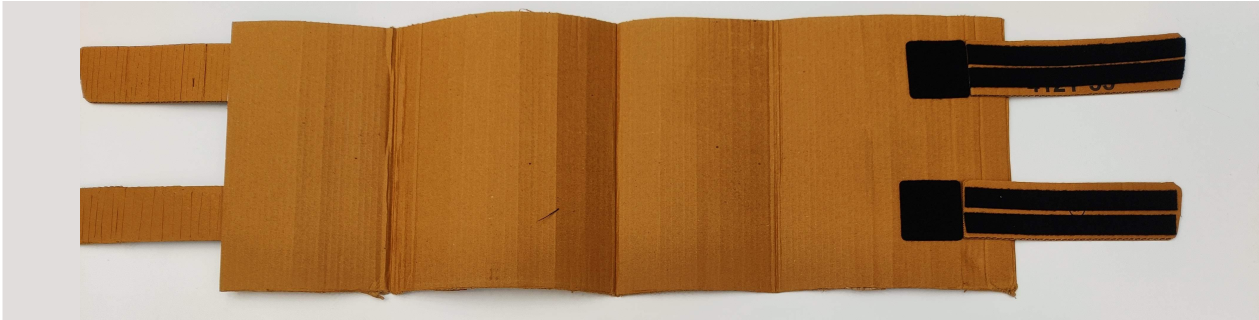


Figure 7.18: Belt Protoype.

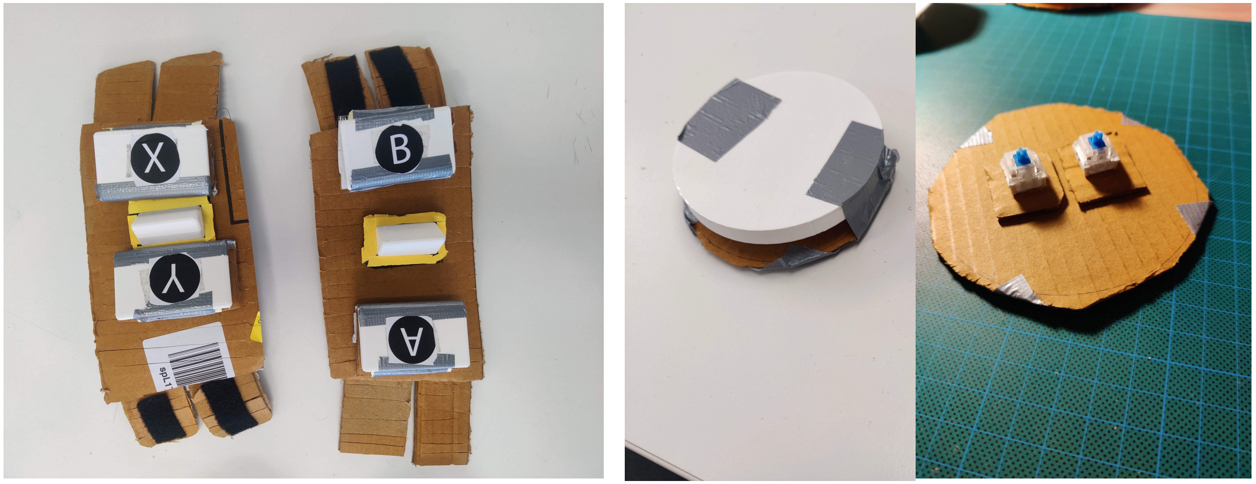


Figure 7.19: Prototype of the arm bands and the button module with the keyboard switch underneath (extreme right).

Components and Materials used

1. **The Belt**

- **Materials Used:** Cardboard, Velcro Duct tape.

2. **Arm Bands**

- **Materials Used:** Cardboard, Velcro, Duct tape, PLA (3D printed parts)

3. **Buttons** (Both small and Large)

- **Materials Used:** Cardboard, Superglue, Duct tape, PLA (3D printed part)
- **Components used:** Cherry MX Blue Keyboard Key switches

How to use it?

Wearing the Belt

The belt is worn around the waist and is held together using Velcro straps. The Velcro can also be used to adjust the fit of the belt according to the user's needs.

Figure 7.20: Wearing the prototype belt.

Wearing the armbands

The arm bands are worn around the wrist for Hand amputation and moved higher near the elbow during the trans-radial amputation test. Similar to the belt, the armbands are also held and adjusted using Velcro straps.

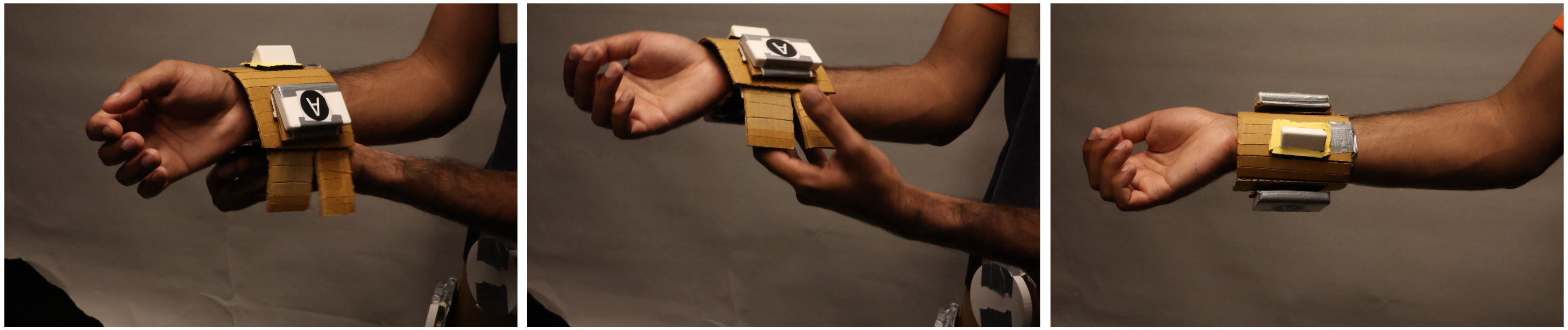


Figure 7.21: Wearing the prototype Arm bands

Placing the buttons

To place the buttons on the belt, users stick the loop side of the Velcro patch to the desired location. Users will then place the button (already with the hook side of the Velcro attached in the back) to the patch on the belt.

Figure 7.22: placing the buttons on the Belt.

Results

Performance score of users

Hand Amputation

TBL (Without VR Headset)

Two users completed the Torch task without errors using the three-button layout system. After an initial practice session, both users found it easy to adapt and use the controller with experience. As for the rest of the users, they completed 4-5 of the seven tasks. All three users had issues pausing the game and unequipping objects from their hands/Arms. Both had to be executed through the Action buttons (XYAB) on the Armbands.

TBL (with VR Headset)

Surprisingly, All users performed every task successfully while wearing the headset. Tasks were prompted twice to confirm the user's adaptability to the controller. When asked if the VR headset made it any more difficult to use the controller, Users mentioned that they had already adapted to the button mappings and their location and found it very easy to find and execute the buttons. Furthermore, users had also adapted quite well to the Armbands, where almost every user used the rubber hit pads to press the buttons.

FBL (without VR headset)

With the Five Button layout, three users performed all the tasks successfully without a headset, while the rest (two others) completed all but one task. There were no common factors between the two, however.

FBL (with VR Headset)

When users wore the VR headset, they showed hesitation while executing the tasks. While time was not a factor in these activities, it was generally observed that Users were slower (by 1-2 secs) to execute the task. This is due to the increased button density in the layout. Nevertheless, two users still completed all the tasks without errors, while the rest predominantly failed in tasks that needed pressing buttons on the belt. However, not all users showed the same initial signs of difficulty using the armbands.

Trans-Radial Amputation

With the Trans-Radial amputation tests, Users would still wear the socks and the VR controllers on their hands while the armbands are shifted higher up the forearm (near the elbow joint).

TBL (with VR Headset)

All users changed their button positions before the activity. After the initial practice rounds, all users will adjust and move the buttons close to their arms while in a neutral position. This saves time when actuating and adapting to disability and the reach of the buttons. Users could no longer position the buttons in the middle of the belt as it was too hard to reach.

Even without the initial torch test (without VR headset activity), almost all the users (fours) executed the task successfully without any errors.

FBL (with VR Headset)

However, during the Five-button layout tests, users found reaching the buttons they were looking for extremely difficult. Furthermore, the Armbands proved quite difficult to use in this layout. Many users would hit the right buttons but would hit them using the action buttons on the arms, pressing two buttons simultaneously and completing two tasks simultaneously. Therefore, using the armbands to hit the desired buttons was challenging and hard. All users could complete 3-4 of the seven tasks during the test.

Observations

Large buttons were, in most cases, always in the middle

Throughout the test, large buttons, irrespective of function, were always positioned in the middle of the belt. This was an attempt to reduce the time to press the button in the middle. Users could reach the buttons faster and easier by making the buttons larger.

Larger buttons made a difference when wearing a headset

Users were quite confident in using larger buttons, which were helpful when wearing a headset. However, their performance showed little difference while pressing small and large buttons.

As the severity of amputation increased, buttons switched to a neutral position

As mentioned earlier, when the armbands were moved higher on the arm, users preferred to have the buttons (irrespective of size) of the centre and the sides closer to their elbows and forearm

Most never used the Grab Button

The grab button was never universally preferred over the grab-and-move gestures. Almost every user found the button redundant, especially considering the gesture's effectiveness during the tests. Three users actively hated it, while the rest removed the button entirely from the layout.

Inverted controls (FBL)

Every user mapped and inverted their button mapping system when using the five-button layout. All buttons on the right side of the belt would control actions on the left arm, and all buttons on the left would control actions on the right arm.

Wearing the Headset had an impact while using the Five button layout

Users were particularly less confident and performed worse when using the five-button layout while wearing the headset. This was due to increased button density and not having a clear visual aid while hitting the buttons.

Most of the frustration – Arm Band

Users were predominantly frustrated when using the Armbands. The inability to change the location of the buttons and lack of tactile and audio feedback when pressed made it harder for the users to confirm their (armband) button presses.

Furthermore, in many cases, due to the rigidity of the Cardboard prototype, the armbands would frequently rotate and change position, which changed the orientation of the buttons and the rubber pads on the bands, leading to users accidentally pressing the button on the belts using the action buttons the Armbands.

TBL was preferred for hand amputation

Every user preferred the Three-button layout over the five-button layout due to its simplicity and ease of use during the hand amputation tests.

FBL was preferred for Trans Radial

However, users preferred the five-button layout during the trans-radial tests due to the severity of trans-radial amputation affecting the reach of buttons in the middle of the belt. This layout provided users the opportunity to have a button for each arm. Furthermore, positioning the buttons closer to their arms made reaching and accessing the necessary buttons easier.

All got used to the controller

Every user was eventually accustomed to the layouts and the controller (both belt and armbands). While users found some frustrations with the armbands, they did like their functionality and how it was used to press and actuate buttons on the belt. Every user would eventually be confident using the controller and executing their tasks. Users found the Button mapping quite intuitive and easy to use.

Feedback and takeaways

Reported ratings

A small questionnaire was asked to the participants after each activity. The questions were aimed at understand the relative impact of the Three Button Layout and Five button Layout.

What was your overall confidence using the device?

Three-button Layout	Five Button Layout
3.5/5	4/5

How intuitive was the Button mapping to use?

Three-button Layout	Five Button Layout
3.7/5	3.6/5

How easy was to Actuate (find and press) the buttons?

Three-button Layout	Five Button Layout
3.7/5	3.6/5

Getting used to the Controller when given enough time (Y/N)

Three-button Layout	Five Button Layout
100%	100%

Discussion: Feedback from the users

Belt

- Both Button Sizes are comfortable to use.
- Velcro Mechanic is a valuable feature.
- Can remove the Grab button (or make it optional).
- It could have been improved for armband-belt communication. When the users try to press a button on the belt using the armbands, all button actuation on the armbands is deactivated or ignored.
- Keep the tactile feedback mechanism on the buttons.
- Freedom to Customise Button mapping is crucial.

Arm Bands

- **I n**eed complete freedom. The compact button layout was hard.
- The lack of feedback on action buttons confuses users.
- Users found it uncomfortable to hit in trans-radial conditions.
- Users suggested having an in-game representation of armbands that not only indicates an understanding of position in space but also represents the orientation of the armbands on the arms.
- Rubber Hit Pads helped very much while wearing the headset.

Discussion

Desirability

The desirability of the Django controller is dependent upon the desirability of VR as a whole. Without the platform, there would be no direct use of the controller. And as discussed earlier, VR/AR is an emerging technology. While the platform is not completely mature, it is mature enough to have a steady application marketplace with multiple companies investing in it. It is hard to say how much VR and AR will change our lives. We know it will have fingerprints in Entertainment (gaming included), Education, Research, Engineering and more (Accessibility in AR/VR: How to Make Immersive Digital Experiences More Inclusive, n.d.). Eventually, when enough applications and users are using the platform, there will be a need for more disabled users also to access the same tools as able-bodied users. With the latest reports, it is estimated that the total number of VR headsets in the market will increase from (approximately 16.44 million units in 2021 to 34 million units in 2024 (Statista, 2024). With a steady increase in user base, companies, creators, and developers would want to develop and create more VR applications, games, experiences and tools. When that time comes, disabled users will not have access to the same tools and resources as abled users, putting them at a massive disadvantage.

Therefore, while there is already a need for an accessible VR controller, it will only increase with time.

Feasibility

The development of the VR controller for hand amputees is highly feasible, driven by the maturity of the underlying technology and the materials' reliability. Utilising well-established components such as motion sensors and tactile buttons ensures that both prototyping and production processes are straightforward and cost-effective.

The Armbands and the belt are predominantly fabric-based main body. Traditionally, back support belts in the market have the same type of structure and application (minus the back support) and use Neoprene as the primary fabric material. Neoprene is lightweight and breathable, making it perfect for our Django belt and armbands, as users tend to be more active while using VR systems. Therefore, having a breathable fabric would help deal with sweat and heat exchange.

The Buttons, however, would use ABS plastic as its primary material, which would have to be injection moulded into the parts. Both the buttons' material and manufacturing process have been well established and are pretty cheap when manufacturing in bulk quantities.

Viability

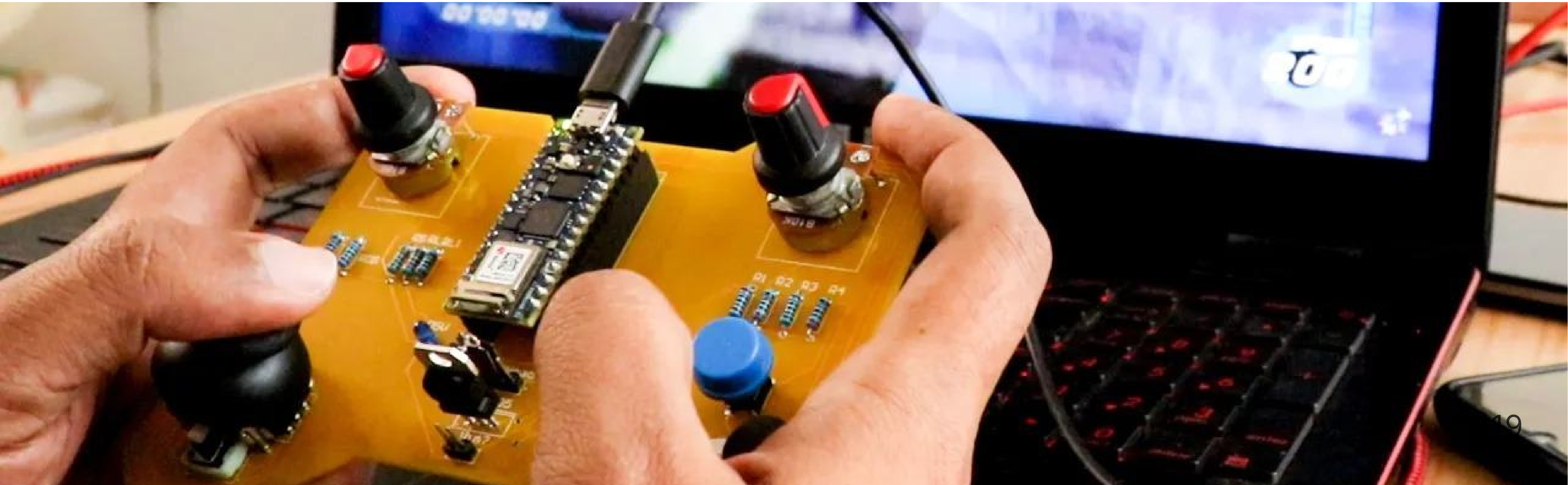
Due to the niche nature of the product, it is quite a challenge to make this product a viable business option. While the business aspect of the product is not a part of this project, it is crucial and very important for any design project to explore it.

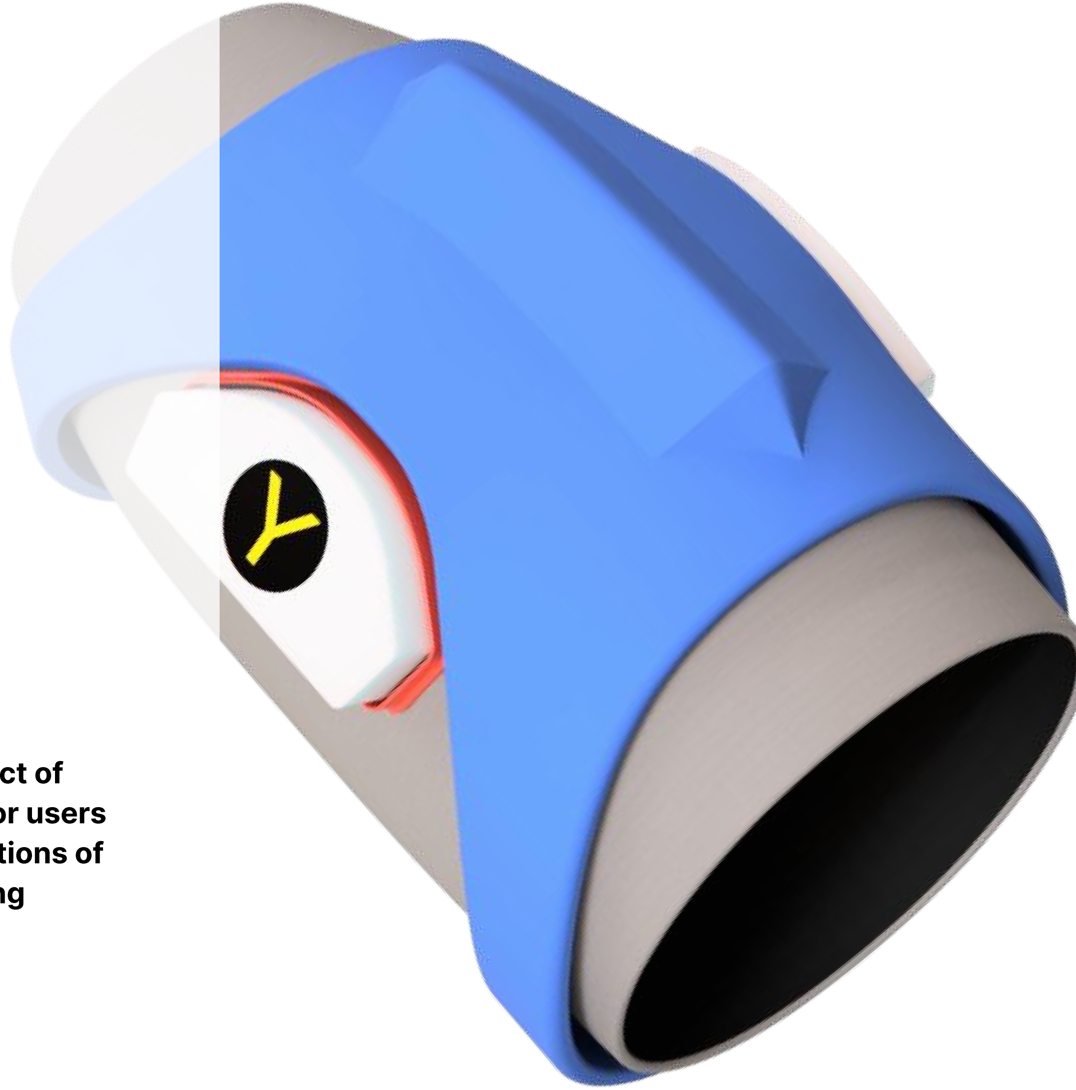
Many of the niche products built for disabled users tend to go bankrupt due to the lack of sheer numbers in sales. Furthermore, many of these devices are manufactured at a reduced scale and in smaller numbers, increasing manufacturing costs. Combine that with unique design and implementation of new technologies. The products tend to be overpriced and, in most cases, out of reach to many users (Archer, 2023).

There is, however, another approach to bridging the disability gap. Instead of making an entirely new product for disabled users, why not make existing products more accessible? Many devices, like smartphones, smart watches, etc, have added accessibility features. Moreover, VR systems have also followed suit.

Therefore, DIY solutions jump in to fill in the gap. These solutions are hand-crafted, designed add-ons or complete products that give disabled gamers the freedom to choose how they play, customise, and modify their products to suit their needs and comfort. And that is the sweet spot for Django as a product. While the feasibility of the product is quite high, the viability of it is hard to justify. If Django as a product is only marketed for Gamers with hand impairments? The numbers would be too low to make any financial sense. Furthermore, as discussed earlier, disabilities and impairments are not set in standard conditions; they can be visualised as a spectrum, complicated and unique to each individual. Therefore, the best way to move forward (if it does) would be to make it completely open-source for users to customise and build their controllers. This will finally allow users to completely modify and/or customise their controller to their needs.

Figure 7.23: A DIY gaming controller made using an Arduino Board (Team, 2022).

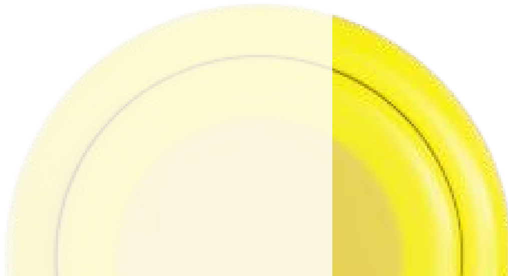




Chapter 8

Conclusion

The conclusion of this report discusses the key findings and outcomes of the project. This chapter will summarise the impact of the final design on improving accessibility in VR, particularly for users with hand impairments. It will also discuss the broader implications of this work for the field of VR design and accessibility, suggesting areas for future research and development.



Contribution of Current Work

This project explored the design space and tested some of the design principles behind VR controllers for hand amputees. Some of its contributions

1. **Literature Review:** A comprehensive review of existing accessibility solutions for gaming hardware and current research trends in VR accessibility was conducted. It was concluded that there is limited literature directly linking hand amputees to VR accessibility, highlighting a significant gap in the field.
2. **Gaming Controller Research:** Research was undertaken to understand the evolution of gaming controllers and their continued inaccessibility for users with hand impairments. This included an investigation into the relationship between game controllers and movement (6 DOF movements, action buttons, etc.) within games.
3. **User and Expert Insights:** Initial interviews with users and experts were conducted to gain insights into their daily challenges and the specific difficulties they face. This research informed the subsequent design process and the creation of co-design sessions.
4. **Co-Design Sessions:** Insights from the initial research led to the design and execution of co-design sessions with users and an expert. These sessions helped refine the focus on technology affinity, hardware preferences, and gaming interests.
5. **Concept Development:** Feedback sessions on initial ideas led to the development of three concepts, with the concept "Django" being selected as the focus of the project. Django was further developed and tested with a physical prototype, and it was integrated into a VR interaction structure that supports both seated and standing use.
6. **User Testing:** The prototype was tested with users to successfully verify the design and button mappings, ensuring the product's effectiveness and usability.

Discussion

I initiated this project with the goal of addressing an accessibility issue within the gaming industry. Ultimately, I chose to focus on Virtual Reality (VR) because the platform is still in its early stages of development and has not yet fully matured. As the project progressed, each interview & discussion time gradually revealed the complexities of the problem at hand. What became clear is that solving accessibility issues is an incredibly intricate challenge. It is nearly impossible to create a solution that caters to every individual with an impairment, given the diverse range of needs and conditions.

The project would have been impossible to achieve if not for the insights and feedback I received from users and experts. Having the users take part in the project to receive active feedback and reflect on it helped me a lot to fine-tune and fix my concept and idea.

Despite these challenges, the project successfully achieved its primary objective: designing a game controller specifically for gamers with hand amputations. The VR controller, named "Django," is capable of accommodating users with various levels of hand amputation, from partial hand amputations to trans-radial amputations. Moreover, the product also provides access to VR for users with bilateral amputations, an advancement that has not been realised before. By utilising existing and well-established technologies, the Django controller not only addresses a critical gap in the market but also enhances the overall viability of the product, making it a practical and achievable solution.

In the end, although the project achieved its main goal of designing an accessible VR controller, it is far from being over. This project could be used as a stepping stone for deeper explorations into accessible gaming.

Suggestions for Future Work

While much was learnt, the design can be further worked on, which wasn't covered in this project.

- Test it with hand amputees with a more extensive sample set.
- Testing the design with a working prototype with fully functioning electronic subcomponents and a system that can effectively communicate with the VR system.

More frequent in-person co-design sessions and workshops with users and experts are needed.

- Exploring the design's effectiveness when sitting down.
- Exploring the "Rockwell" concept and other foot-based solutions.
- Research and explore products' quality of life features.
- Explore software-based solutions for VR games.
- Exploring ways to design a common software-based platform enabling all DIYers to custom design solutions for the ecosystem.

Gaming has been an essential part of millions of lives across the world. Having such a strong medium of expression and experience significantly impacts people and how they spend their time. A medium such as this should ideally never exclude parts of society who do not have access to it through no fault of their own.

Furthermore, VR and AR will be a significant part of our lives in the future. Just like the technological innovations that came before, learning to live and using it as a tool will benefit all of us. At this point, not making the platform accessible prevents many users from experiencing and taking part in cultural movements. Therefore, efforts must be put into making these systems as accessible as possible. With the current maturity of technology, it is the right time to put our efforts into these explosions. This course will take time, and we move ahead one step at a time. This project was my attempt to explore and bridge that gap to help a small part of the user group experience VR.

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Appendix

TU Delft

DESIGN FOR our future

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Arjun Srivathsa	IDE master(s)	IPD ✓ DfI ☐ SPD ☐
Initials		2nd non-IDE master	
Given name	Arjun Srivathsa	Individual programme *(date of approval)*	
Student number	5804116	Medisign	☐
		HPM	☐

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Marijke Dekker	dept./section	Human-Centered Design
mentor	James Scott Broadhead	dept./section	Sustainable Design Engineering
2nd mentor			
client:			
city:		country:	
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name *Marijke Dekker* Date *26 March 2024* Signature [signature]

CHECK ON STUDY PROGRESS

To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ______ EC

Of which, taking conditional requirements into account, can be part of the exam programme ______ EC

X	**YES**	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name Robin den Braber Date 06-05-2024 Signature RdB

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	V	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

V	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name Monique von Morgen Date 7/5/2024 Signature MvMorgen

Personal Project Brief – IDE Master Graduation Project

Name student Arjun Srivathsa **Student number** 5,804,116

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Designing game controllers for gamers with Hand Amputation

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The current gaming market has a lot of innovative ways to interact with our gaming systems from the traditional controller to wireless handsets used in VR/AR environments. No matter the extent of innovation, the industry severely lacks in the inclusive department and this is especially true for any gaming medium that uses motion sensing as a core part of the experience. Gamers with physical disabilities hit a major roadblock when trying to access the games that they want to play. This is because of two major reasons

1. Disabled gamers represent a small fraction of the gaming user base, making it an extremely niche user base. Therefore companies would prefer not to spend a lot of resources on research and development of products that are going to be barely mass manufactured.
2. Due to the unique nature of disabilities, it is hard to design a controller that would work for every user. Two individuals, though having the same type of disability, would still drastically have different experiences in their everyday lives. Therefore catering to every user's unique needs is quite difficult.

Key Stakeholders

Gamers with hand amputations: They are the main users of the product. Currently, no widely available motion controller can be bought and set up by the users. Current solutions involve DIY projects that predominantly depend on taking each user's needs to design a controller for them. While this solution works, it is not widely available, in some cases expensive and leads to compatibility issues with the console/system. Furthermore, support for repair and other forms of maintenance is either really difficult or near impossible.

Video gaming companies: They are the other key player in this project. Companies are more motivated to develop and manufacture controllers if the product can be mass manufactured and used by not just the physically disabled but also the general population. Furthermore, it is only the support of games and its compatibility with the controller that can convince users to buy the product in the end.

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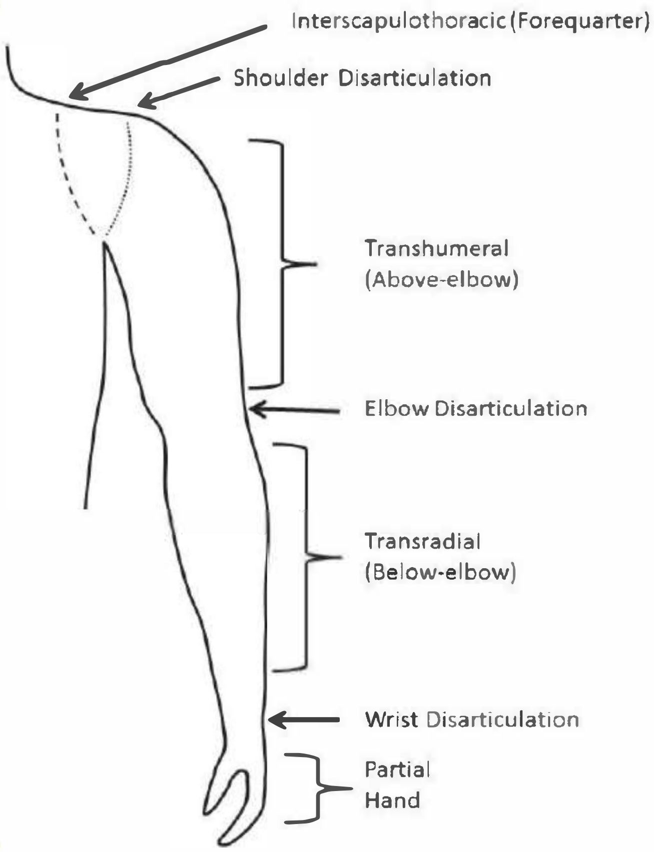

image / figure 1 Levels of upper-limb amputation (Schuch and Pritham, 1994).

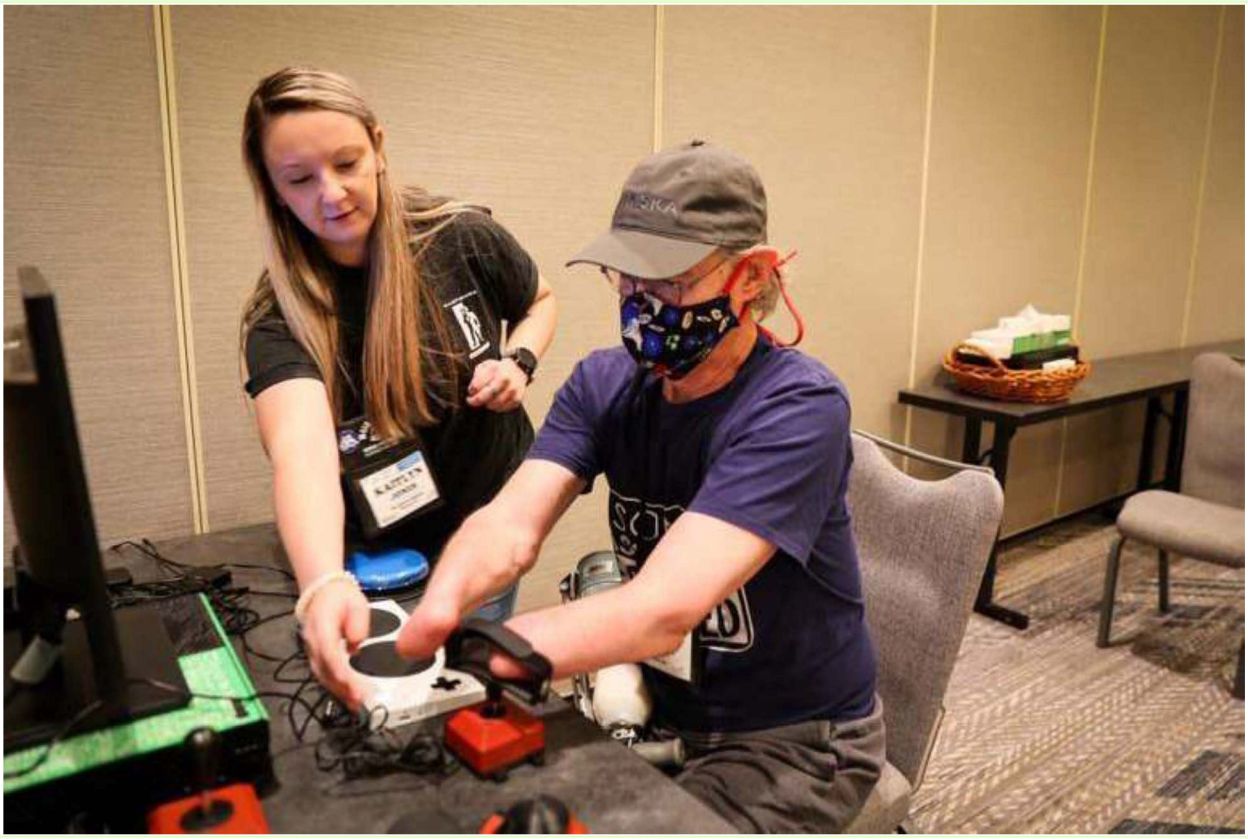

image / figure 2 Exisitng DIY solutions for Hand amputees to access gaming. Image source: tapinto.net

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Gamers with hand amputations currently have no viable option to play games that utilise motion sensing. Which results in excluding a large number of gamers from getting the same experience as their peers. It's crucial to do a thorough literature study on the current market, existing solutions and research done in the human-computer interaction sector for the physically handicapped. The approach would be to understand the user's current problems and needs through performing observations and interviews.

The product in the end should ideally:
1. Give gamers with hand amputations (Partial hand to Trans radial/Below the elbow, see Figure 1) a way to interact with motion-based games.
2. Should be ergonomic and comfortable to wear and use.
3. Should be versatile and compatible with different types of games.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design a game controller that enables gamers with hand amputations to access video games, thereby, enabling them to access and experience gaming just like gamers with full functionality of both their hands and arms.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The approach for the project would be to develop a controller prototype (stand-alone or as an add-on to a game hub system similar to the Xbox adaptive controller, refer to figure 2) that can cater for gamers with hand amputations on both hands (Extent of Amputation: Partial hand to Trans Radial/Below the Elbow). The project will predominantly focus on theergonomics of the product that impacts the user experience.

Key Activities of the project
1. Initial literature review
2. Analyse existing solutions in the market.
3. Conduct ethnographic research and user interviews.
4. Rapid prototyping and testing (Ergonomics)
5. Fabrication of prototypes.
6. Test prototypes with users (Second Iteration)
7. Future recommendations

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting, mid-term evaluation meeting, green light meeting*** *and* ***graduation ceremony****. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	5 Mar 2024
Mid-term evaluation	15 May 2024
Green light meeting	17 Jul 2024
Graduation ceremony	27 Aug 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	✓
For how many project weeks	10
Number of project days per week	4,0

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

Throughout my life, I have been heavily influenced by stories through different mediums (movies, TV shows, novels, plays, etc), one of them being through video games. The power to narrate a story and engage the user is truly one of the best and most effective ways to impact the user and give a powerful and, in many cases, meaningful experience. And for a user such as myself who has clocked in countless hours of gaming, it has profoundly impacted me. Therefore, I think it's a shame that one of the most influential and powerful ways of storytelling cannot reach a considerable number of people, limiting their experiences that they can have through no fault of their own.

This project is my attempt to provide access to a small chunk of that user base to help them interact with games and other applications (Eg, VR/AR-based interactive learning tools, creative platforms, etc.). It is also a way for me to understand the process, the nuisances and the challenges while working on an inclusive design project. The project, in the end, is a stepping stone for me to design products/services that are as inclusive as possible in the future while not compromising on the impact and user experience that it delivers, irrespective of the user or their challenges.

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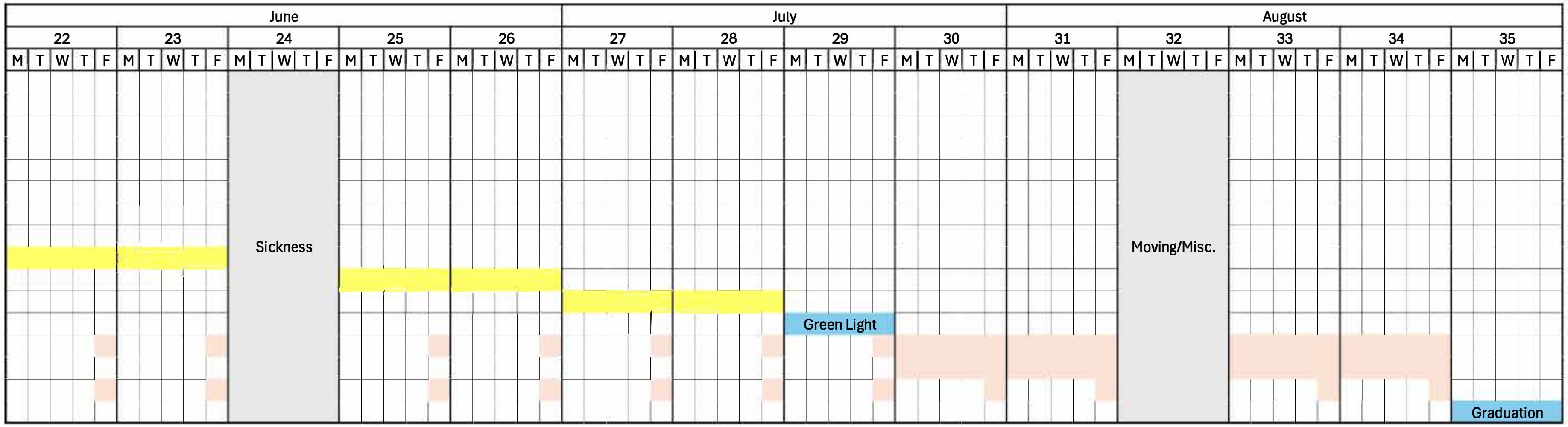
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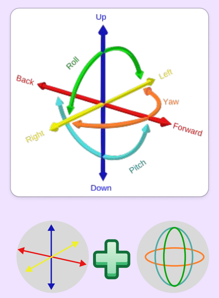
Moving/Misc.
Green Light
Graduation

Games n Gameplay

Games and Movement



Six Degrees of Freedom

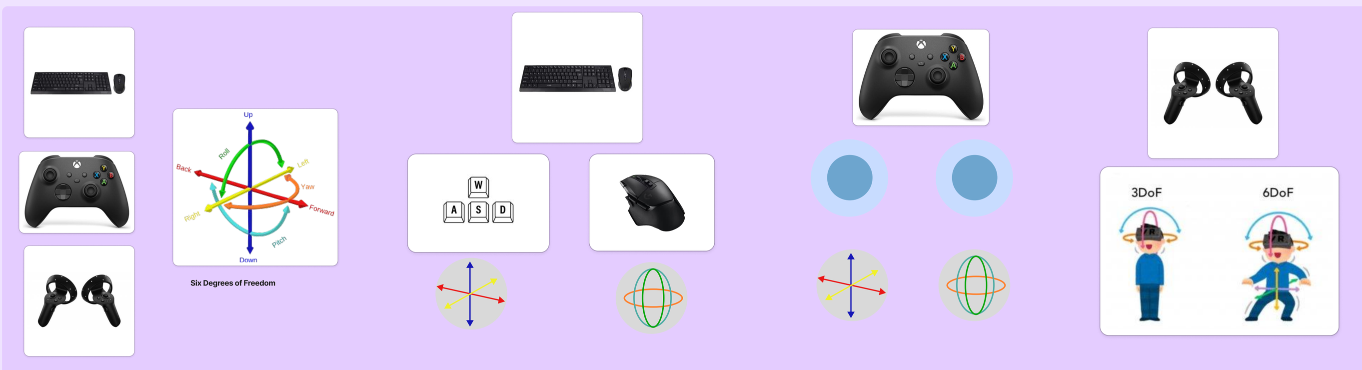
First person Shooter
Role Playing Game
Third person perspective gameplay

1	Forward/ Backward
2	Up/Down
3	Left/Right
4	Look up/down
5	Turn Left/Right
6	Lean left/right

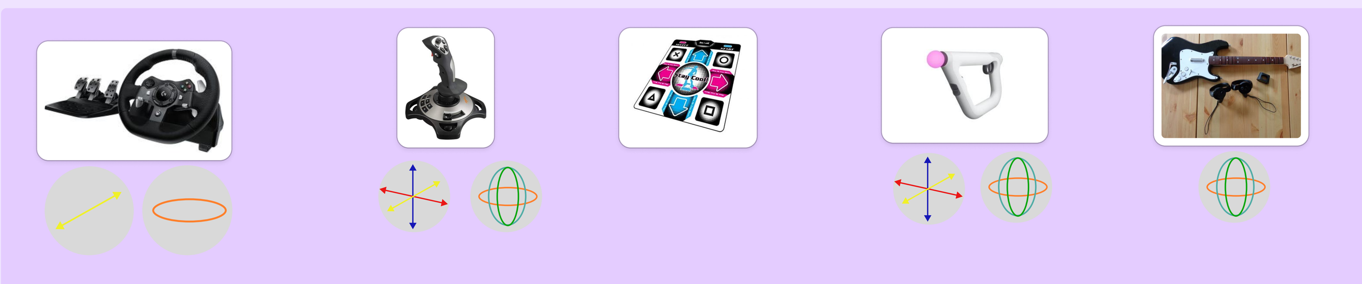
Other Forms of input

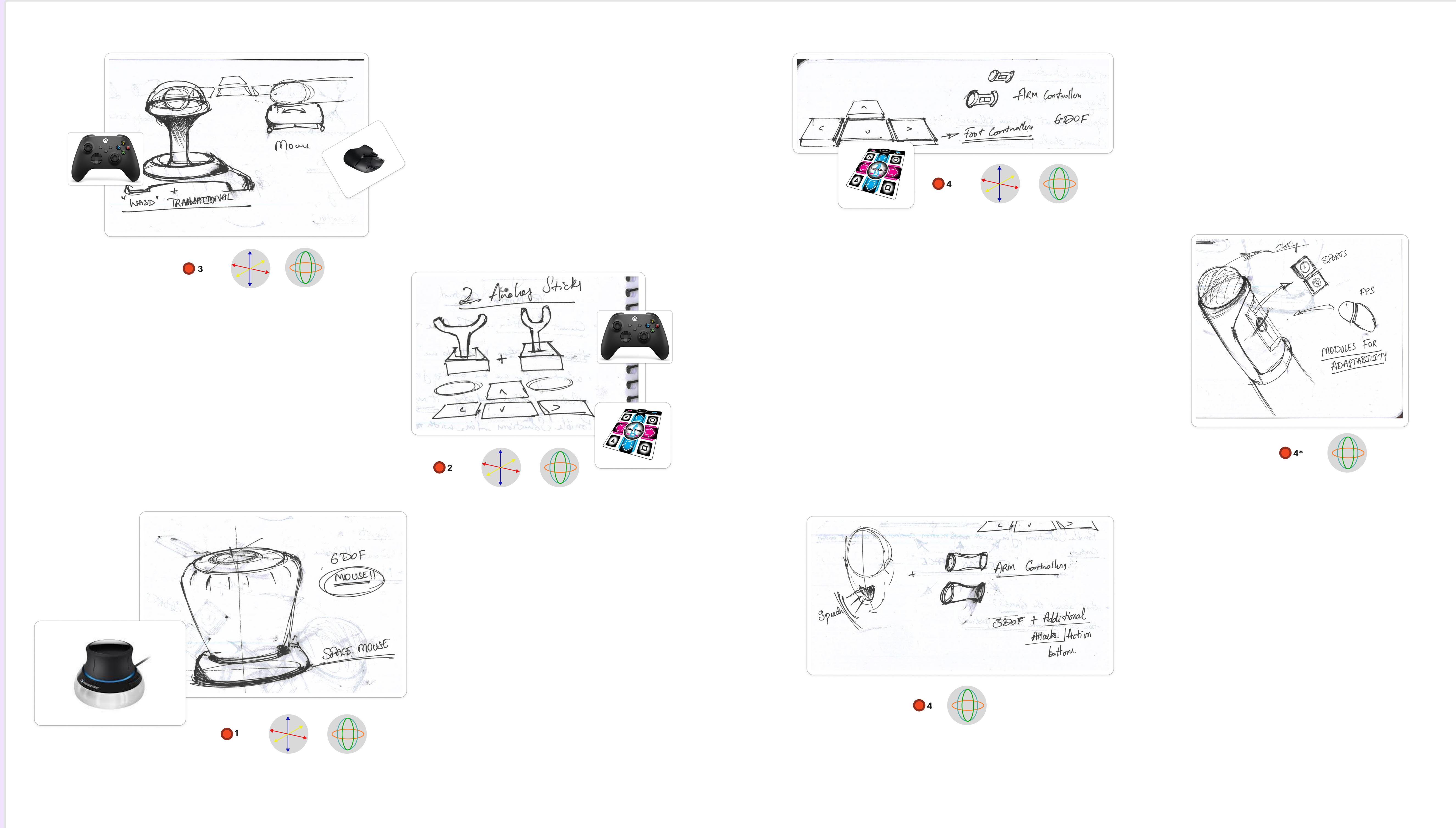
Let's call them Action Buttons
For Reload, Chat, Action etc.

Current Solutions

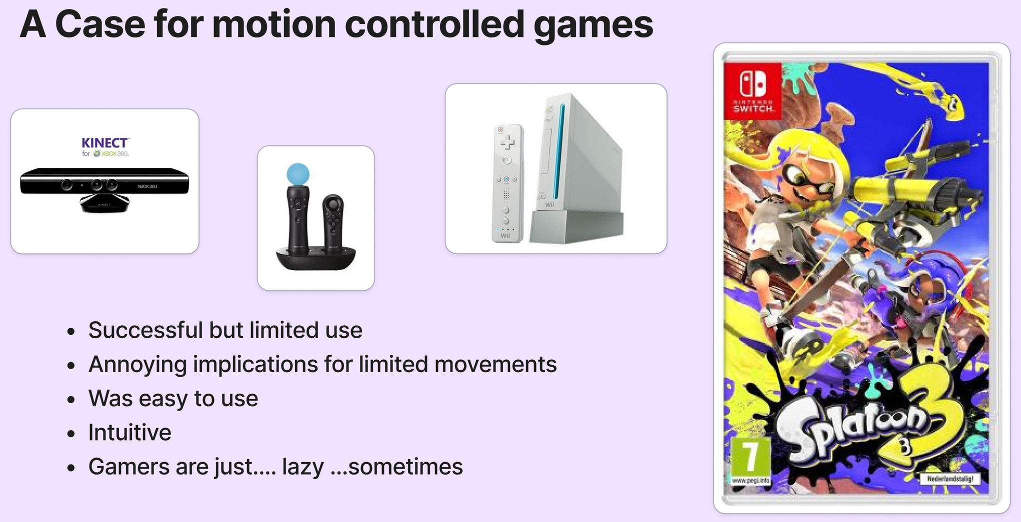


Other 3-6 DOF Solutions





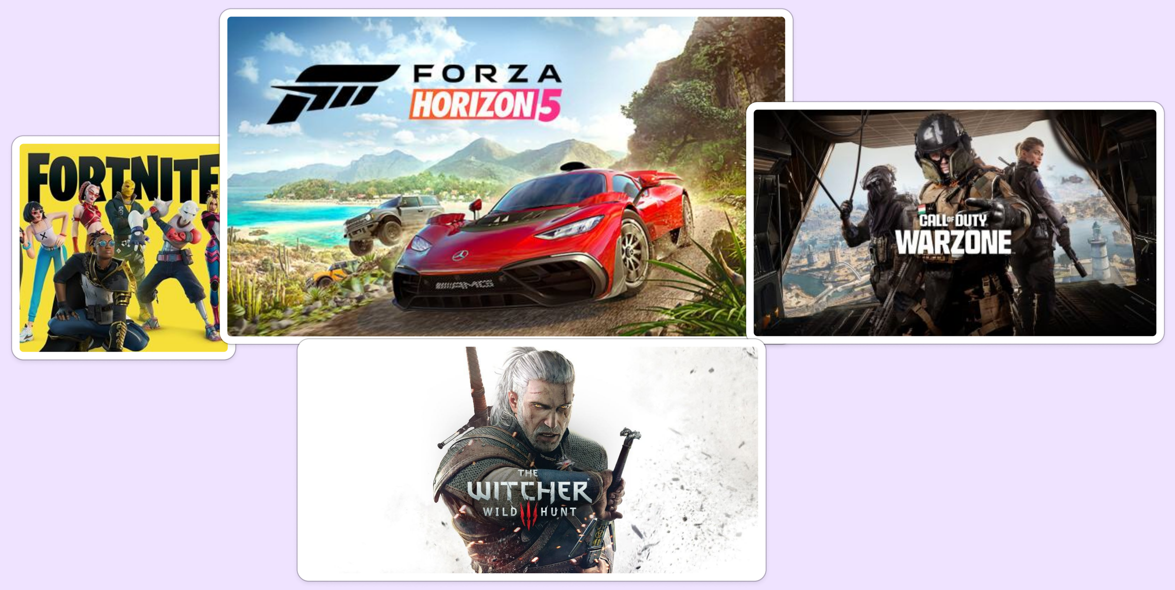
A Case for motion controlled games



- Successful but limited use
- Annoying implications for limited movements
- Was easy to use
- Intuitive
- Gamers are just.... lazy ...sometimes

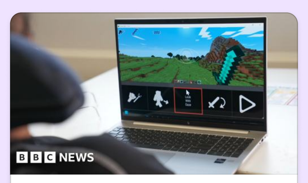
Meaningful and well adopted products have shown huge success in motion control.
It's always the game and the controller. Never alone

Current state of Games



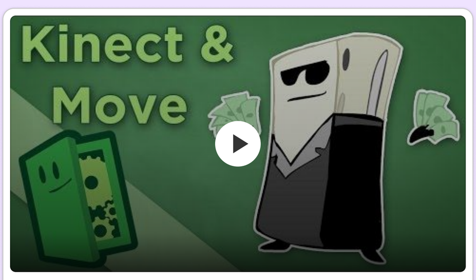
Current Games are more Fast paced, requires skill (some) and include complex player mechanisms.
They were never designed to be played by everyone.

The Big Question: Are you a Core Gamer or a Casual one?

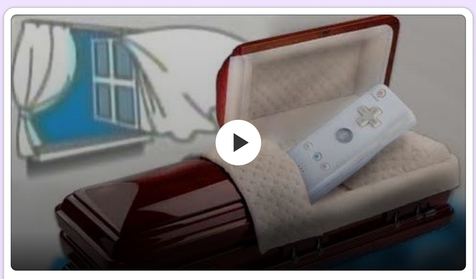


Can touchless tech create 'equitable' gaming?
Click reporter Paul Carter has a go at playing Minecraft with his eyes.
bbc.com

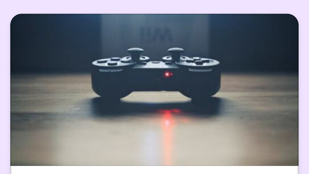
Motion controller - Wikipedia
en.wikipedia.org



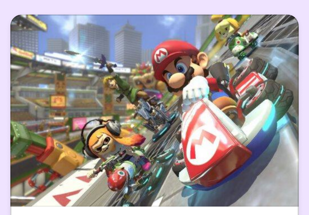
Kinect and Move - Can Motion Control Ever...
YouTube



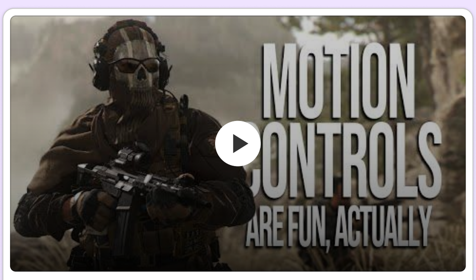
Motion Control and the Rejection of Progress
YouTube



Why aren't there more motion-controlled video game c...
Answer (1 of 11): (don't forget PS Move) The reason why doesn't work...
quora.com

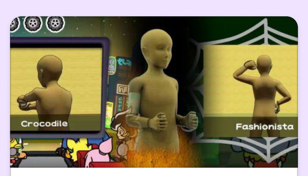


An Argument for Motion - Controlled Gaming — GNL Ma...
Intuitive, motion-controlled gaming has so many benefits. Here are just a few...
genelmag.com



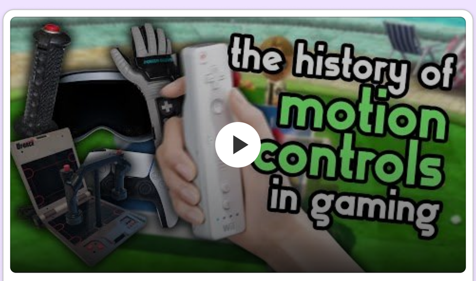
Motion Controls are Fun, Actually
YouTube

Moving Targets: The Rise of Motion Control
In this week of Kinect Sports Rivals' release, we thought we'd republish...
vg247.com

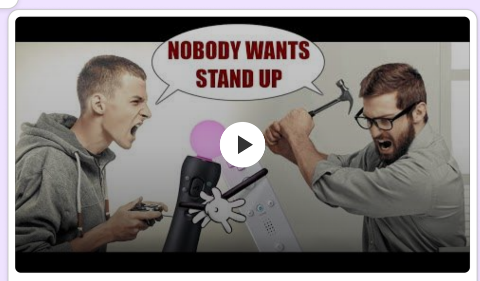


WarioWare: Move It Proves That Motion Controls Are Still Stuck...
Motion controls continue to be the thorn in many players' sides to this...
gamerant.com

Kinect Disconnect - How NOT to Do Motion Control -...
YouTube



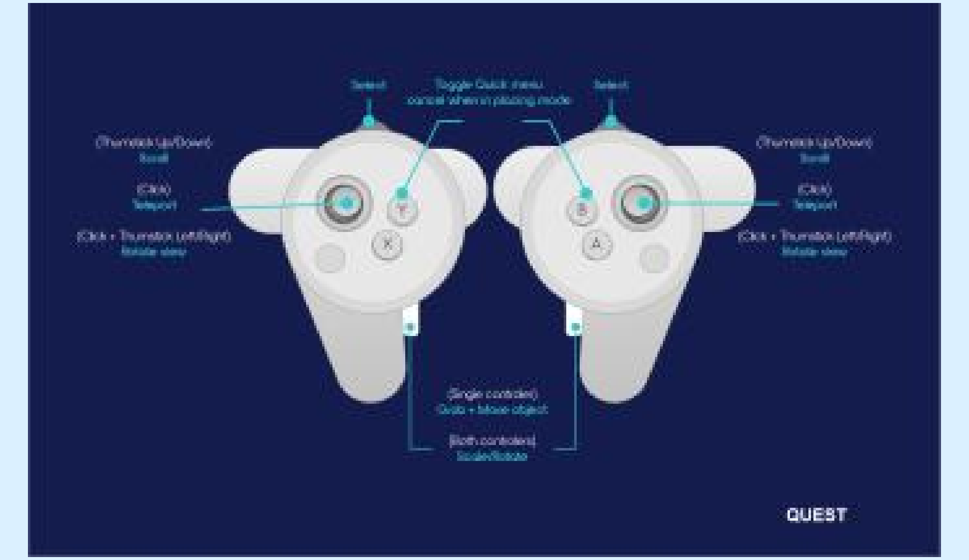
the history of motion controls in gaming
YouTube



Why Gamers Hate Motion Control (In Their Own Wo...
YouTube

Framework

Current VR Controller



Object Based Interactions

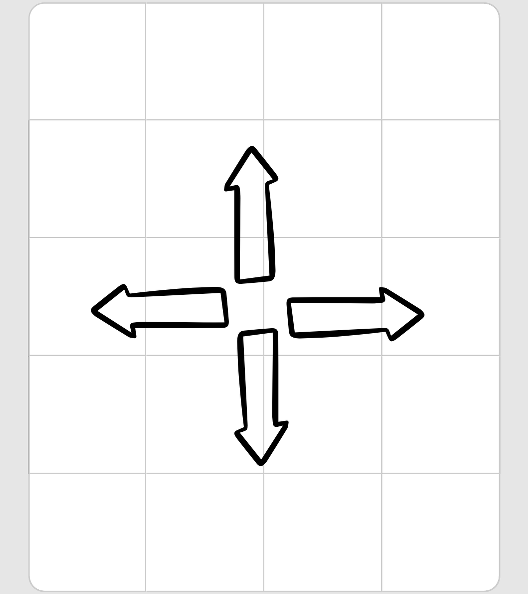
Select

Use

Move

Rotate

Locomotion



Interactive Menu

Pause

Resume
Settings
Back to Main menu

Workshop

Activity 1

Activity 1

Goal: To use Technology listed below (or your own) to create a VR controller.

- You **can use Multiple instances** of the same technology.
- You can also make your own Interaction Mechanic or choose your own Tech in the "**My Tech**"

Duration

15 Mins

Technology list

Foot Pedals
Voice Control
Eye Track
Muscle sensors
Joy sticks
Mouse
Body movement
GUI Interface
Physical Button

My Tech

Name: <here>
Function: <Mechanism/ Tech>

Name: <here>
Function: <Mechanism/ Tech>

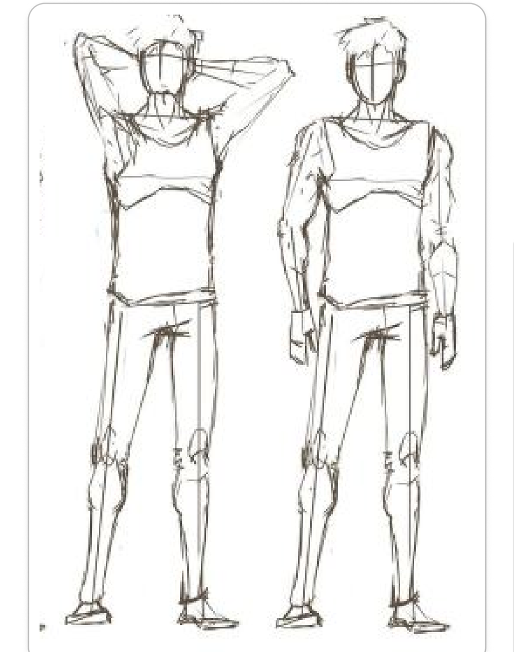


Table Top

Floor

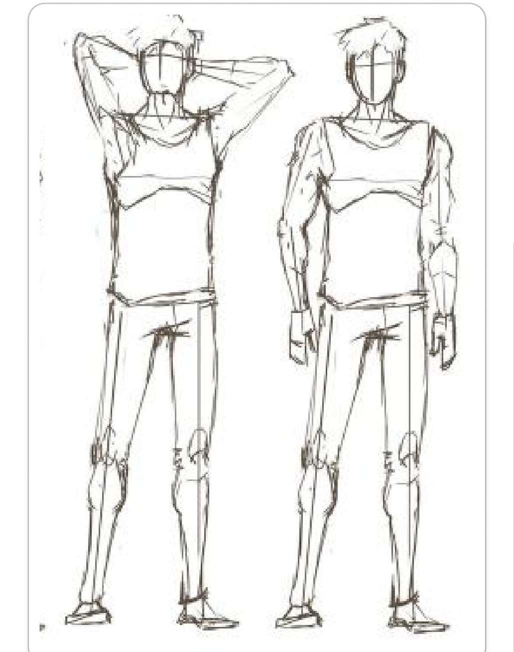


Table Top

Floor

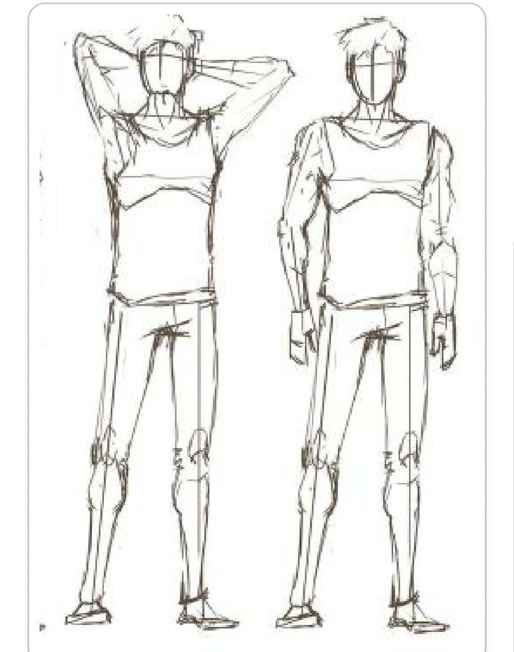


Table Top

Floor

Activity 2

Activity 2

Goal: To use Technology listed below (or your own) to create a VR controller.

- You **can use Multiple instances** of the same technology.
- You can also make your own **NEW** Interaction Mechanic or choose your own Tech in the "**My Tech**"

Duration

20 Mins

Technology list

Foot Pedals
Voice Control
Eye Track
Muscle sensors
Joy sticks
Mouse
Body movement
GUI Interface
Physical Button

My Tech

Name: <here>
Function: <Mechanism/ Tech>

Name: <here>
Function: <Mechanism/ Tech>

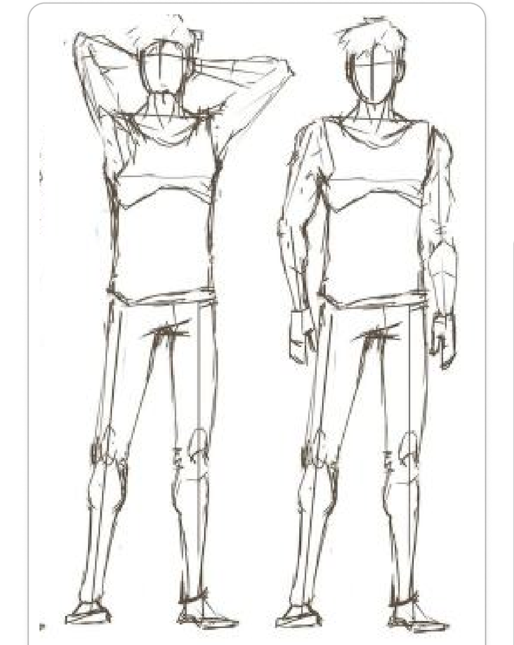


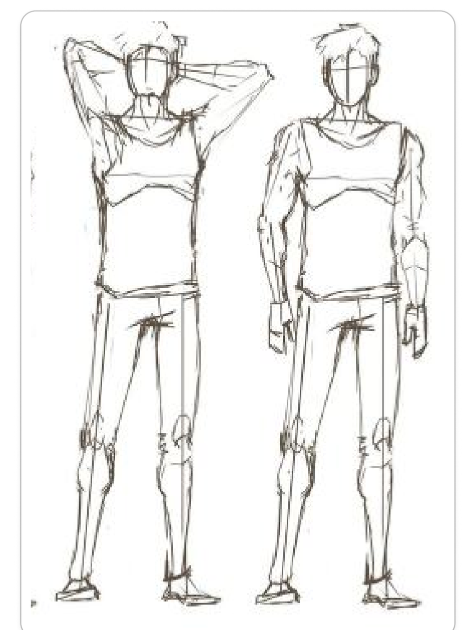
Table Top

Floor

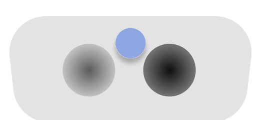
User Test Template

TBL

Button Layout and Position



Three Button Layout



Small Buttons

Large Buttons

Observations
things to look out for
- *User's verbal cues for discomfort or annoyance.*
- *Physical cues for stumbling around to find the button.*
- *Speed of interaction with time. (do they get used to the layout)*
- *Correlation between the button sizes and their rate of interaction.*

Arjun Srivathsa

U Use · G Grab · T Teleport (small buttons)
U · G · T (large buttons)

Without VR Headset

Action List

- [ ] Selecting two objects
- [ ] Moving them
- [ ] Equipping the Torch
- [ ] Teleport to a new spot
- [ ] Use the torch
- [ ] Unequip the Torch
- [ ] Pause the Game

Observations

- OBS 1

Interview

- Was the button mapping easy to follow or get used to?
- If not. do you think with sufficient time you would've eventually gotten used to the button mapping process?
- How easy/difficult was it to find the buttons on the belt?
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WithVR Headset

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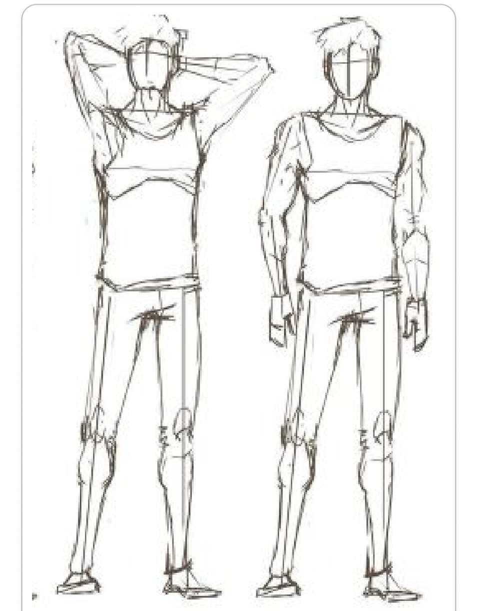
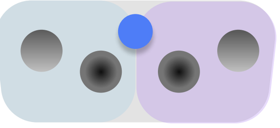
FBL

Button Layout and Position



Five Button Layout



Small Buttons

Large Buttons

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Arjun Srivathsa

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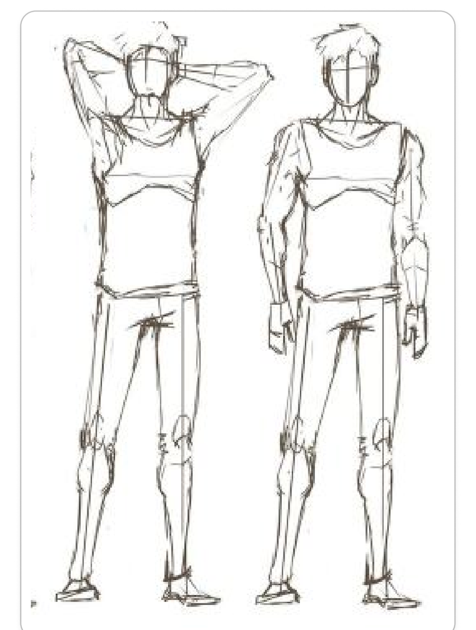

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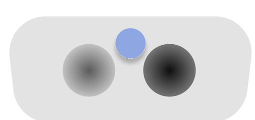

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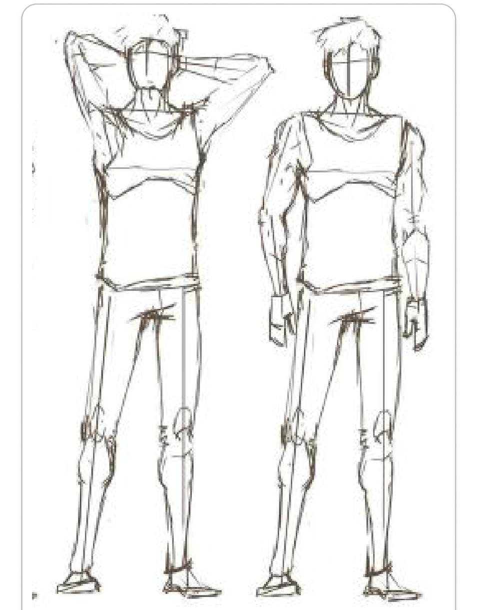

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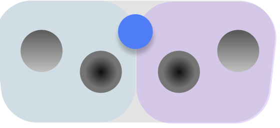

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