Enhancing Neonatal Intensive Care through Mixed Reality Patient Monitoring

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Enhancing Neonatal Intensive Care through Mixed Reality Patient Monitoring

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Declaration

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Abstract

Recent advancements in mixed reality hardware present significant opportunities for enhancing patient care in healthcare settings. This research explores the potential application of mixed reality in neonatal maternity wards, particularly focusing on patient monitoring. Potential benefits include anonymity, hands-free data visualisation for improved hygiene, and the ability to view dynamic and spatial data. Despite these potential benefits of mixed reality, its utilisation in neonatal healthcare remains limited. This study aims to address this gap by developing a proof-of-concept mixed reality application. The application will integrate real-time physiological patient data from cot-side monitors and other sources, along with relevant aspects of the patient's care record. This research involves selecting appropriate technology, conducting design workshops with clinical specialists, and developing two full-stack mixed reality applications. Subsequently, the applications are reviewed through a user evaluation. By introducing mixed reality technology to neonatal healthcare, this research aims to enhance patient monitoring practices and improve clinical outcomes.

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Chapter 1

Introduction

The potential of extended reality (XR) applications has been a topic of renewed discussion due to the significant advancements in headset technology in recent years (Banchi et al., 2024). Extended reality encompasses virtual reality (VR), augmented reality (AR) and mixed reality (MR). VR is a fully virtual experience, which first became popular within the gaming industry, with headsets such as the Oculus Rift and MetaQuest (Wohlgenannt, Simons and Stieglitz, 2020). Alternatively, AR overlays virtual objects onto the real world (Chuah, 2018). Augmented reality has found more use cases in marketing and social media (Mekni and Lemieux, 2014). MR combines both VR and AR, allowing the manipulation of virtual objects in the real world (Chuah, 2018). Recent improvements in microelectronics have enabled the possibility of MR headsets such as Microsoft's HoloLens and the Apple Vision Pro. This has been achieved by integrating cameras, sensors, and eye trackers, with high-definition screens to provide a fully immersive mixed reality experience.

Extended reality has provided great benefits to both small and large businesses. Both VR and AR have been utilised to help the visualisation of 3D objects within product design (Amuso, Poletti and Montibello, 2021), and also to overlay annotations and information onto objects in a user's view, which has enabled remote colleagues to contribute to discussions and design (Billinghurst and Kato, 1999). Being able to view dynamic data spatially through a headset also allows both hands to be free when working, which has allowed extended reality to be used within manufacturing (Amuso, Poletti and Montibello, 2021). This is particularly useful in a healthcare context as it means fewer devices and monitors need to be touched to be interacted with, which improves overall hygiene in a medical space. A further benefit of using extended reality headsets for viewing data is that the virtual objects are solely visible to the user. This allows for sensitive data to be visualised, without the risk of unauthorised viewers, which is beneficial to the healthcare industry, due to the high prevalence of sensitive data (Gritzalis and Lambrinoudakis, 2004).

AR was first introduced to healthcare by Roberts et al. (1986) by overlaying scaled computer data onto a microscope's view. This was to aid surgeons in seeing important information such as tumour boundaries while looking through a microscope. Today, medical students and professionals are being trained using augmented reality for simulating surgeries, learning about neurological procedures, and visualising anatomy (Barsom, Graafland and Schijven, 2016). However, very little research has looked at extended realities potential in neonatal care.

This research proposes a solution to the lack of extended reality being used in neonatal care, by developing a proof-of-concept mixed reality application to enhance patient monitoring. This application will merge real-time physiological data from cot-side monitors and other sources, alongside essential components of the patient's care record. The concept of the application is to visualise data in a 3D mixed reality which is currently being displayed on devices, monitors, paper, computers, and tablets.

Methodically, this research was completed by first selecting the hardware technology which was most suited to the project requirements. This was based on the technology review conducted in the literature, technology, and data survey. Multiple user-centred design workshops were organised with both neonatal clinical specialists and medical software experts to gather ideas and requirements for the prototype designs. Using this information, two mixed reality applications were developed using the architecture which is native to the chosen hardware. After the development stage of the prototypes was completed, the applications were reviewed by clinical specialists in the form of a user evaluation to evaluate the effectiveness and suitability of the concept.

This project aims to develop a collection of proof of concept mixed reality applications for displaying a combination of real-time physiological patient data from cot-side monitors and other sources, along with various aspects of the recorded care record for that patient. The aims of this project include:

- Identify the benefits and restrictions of using augmented, virtual and mixed reality in the healthcare industry, specifically, the neonatal intensive care unit (NICU).
- Work with clinical specialists and MedTech domain professionals to design the functionality and features of a range of mixed reality applications.
- Develop a collection of proof of concept applications which target the specialist's requirements.
- Evaluate the effectiveness and suitability of these applications and the technology as a tool in the healthcare industry and the NICU environment specifically.

Chapter 2

Literature and Technology Review

2.1 Functionalities of Extended Reality

Extended reality (XR) is a broad term which is used to cover virtual reality (VR), augmented reality (AR), and mixed reality (MR) (Chuah, 2018). It refers to the spectrum of all combinations of real and virtual environments, enabling a bridge between the physical and digital worlds (Morimoto et al., 2022).

Virtual reality is a "completely artificial computer-simulated image and environment with real-time interaction" (Khor et al., 2016). The concept of VR was first introduced by Sutherland (1965), although, for a long time, hardware struggled to meet the functional requirements, which led to some researchers believing that VR was a "dead" idea (Slater and Sanchez-Vives, 2016). However, the decades that followed saw rapid technological development, which enabled the development of low-cost VR headsets. These have had a huge impact on both the gaming and entertainment industries (Wohlgenannt, Simons and Stieglitz, 2020). VR games allow users to be transported to a fully immersive digital world, which can provide an enhanced gaming experience, largely due to the relative novelty of such gaming. Although some research suggests there are potentially negative effects such as addiction which come with a technology as immersive as this (Rajan et al., 2018).

Carmigniani and Furht (2011) define Augmented Reality as "a real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it". AR has traditionally been accomplished by projecting an image to an eye-piece to create 'smart glasses' (Hua, Brown and Zhang, 2011). There are many applications of AR, including for military purposes, manufacturing, the medical industry, visualisation, robotics, as well as the gaming and entertainment industry (Mekni and Lemieux, 2014). Although the name 'augmented reality' was first introduced in the 90s, it is still a relatively new concept and research is still to be done with regards to its applications.

Mixed reality is an amalgamation of both virtual and augmented reality (Tepper et al., 2017). This creates an immersive experience which allows users to interact with both real-life and computer-generated objects. Recent improvements in microelectronics have allowed MR to work using head-mounted projection displays (HMPD), which integrate cameras, sensors, and eye trackers, with high-definition screens to provide a fully immersive MR experience. The most notable of these is the new Apple Vision Pro, which was released at the start of 2024, and Microsoft's HoloLens, which was released in 2016, with the HoloLens 2 being released in

2019. Due to how recently The Apple Vision Pro (AVP) has been released, there is a lack of research thus far, evaluating the potential of this new technology.

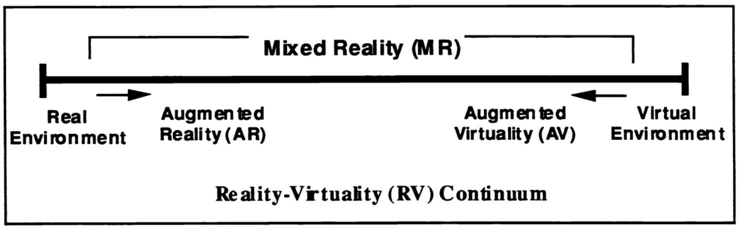

Figure 2.1: Spectrum of Extended Reality (Milgram et al., 1995)

In a real-life patient monitoring context, it is important that the real world is still visible, and any virtual data and information should be able to be interacted with to truly benefit from using extended reality. Therefore, this project will focus on developing a mixed reality application.

2.2 Extended Reality in Healthcare Applications

2.2.1 Medical Training

One of the most popular uses of augmented reality for medical training is the HoloAnatomy software developed by Case Western Reserve University (Wish-Baratz et al., 2019). This works with the Microsoft HoloLens to visualise detailed models of human anatomy. The user can interact with the virtual body and select smaller more detailed models. Multiple AR headsets can be connected to view the same model, allowing both teachers and students to collaborate. Ruthberg et al. (2020) published a study which looked at the learning time of medical students when revising anatomy using the HoloAnatomy software compared to cadaveric dissection, which is the traditional method. The study found that the students using HoloAnatomy averaged 4.5 hours to learn the material, compared to the 7.3 hours average time of the group using cadaveric dissection. This highlights how extended reality can be used as a tool to improve the learning time and experience of medical students.

The ability to practice complex surgeries and procedures can be achieved using extended reality. Cervical screw placement is renowned for being one of the most challenging spinal operations, which has led to Hou et al. (2018b) developing a virtual surgery simulator to help students practice the complex procedure. A group of non-experienced resident students used the virtual training and their procedure outcomes were then compared to those of a control group, to evaluate the effectiveness of the virtual training. The results showed a drastic difference between the groups, with 100% of the trained group's procedures being classed as 'acceptable', compared to the 50% of the control group. This study was backed up by the same researcher, who published a similar study looking at thoracic screws (Hou et al., 2018a). This paper showed 'acceptable' procedure rates of 100% and 93% by the trained group and control group respectively. They also state that the screw penetration rate of the trained group was 7% compared to the much higher rate of 30% for the control group. These research studies highlight that being able to visualise and interact with dynamic and spatial data can massively benefit the accuracy of procedures performed in the healthcare industry.

A further example of XR being used for surgical training is the research completed by Condino et al. (2018), who developed a patient-specific virtual simulator to help surgeons perform orthopaedic open surgery. Data from CT scans were used to create a 3D model of a patient's bone. From this model, they were able to scale the model to visualise the surrounding area in the body, where the procedure was taking place. This model was visualised using Microsoft's HoloLens, to provide the user with a more accurate understanding of the patient's anatomy during the operation. The testing simulator was trialled by experts and received positive feedback, which further emphasises the potential for extended reality to be utilised as a tool in healthcare.

2.2.2 Patient Monitoring

Extended reality has also been proposed as a solution for improving general patient monitoring. Teng et al. (2019) developed a mixed reality application which allows a user to monitor multiple patients across different rooms, from one place. This system incorporates monitoring devices for patient vitals and a live-streamed webcam in each patient's room, these are connected to a local server which is accessed by the MR headset. The application interface can be seen in Figure 2.2. The application was shown to a group of staff and students at the College of Nursing, and the feedback that was provided was "very positive". However, the group also highlighted that the hardware limitation was a key drawback. This research used the Magic Leap One headset which has a resolution of 1280x960 pixels (Teng et al., 2019). This is low compared to the mixed reality headsets available today, as seen in Table 2.1. Furthermore, the primary purpose of this application is to make it easier to spot potential problems with patients in care, however, this technology involves the user being in another room, accessing data for multiple patients. Therefore, if the user notices an issue, there is still a time delay as they will have to notify another doctor or nurse to attend to the issue. This suggests that the concept of a mixed reality patient monitoring application is sound, but the quality and implementation of the application are crucial.

Figure 2.2: Spectrum of Extended Reality (Teng et al., 2019)

More recently, Tanbeer and Sykes (2024) proposed a mixed reality application for monitoring patient vitals, using Microsoft's HoloLens. This project creates a virtual dashboard surrounding the patient which displays important data and information, as seen in Figure 2.3. The application uses facial recognition of the patient to display the correct information. However, this could cause potential problems with data security, as it is using a third-party facial recognition software which can't be fully relied upon to be accurate and also requires patient consent. Despite this, a user evaluation was completed, and the results suggested that the application was positively received, and 89% of participants believed that users would enjoy utilising the system (Tanbeer and Sykes, 2024). It is also emphasised that the inherent anonymity of visualising data through a headset helps with data security and allows for users with different levels of authentication. This research highlights the potential for a mixed reality patient monitoring system.

Figure 2.3: Spectrum of Extended Reality (Tanbeer and Sykes, 2024)

2.2.3 Maternity and Neonatal Care

The first implementation of extended reality being used in a maternity care setting was by a team at the University of North Carolina in the 90s. They developed a mixed reality system which projects the view of an ultrasound (typically displayed on a computer monitor) onto the abdomen of a pregnant person being scanned (Bajura and Ohbuchi, 1992). The projection is seen by the operator using an MR headset, allowing for a more in-depth understanding of the location of the area being scanned. This research set a precedent for what is possible using extended reality within maternity care.

The only example of extended reality being utilised in neonatal care to date is resuscitation simulation for training purposes (Ricci et al., 2021). This uses a physical baby doll whose movement is detected using microcontroller infrared sensors. This creates a 3D model of the baby which is visualised in a virtual reality delivery and operating room. This allows for a fully immersive experience when practising procedures such as resuscitation simulation. It is highlighted in this research that "neonatal tools are missing" when it comes to extended reality training, and that there is potential for it to be a useful tool.

2.3 Limitations of Healthcare Software

Developing software for the healthcare industry can be challenging due to the importance of patient data security (Fatima and Colomo-Palacios, 2018). Security is always an important consideration when developing software, but the confidential and sensitive nature of data used in healthcare makes it a primary priority (Gritzalis and Lambrinoudakis, 2004). Although it is important to protect data against hackers and security breaches, Fatima and Colomo-Palacios (2018) published a study which found that inside staff is the biggest threat to data security. This was mainly caused by password sharing amongst people and using one password for multiple accounts and devices, caused by a "lack of awareness and good practice among the staff". Interestingly, Narayana Samy and Ismail (2010) found that power failure is the biggest threat to patient data security, with human error being second. However, that paper is eight years older, which means the difference in results could be accounted for by an improvement in power reliability.

A further aspect that must be considered is the importance of being able to link to other medical devices (Kozareva, 2022). Hospitals and medical practices need to use multiple different software packages, so it is beneficial if they can communicate with each other, as this will improve patient data quality. This has been made possible by Health Level 7 (HL7), which is a healthcare messaging standard for data transfer (Dolin et al., 2001). The standard message formats use a set of codes for different medical terms and procedures, which allows devices, sensors, and software to communicate with each other. However, Xu (2021) found that some users describe the HL7 format as "really old", and that there is a "push" towards using the newer FHIR format. Fast Healthcare Interoperability Resources (FHIR) is built on the foundations of the HL7 format but allows specialists to provide more detail in messages (Bender and Sartipi, 2013). It also uses modular components, which allow for smoother transitions, and utilises the latest web service technologies, making it widely used as an industry standard.

One of the main limitations of ER in healthcare is related to accuracy issues and delays (Munzer et al., 2019). Incorrect data, or data being shown too late could have catastrophic effects on high-risk scenarios such as surgeries and emergency care. This is accompanied by the lack of haptic feedback when interacting with virtual objects, and the current high cost of ER hardware (Viglialoro and Gesi, 2021). However, further research and development in this field should mitigate these limitations.

2.4 Extended Reality Technology Review

The following section is a review of three popular extended reality headsets, the Apple Vision Pro, Microsoft HoloLens 2, and the Meta Quest 3.

2.4.1 Apple Vision Pro

The Apple Vision Pro (AVP) is the newest hardware to be added to the Apple ecosystem. It is a mixed reality headset which connects seamlessly to other Apple products. It was released at the start of 2024 after being announced in the summer of 2023. It tracks the user's eyes, hand position, and hand gestures to allow full control of a three-dimensional user interface. Even though the headset covers your eyes, it has cameras on the front which show a high-resolution display of the real world, making this a mixed reality system.

As this has only just been released, there are only a few apps which are designed specifically for the AVP. However, due to its ability to connect to other Apple products, one of the benefits of the AVP is the fact you can create a three-dimensional workspace which can connect to existing web applications and iOS apps. Apple has also developed visionOS which is the "world's first spatial operating system" (Apple, 2023), that allows for applications to be developed by anyone for the AVP.

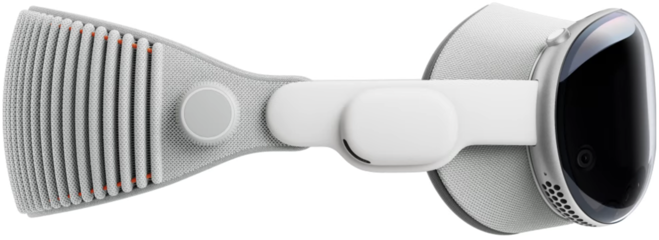

Figure 2.4: Apple Vision Pro (Apple, 2024a)

2.4.2 Microsoft HoloLens 2

Microsoft released the first HoloLens in 2016 as their first mixed reality headset. It is closer to augmented reality than virtual as the headset is similar to glasses with a screen for projection. It can be used to interact with 3D virtual objects which makes it classed as mixed reality.

Figure 2.5: Microsoft HoloLens 2 (Microsoft, n.d.)

The HoloLens 2 - the next generation of HoloLens - was released in 2019. However, since then, Microsoft has announced that they are not going to develop a third generation. Microsoft did not intend for the HoloLens to be used by the everyday consumer but instead wanted it to be used in industry for manufacturing, engineering, healthcare, and education. The device also uses hand, gesture, and eye tracking to interact with 3D virtual objects.

2.4.3 Meta Quest 3

The Meta Quest 3 is the newest generation of Meta's virtual reality headsets. This is the first Meta headset to feature sensors and colour pass-through, which allows for it to be used for mixed reality. It was announced in the summer of 2023, and released later in the year for commercial sale. The Meta Quest 3 has become popular due to its powerful VR gaming experience, which is the primary focus of the headset design. Additionally, the Quest 3 can be connected to a computer to create virtual reality monitors. The Meta Quest 3 does not utilise eye, hand, or gesture tracking, but instead has two handheld controllers which allow the user to interact with the virtual environment.

Figure 2.6: Meta Quest 3 (Meta, n.d.)

2.4.4 Comparison

It is highlighted in section 2.2 that some of the potential benefits of extended reality in healthcare include anonymity, hands-free data visualisation for improved hygiene, and the ability to view dynamic and spatial data. Table 2.1 shows a comparison of the headsets described in section 2.4.

Table 2.1: Comparison of Headsets

Device	Released	Cost	Hands Free	Resolution	Refresh Rate
Vision Pro	2024	$3499	Yes	3660 × 3200	100 Hz
HoloLens 2	2019	$3500	Yes	1440 x 936	75 Hz
Meta Quest 3	2023	$499	No	2064 × 2208	120 Hz

The older technology of the HoloLens 2 is not up to the standard of the more recent headsets. It has a lower resolution and refresh rate, which will negatively affect the quality of interaction with dynamic and spatial data. Although the Meta Quest is considerably cheaper than the Apple Vision Pro, its lack of eye tracking and gesture recognition means the interaction with virtual objects is done using hand-held controllers. Not being hands-free takes away the hygiene benefit of using a headset for data visualisation. All three headsets fall into the bracket of mixed reality, which means that virtual objects are only being visualised for the user. This gives all three options the ability to have anonymity integrated into their applications.

2.5 Summary

There is a clear need for further research to be completed which looks at the potential for extended reality to be incorporated into neonatal care. The concept of using ER for patient monitoring has been proven to have potential once the hardware can meet the expectations. Data security, following industry standards, and the ability to connect to other devices and software are important considerations for developing healthcare software. The Apple Vision Pro is the most suitable mixed reality headset for patient monitoring due to its high resolution, fast refresh rate, and its ability to manipulate virtual data hands-free.

Chapter 3

Methodology

3.1 Overview

This research aimed to develop a novel application to analyse the suitability of mixed reality in neonatal intensive care. To gain an insight into the potential benefits, limitations, and functional requirements of such an application, six industry specialists were recruited to conduct three user-centred design workshops (Chapter 4). The results from these workshops were used to design two mixed reality applications, which are described in detail in Chapter 5. Finally, the participants from the design workshops were shown a demonstration of the prototype as part of a user evaluation, which provided qualitative feedback on the quality and suitability of the design (Chapter 6).

3.2 Methodological Justification

For this research, a user-centred design (UCD) workshop will be conducted to define design requirements for the mixed reality application. A user-centred design workshop is an approach to the development of software or hardware which actively involves the users, iterates through multiple designs and solutions, considers both user and system functionalities, and works with multifaceted teams (Gulliksen, Lantz and Boivie, 1999). A UCD workshop involves collaborating with end users of a product or system through an interview or group discussion to aid the design process. These can be with individual participants, or with larger groups. Gulliksen, Lantz and Boivie (1999) also highlight the importance of prototypes and visual aids for generating new ideas, better feedback, and a more in-depth interaction with the users. Edwards et al. (2003) call attention to the fact that using UCD as the methodology for technology development can lead to an initial scope which is too broad. This is due to participants suggesting too many functionalities before the core requirements have been decided and implemented. However, this project focuses on the early stages of design, meaning the broad perspectives provided by clinicians and specialists, which are unknown to the researcher, are crucial to the development of this application. This is supported by Gausepohl et al. (2016) who emphasise the importance of using UCD for healthcare solutions, due to the high number of potential end users. Medical software is used by doctors, nurses, patients, and many others, which means that focusing on user requirements is imperative for an effective solution.

Sirimsi et al. (2023) developed a toolkit to improve interprofessional collaboration and integration in primary care, to improve the workflow of care providers working internally with their colleagues, and externally with different medical practices. This was achieved using an iterative and interactive design process which included "13 in-depth interviews", "five focus groups", and "eight co-design workshop sessions", which were conducted using 65 care providers and academics. The data collected from these sessions was used to develop the content for their toolkit. The paper's researchers believe that the chosen methodology massively benefited the quality and usefulness of their software, due to the exact requirements of the users being achieved. A further example of UCD workshops being used for technology development is the research conducted by Fraune et al. (2022). They aimed to develop a socially facilitative robot to help older adults who suffer from loneliness and isolation. Groups of participants were interviewed with the session having a heavy focus on the participant's life experience. The researchers state that this built a solid foundation for the conversation which helped engage the participants and allowed them to be more creative. These papers highlight the positive results of using user-centred design workshops as the methodology for technology development.

3.3 Participants

A group of 6 participants (P1-P6) were recruited for this research, who were a combination of clinical specialists and medical technology professionals. The clinical specialists included senior neonatal intensive care nursing specialists and consultants, a neonatal nursing manager at an NHS Trust, and an NHS Trust Information Technology Clinical Lead. These two backgrounds were chosen to bridge the gap between the functional needs of nurses and doctors and what is achievable in medical software. The three user-centred design workshops and user evaluations each had two participants, which allowed for group discussions in all activities.

3.4 Data Processing

A lightweight thematic analysis of the transcripts was conducted to identify the relevant qualitative data gathered from the user-centred design workshops and user evaluations. Thematic analysis is an analytical method for processing qualitative data to identify and analyse themes (Braun and Clarke, 2006). The recorded audios of the sessions were transcribed, and reread multiple times so that the researcher could familiarise themselves with the data. The important ideas highlighted in the transcripts were segmented into features (also known as codes), allowing themes to be defined based on the original data. These themes then went through a review process to ensure that they were clear, specific, and had enough data to support their relevance. The themes of the design workshops were used to design the prototype mixed reality applications. Additionally, the most prevalent themes from the user evaluations were used to assess the effectiveness and suitability of the design.

Chapter 4

Design Workshop

4.1 Overview

Three user-centred design workshops, each with two participants, were carried out with the goal of identifying and discussing the potential benefits and limitations of a mixed reality application for enhancing neonatal clinical care. These were then used to define a set of functional design concepts. Each workshop lasted between 40-60 minutes, with the first 10 minutes being an introduction to the research, a description of mixed reality, and an introduction to the Apple Vision Pro. As described in Section 3.4, thematic analysis was used to identify themes in the workshop discussions, as seen in bold below.

4.2 Benefits

One of the main benefits the participants highlighted is the ability to have very **ultra-wide application windows** (Figure 4.1). The clinical specialists described how a lot of their work consists of comparing notes and data from different applications, and that being able to see all of them clearly would be of great benefit. Therefore, they suggested it would be really useful to show all this information simultaneously for easy comparison. Two different participants gave the example of nursing charts, which before modern software technology, were printed-out A3 charts that the nurses used to monitor patients. Now these charts have been moved to screens but are limited in size due to hardware dimensions, which means they have either been broken up into smaller charts or require vertical and horizontal scrolling. They suggested that going back to large nursing charts would be useful, which the Apple Vision Pro could allow. Participant 6 also suggested that being able to turn the data on these charts into graphs would make it easier to identify points of interest. These charts are updated hourly by the nurses who complete 'observation rounds'. This involves taking readings from devices and qualitative data from looking at the baby, which is then inputted into the patient monitoring software that they are using.

An extension of this idea is to use the AVP's ability to seamlessly **integrate into the Apple ecosystem**. It can be connected to an Apple Mac laptop to create an extra-wide virtual display, which would allow users to view the applications they currently use on a large display.

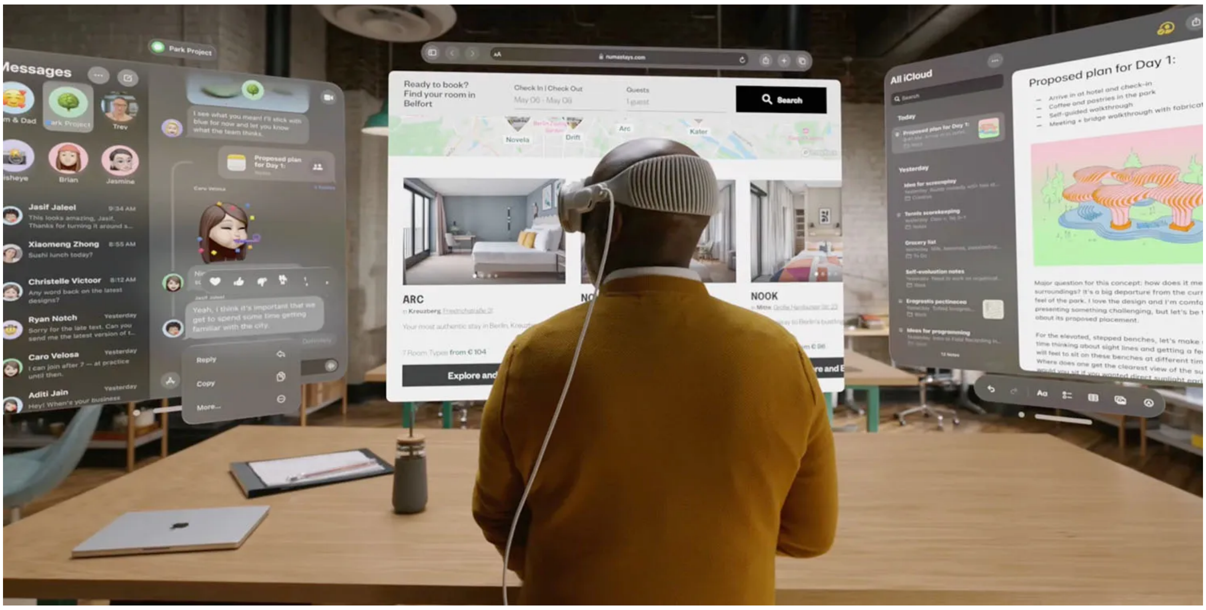

Figure 4.1: Apple Vision Pro User Interface (Apple, 2024a)

Multiple of the Med-tech professionals suggested that they don't see the AVP as a mixed reality headset but as a **single human-computer interface**. They highlighted that they currently use multiple interfaces for different software packages, devices, and medical kit. They require users to move to and interact with a physical device and they usually need to log in each time. The AVP could allow for one interface for all these solutions. This idea was also brought to light by one of the nurses who described how doctors are constantly asking nurses to temporarily log off the cot-side computers so that they can use them, which wastes time, and requires the keyboards to be sanitised between uses. This discussion led to one of the clinical specialists proposing the idea that as you approach a baby in a cot, specific data about that baby could be shown to the user. This would allow them to quickly find out information about that baby without having to look them up in their patient monitoring software. However, it was noted that for it actually to be useful, it would have to be really simple and intuitive, otherwise, simple paper notes would still be superior.

Participants 1 and 2 discussed the potential for virtual whiteboards to be used in wards. Currently, most neonatal wards have a whiteboard on the wall with some basic information about the babies in each cot. This helps with the changeover of staff and for easy familiarisation of the babies. However, they noted that some parents have started complaining that their baby's data is being shown to other parents who are visiting the ward. This led to the idea of having the **whiteboard as a virtual window** as part of an application so that only relevant staff with an AVP headset would be able to see this information. It would allow you to also include more rich data, as well as, showing sensitive information such as important social notes about the parents. Participant 4 similarly described this concept but suggested that different roles could see slightly different things.

A key functionality of mixed reality software is the ability to **view and interact with 3D models**. The participants suggested that this could be useful, but would more likely be used as a tool for training. Participant 2 also proposed that being able to visualise 3D things like hearts, digestive tracks, and bowels would allow better explanations to parents if their babies have problems with theirs. Apple has also developed a machine learning API which allows the Apple Vision Pro to use **object detection** for predefined 3D models and 2D images. This could also be used for training purposes, to teach students about different pieces of equipment, and by parents, to help understand the care their baby is receiving. Participant 5 proposed that the object detection API could have some value. They suggested that if a name and short summary of a device were shown when detected, this could be used by parents to understand the devices being used to treat their baby. Additionally, since the device is aware of what you look at, this could be turned into data. For example, it could create a log record of what cot a nurse walked up to, and what machines they looked at.

The participants frequently mentioned how important data collection is for reviewing decision-making to improve future care. Participant 4 reported that their ward had considered using body cameras during crises. The Apple Vision Pro not only has the ability to **record the user's point-of-view** but also the exact point of the screen where the user's eyes are looking. These videos could be used for reviewing important decision-making moments, training, and solving liability issues. The ability to record the user's view means that **screen sharing** while on a call to someone is possible. This could massively benefit consultants who are working from home, to get a better understanding of issues occurring in the ward. A mock-up design for this concept has been provided by Apple (Figure 4.2). This same concept could also be used by nurses and parents if they are unable to be present in the ward. The clinical specialists highlighted how important the relationship is between nurses and parents, and that this feature could improve that connection.

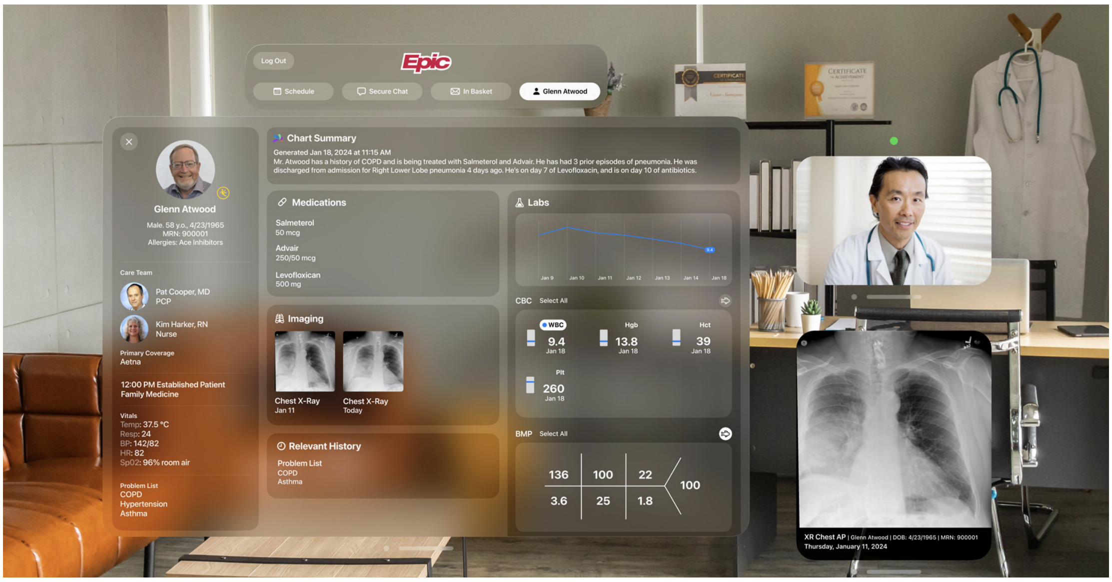

Figure 4.2: Apple Vision Pro Concept Design (Apple, 2024b)

A further benefit of the Apple Vision Pro is the integrated **dictation for text input**. Participant 3 described how keyboards are *"really common causes of infection"* due to the difficulty of cleaning them. Therefore, it was noted that being able to input data into forms hands-free could reduce the risk of infection in the ward. Participant 5 also noted their appreciation for the speech-to-text input and suggested that this could be used for writing long-form patient notes. The ability to use **spatial computing** was noted as a potential benefit. Often, when performing procedures on a baby, nurses and doctors need to memorise a few key bits of information. If they could pin a window of notes in space next to the location of the procedure, then this would be really useful.

4.3 Limitations

A critical limitation that most of the participants mentioned is the fact that the **headset can't be sterilised**. This is a requirement of all equipment that is used in the ward, but due to the fabric headband of the AVP, this is not possible. Additionally, some of the participants complained about the **bulkiness of the headset** (shown in Figure 4.3), with participant 2 saying it *"looks ridiculous to be walking around a ward wearing it"*. However, it can be presumed that future generations of the hardware will likely reduce in size and not require this fabric head strap. It was also pointed out that during the Covid-19 pandemic, nurses and doctors were forced to wear masks and visors which the parents found unsettling initially. Eventually, they got used to them, and this became the norm. Furthermore, with the current price of the AVP being £3500, the **cost is a crucial limitation**. Every staff member in the ward would require their own headset to reduce infection risk, and Apple intends for the devices not to be shared. Most neonatal wards would not have the budget to purchase these for all staff members unless they provided a serious benefit. Nonetheless, the price of these headsets should likely be reduced with further generations.

Figure 4.3: User Wearing the Apple Vision Pro (Apple, 2024a)

Participant 1 was concerned with the amount of **training** that would be required for the users before any application could be used. Mixed reality is a completely novel concept to most people, and so integrating it into the workflow of nurses and doctors would take a long time. It was also highlighted by Participant 1 that the *"modelling of 3D objects in this setting is quite limited by the kit"*. A lot of the devices used in neonatal **can't create 3D models** of things. This could be made possible with 3D X-rays, but when dealing with babies, this would be very difficult. This is backed up by Participant 4 who said *"There is very little data in neonatal care which is being collected in 3D. I can't see much benefit to viewing 3D models in this setting, other than for the purpose of training using 3D object simulations."* This suggests that the ability to utilise the 3D modelling capabilities of the AVP is being limited by the state of the industry's technology.

Some of the clinical specialists were concerned with the **potential distraction** that these virtual windows could cause. Participant 2 suggested that the automation of data being shown could stop nurses from looking at and interacting with the baby they are caring for, as they become too reliant on data. They highlighted the fact that no amount of data can't pick up small nuances such as slight changes in colour, facial expressions, or a slightly swollen belly, which is why looking at the actual baby should always be the priority.

4.4 Functional Ideas

After discussing the possible benefits and limitations of mixed reality in neonatal intensive care with the clinical specialists, a list of possible functional design requirements was created. Table 4.1 lists each of these features with a corresponding priority of development (1-8, where 1 is the highest priority), which the researcher decided. The priority refers to the order in which the researcher aimed to develop each functionality into the prototype application based on the findings from the design workshops. Due to the short development time of this research, it was important to focus on the most impactful design features. For further justification of using the Apple Vision Pro for this research, each of the mixed reality headsets described in the literature review has been compared to show which are compatible with each functional requirement.

Table 4.1: Functional Design Requirements in order of design priority, with a comparison of three major headsets' ability to incorporate each function

Priority	**Functionality**	**Apple Vision Pro**	**Meta Quest 3**	**HoloLens 2**
1	Ultra-wide Applications	Yes	Yes	No
2	Virtual Location Association	Yes	No	No
3	Screen Sharing	Yes	No	Yes
4	Speech-To-Text	Yes	Yes	Yes
5	Image and Object Detection	Yes	No	Yes
6	3D Model Interaction	Yes	Yes	Yes
7	Record User View	Yes	Yes	Yes
8	Ecosystem Integration	Yes	No	No

The highest priority concepts were the ultra-wide application windows and the virtual location association. This is due to the fact that on numerous occasions, the participants mentioned that they would like to be able to view charts and other data forms on a large screen. The concept of real-world location association is important in the context of walking up to a cot and having summary information shown in front of you, as well as the idea of pinning relevant notes next to you during a procedure. Both the ability to share the user's screen with others and use dictation for text input were deemed to be really useful by the participants, but they are built into the AVP so they don't require any additional development. It was decided that interacting with 3D models wasn't a high priority due to the lack of 3D data collection in neonatal intensive care. However, it was highlighted that there could be scope for the image and object detection features as a training tool for parents. Finally, both the ecosystem integration functionality and the ability to record a user's point of view could have potential use cases, but again they are already integrated into the headset so don't require any specific development.

Chapter 5

Detailed Design

5.1 Overview

After conducting the user-centred design workshops, the concepts that were deemed to be of the highest priority were utilising large spatial windows for viewing multiple forms of patient information, and the ability to have summary information associated with a physical location for quick hands-free data viewing. Therefore, it was decided that two mixed reality applications would be developed, **MED-MR-Desktop** and **MED-MR-Ward**. This Chapter presents the design of these two applications and describes their functionality.

5.2 MED-MR-Desktop

The purpose of the MED-MR-Desktop application is to provide medical professionals with the ability to view patient notes in the form of multiple large spatial windows. It is designed to be used while sitting at a desk and in conjunction with other applications. Figure 5.1 shows an example main menu of a patient's notes. It is made up of several modular blocks which can easily be set up for different configurations, each of which represents a type of patient data.

Figure 5.1: Prototype Application MED-MR-Desktop Main Menu User Interface

The first block provides patient summary information such as the name, weight, and gestation of the baby, as well as the allocated nurses and consultants. These key-value pairs can also be used to display colour-coded parameters such as social care consideration and infection risks. The second block displays a timeline of the patient's care. This includes when they were born when they were transferred, what day of care they are currently on, and the location of each of these events. This timeline provides the nurse or doctor with a quick overview of the patient's care up until that point.

The main benefit of this application compared to using a regular desktop or tablet application is the ability to view large-scale charts. If the user clicks on the 'View' buttons found on the 'Nursing Charts' block, an additional window will pop up that displays a chart of key patient information. This data can be represented by graphs, tables, or a combination of the two. Two examples of these have been developed which can be seen in Figure 5.2. These are based on the nursing charts described during the user-centred design workshops, which show numerical and text-based patient information. They include core patient monitoring data such as heart rate, oxygen saturation, and medication dosage, as well as neonatal-specific observations such as belly appearance and girth size. These windows can be resized and repositioned anywhere in the user's view, allowing an entire day's worth of data to be analysed in one view. The windows can also scroll horizontally, which allows the user to view older data.

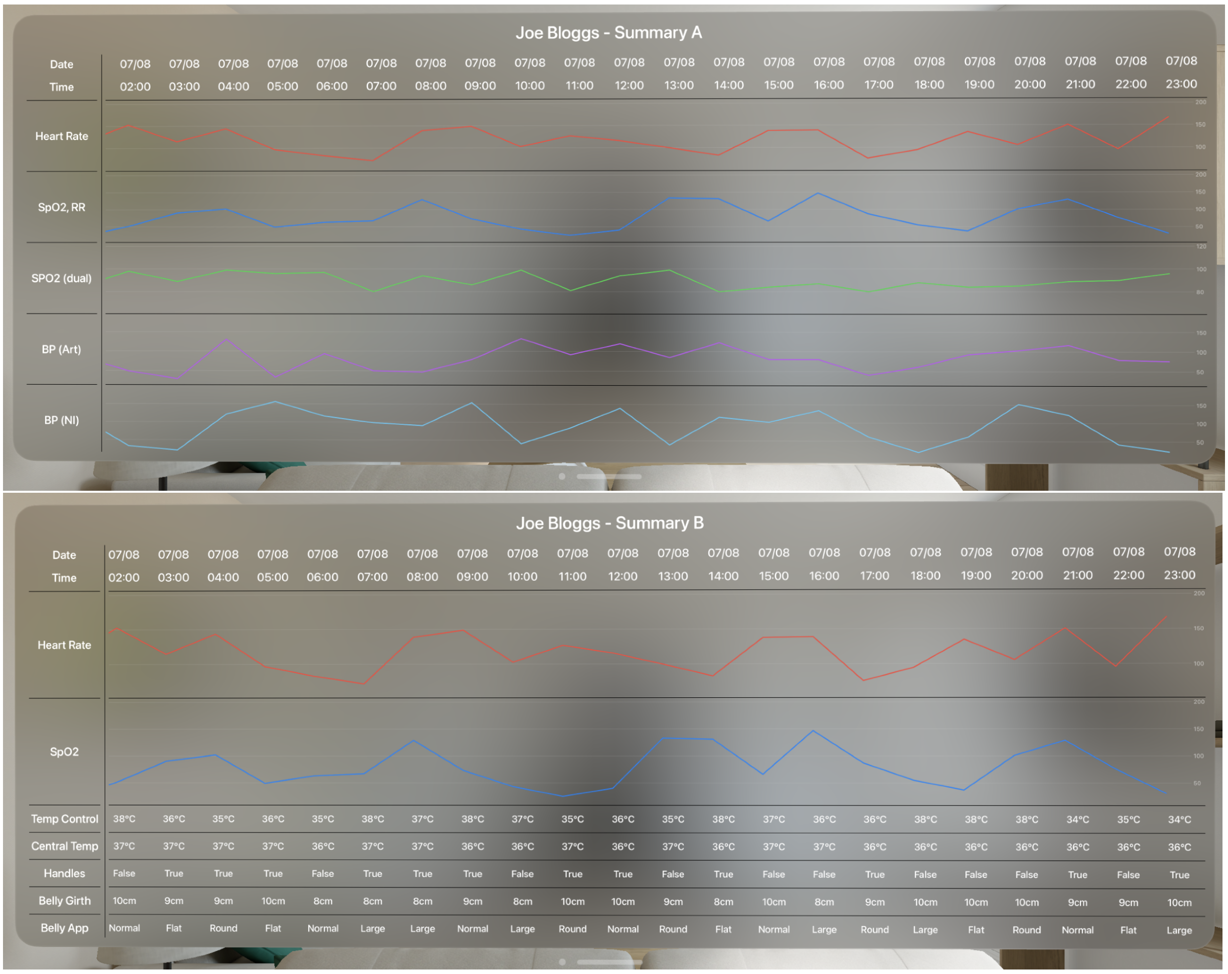

Figure 5.2: Additional windows of the prototype application MED-MR-Desktop which display patient data as both tables and charts

The speech-to-text dication was highlighted by the clinical specialists during the design workshops as having great potential. This has been incorporated into the design of this application through long-form text-based patient notes. The fourth block of the main menu (Figure 5.1) titled 'Detailed Notes' provides a list of submitted notes about the patient. If the user clicks the 'View Detailed Notes' button, a new window is added to the view which displays these notes, as seen in Figure 5.3. The name of the patient is displayed at the top of the window, and there is a list of all available notes on the left. When selected, the full note will be displayed which includes the subject, author, time of entry, and the full-text message.

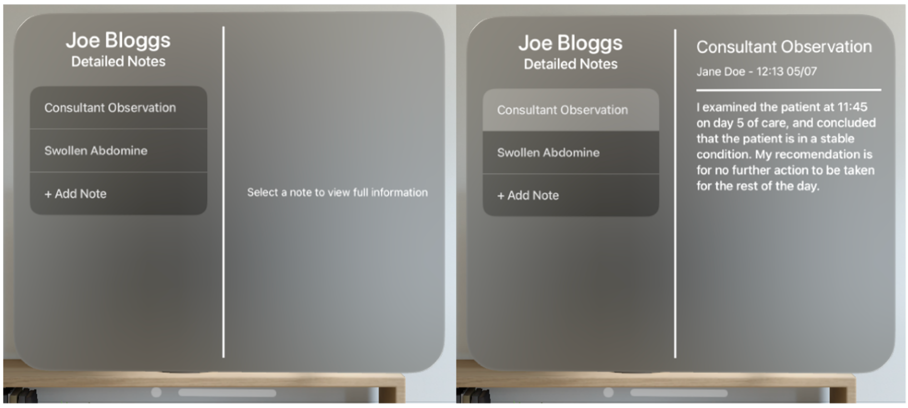

Figure 5.3: Additional window for the prototype application MED-MR-Desktop which displays longer patient notes as text

At the bottom of the left-hand list, there is an option for the user to add a new note. When this is selected, a form appears on the right with text input fields for the note's subject and contents (Figure 5.4). The user can enter information using the pop-up keyboard, or by clicking the microphone icon in the top left to start dictation. Once they have finished dictating, they can click the 'Submit' button, and the note will be added to the list. This provides a hands-free way of quickly creating patient notes.

Figure 5.4: Example demonstration of using speech dictation to add a patient note to the prototype application MED-MR-Desktop

An additional feature of the MED-MR-Desktop application is the pop-out image windows. Examples of these windows can be seen in Figure 5.5, including chest X-rays, cranial ultrasounds, and cot-side images. These windows display a collection of images which the user can cycle through by horizontally swiping the image. Each image has an associated time and date, allowing it to be compared to other data types at the corresponding time. Some basic information about the patient is provided above the image to provide necessary context. These windows can be repositioned and resized by the user, which allows them to analyse the images in greater detail, and compare different image types.

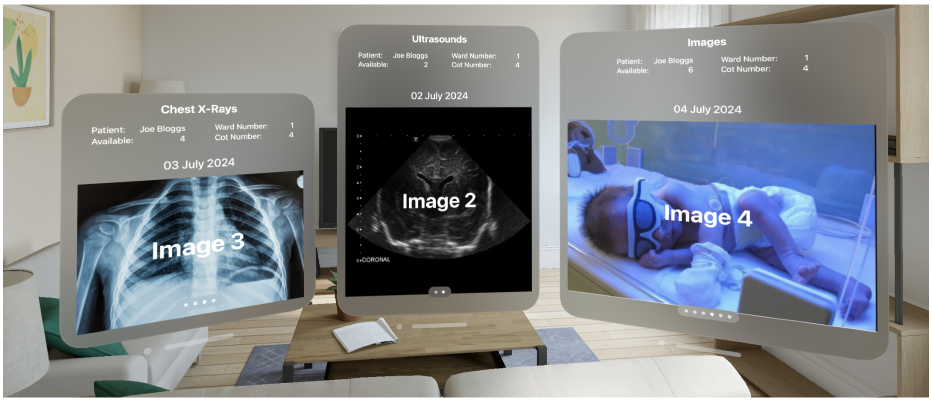

Figure 5.5: Additional windows for the prototype application MED-MR-Desktop which display images such as ultrasounds and X-rays

The modular structure of this application allows for multiple windows to be open simultaneously, as seen in Figure 5.6. The user can change the size and position of each window to create a range of custom views, which allows for a more thorough analysis of all the patient data available. Since every data type has an associated time and date, this app provides detailed insight into a patient's condition at a given time. This single interface for viewing multiple data types was a highly requested functionality from the design workshops.

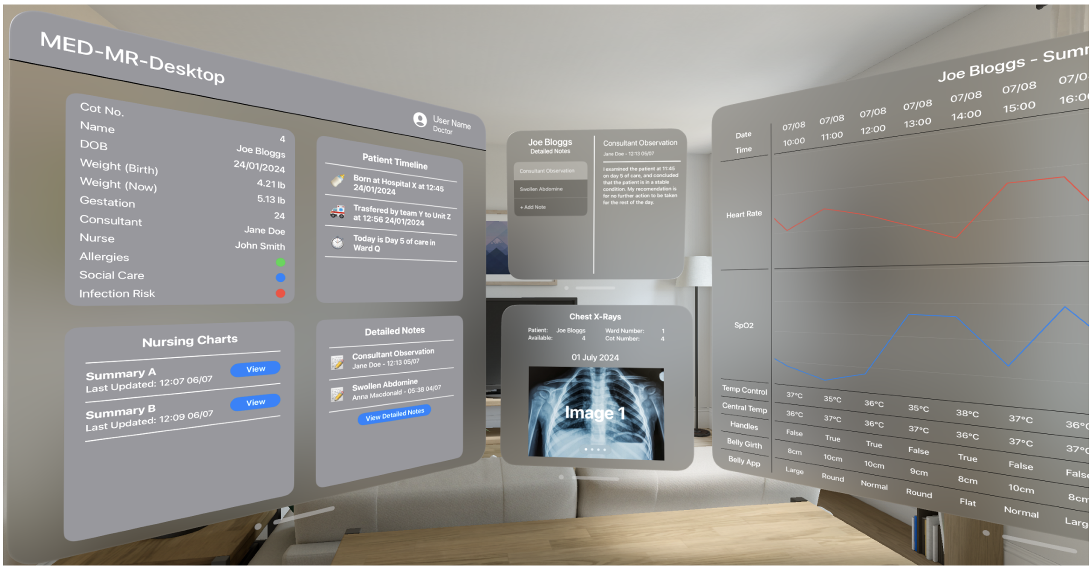

Figure 5.6: A demonstration of viewing multiple windows of a patient's notes simultaneously using the MED-MR-Desktop prototype application

5.3 MED-MR-Ward

The second application developed as part of this research is called MED-MR-Ward. The idea behind this app is that a doctor, nurse, or consultant could walk around a neonatal ward, and as they approach an incubator, they can view some basic summary information about the patient they are looking at. This is a more immersive application which leans more towards the concept of spatial computing. When the user opens the app, they are welcomed with the main menu shown in Figure 5.7. Here they can turn on the image detection using the toggle, which is the back-end control of this app. They are also instructed to close this window after turning on the image detection, due to the fact it is no longer needed.

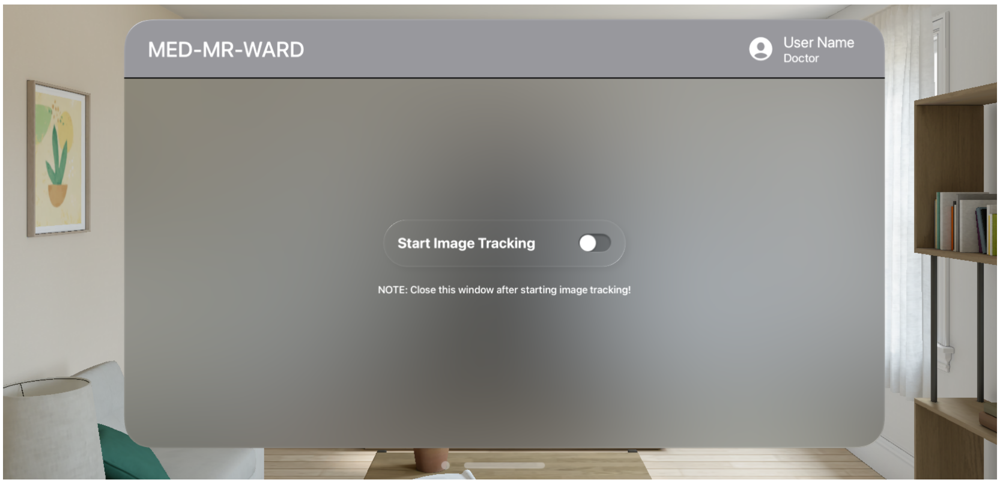

Figure 5.7: Start page of prototype application MED-MR-Ward which allows users to start image tracking

Apple have developed their own image detection and tracking API which is used in this application. The API searches for predetermined images, which for this to work effectively need to be high quality, textured, have no uniform coloured regions and have a high contrast pixel histogram. The images that were created for this app can be seen in Figure 5.8. When multiple images are being used, they must be different enough for the API to make the distinction. The background images were chosen to be grayscale, so as not to be a distraction when attached to an incubator. Further research should be conducted into the limits and requirements of these reference images.

Figure 5.8: Cot reference images that were used as part of the image detection API for the MED-MR-Ward Cot application prototype

Once the image tracking has commenced, the AVP starts to search for the reference images. Once one is detected, a virtual 3D entity is created with the corresponding patient's name (left image of Figure 5.9). This will float in space 30cm above where the image has been detected and is anchored in this position. This means as you move around the room, the entity will remain in place. If the reference image is moved, then the entity will move with it. This allows the virtual content to have an associated position in the real world. When the user clicks on the virtual entity, a window opens with summary information about that patient. This works with multiple patients, as each reference image has a unique ID associated with the patient. This means that once the user has detected each image, all the different entities will remain in their correct position, and the user can quickly switch between which patient's data they are viewing. This whole process is done hands-free and requires no data input to find the patient of interest, making this a quicker and more hygienic method for patient monitoring.

Figure 5.9: Demonstration of the MED-MR-Ward image detection with virtual patient name entity, the window on the right is displayed when the entity is clicked

As described above, when the user clicks on the entity, the corresponding patient's information is displayed in a new window. This window has a tab bar on the left which allows the user to change views (Figure 5.10). The first view is a summary of the patient's details including name, date of birth, weight, gestation, and assigned nurse and consultant. The second view is a list of the devices currently connected to the patient. These can be selected to view more detailed information about the device, including the recent readings. The final view is a checklist of tasks that need to be completed for that patient with a countdown timer for each item.

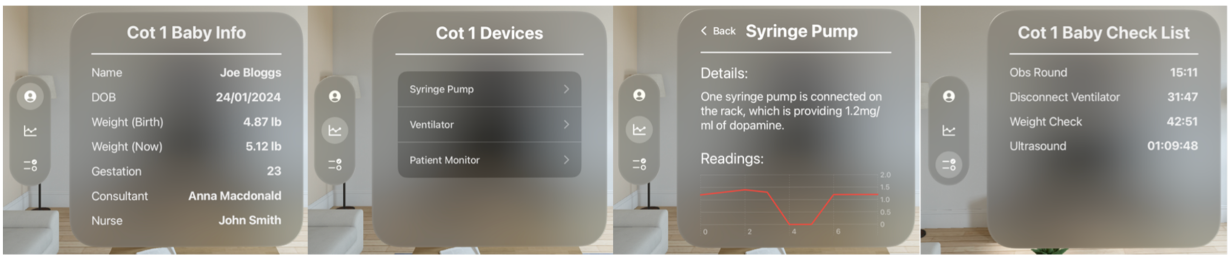

Figure 5.10: User interface of the pop-up patient summary window from the MED-MR-Ward prototype application

This app is designed to be used by nurses, doctors and consultants whilst completing ward rounds, with the purpose of quickly familiarising themselves with the patients being cared for. Further development of this application would focus on introducing additional tabs with more detailed patient data.

Chapter 6

User Evaluation

6.1 Overview

Three user evaluations were conducted, again each with the same two participants from the user-centred design workshops. These sessions lasted between 30-40 minutes and involved a demonstration of the prototype applications and a chance for the participants to try on and use the headset. They provided qualitative feedback on the quality and suitability of the two applications. As described in section 3.4, a lightweight thematic analysis of the transcripts was conducted to identify themes in the collected qualitative data which are in bold below.

6.2 Results

One of the key issues that was discovered during the user evaluations is the **difficulty of sharing** the headset. When you set up the Apple Vision Pro out of the box, there is a lengthy calibration process for both your eyes and hands, this optimises the eye and hand gesture tracking. When you purchase the headset itself, you also must create a 3D scan of your head shape, as there are different-sized moulds for the foam that rests on your face. Since the headset had been set up for the researcher, this meant that when the participants tried on the headset, some found that it either didn't fit very comfortably, the screen was out of focus, or the eye tracking was inaccurate.

The general census of the participants was that both applications were designed well, and had the potential to provide great benefit to the industry. Participant 1 noted that they really liked the fact that what the user is viewing is totally **private** and since a lot of the data they look at is very confidential, this is a really useful feature. They also described how the concept of using the desktop app whilst also being on a call with someone and **sharing your screen** was one of the best use cases. Many consultants have days where they work from home, and so being able to quickly show them all of a patient's data in one view could quickly bring them up to speed with the issue being discussed. Participant 4 also thought that the most relevant feature is the privacy element. They loved how a user could be in a ward with members of the public walking around, or in a busy doctor's office and look at a single patient's record in privacy. This type of information governance isn't being utilised by the current solution of laptops and tablets, which enforces the potential suitability of using mixed reality. Participant 6 said they *"loved the large nursing charts and images"* and described how often they will use large digital whiteboards to review notes, but being able to make these even bigger and be able to show **multiple windows** at the same time could really *"improve the quality of their review process"*. Participant 3 suggested that although the content of the desktop application is no improvement upon current solutions, the ability to turn the whole wall into a multi-window large screen format which would allow them to view *"wider periods of time on the nursing charts, but at the same time see images or lab results"* really appealed to them as a concept. They described that this was how notes were read in the past, with lots of sheets of paper spread out, but that they have lost the ability to do this with the restrictions of screen sizes. Participant 4 really liked the **speech dictation** notes, but pointed out potential issues, such as not being able to read out sensitive information in front of other staff members or parents, and the potential for complex medical terms not being understood correctly. However, they also mentioned that speech dictation will get better, and with large language models and artificial intelligence plugins, the accuracy will improve. When talking about the MED-MR-Ward application, Participant 2 highlighted how they think the hands-free data viewing is a major improvement in terms of hygiene and infection risk, and that this will be the *"future of medical data consumption"*. Every participant said that after seeing the headset in real life and seeing what was possible with the two prototype applications, they were more or equally excited about the idea of mixed reality being used in neonatal intensive care.

However, the most frequently mentioned limitation of these applications was the fact that the **hardware needs to improve**. Participant 1 said that they *"really like the way that you have the modelled apps"* but that *"technology and society need to catch up"* to make these viable solutions. Similarly, Participant 3 said, *"The hardware as it is now, is certainly not appropriate for a neonatal intensive care unit."* However, they also reinforced the idea that in the future, as Apple improves the hardware, the prototype applications could *"become a viable solution"*. Participant 2 made an interesting point about how neonatal care is a very emotive experience, especially between the parents and doctors, and they believed that the size and appearance of the headset made the user appear *"quite creepy"*. However, they believed that the concept had real potential, so if the hardware were to reduce in size in the future, then this could add real value to the care they provide. They described the MED-MR-Ward application as *"really good and really useful"*, but they said it is not appropriate with the current technology and with the current public perception of wearing a mixed reality headset. When analysing the MED-MR-Ward application with Participant 5, they noted that for it to have real value, it must be integrated into what already exists. The patient monitors, devices with interfaces, and the baby itself will always be the priority, but if the mixed reality application can complement these as opposed to replacing them, then that would be a *"really elegant solution"*.

In terms of new ideas, participant 5 believed that the true value of mixed reality applications in a neonatal setting is **for the parents**. They suggested using image and object detection to label and provide information about devices and equipment in the ward to make the parents feel more comfortable. They also noted how a lot of parents are very nervous about coming into the ward at all, and so if they could do a virtual tour of the ward at home using the headset, then that might make them feel comfortable enough to go to the actual ward. They also identified that screen sharing ability would be really useful for situations where one parent is in the ward, and the other is at home or unavailable to attend in person. Whilst wearing the headset they could join a call with their partner and share their screen whilst looking at their baby. This would provide a much more immersive experience for parents who can't attend the ward in person. This was also noted by Participant 2 who made the point of how useful screen sharing could be for parents who can't be in the ward in person.

Chapter 7

Discussion

The majority of the discourse regarding the suitability and efficacy of the two prototype applications has been addressed in Section 6.2, which contains the user evaluation results. This chapter aims to discuss and evaluate the methodical procedure that was used to conduct this research.

User-centred design workshops were chosen as the idea-generation method for the prototypes due to the narrow scope of the project. The difficulty of finding participants who are both knowledgeable about neonatal intensive care and aware of mixed reality as a concept limited the number of participants that were recruited for this research. This resulted in sessions with only two participants each, which led to more in-depth discussions. The participants were recruited to discuss the benefits and limitations of using mixed reality in neonatal care, to create design requirements for potential prototype applications. Although the analysis of these sessions was conducted using thematic analysis, it is reasonable to suggest that since the researcher was also part of these discussions, their influence could have affected the qualitative data collected. However, it should be emphasised that the majority of the researcher's input in the discussions was describing technical features of the Apple Vision Pro to encourage idea generation.

The two prototype applications that were developed for this research successfully demonstrated the potential for mixed reality to be used in neonatal intensive care. Together, they incorporated 6/8 functional design requirements that were defined after the design workshops, with the two remaining features being screen sharing and 3D model interaction. It was not possible to test the shared screen functionality due to the limitations described in section 7.1, and it was decided that due to the lack of existing data, 3D models would not be incorporated.

The three user evaluations that were conducted provided qualitative feedback on the suitability of the prototypes. The same participants from design workshops were used as it meant they were already familiar with the project. Since the prototype applications were very basic and aimed to visualise conceptual ideas, it was difficult for the participants to provide detailed feedback on the user interface and content of the applications. This meant that the majority of the discussions were centred around the limitations of the hardware. The researcher had very little input in these discussions, to allow the participants to provide honest feedback.

7.1 Limitations

This research was limited by the specific and narrow scope of focusing on neonatal intensive care and the fact that it was using a novel technology. The Apple Vision Pro only became available to purchase in the UK on the 14th of July, which was halfway through the allocated research time. This made the development stage of the prototypes very short, as many of the APIs and AVP-specific features could not be tested using simulation software. Due to the cost of the headset, only one was purchased for the research, this meant that the shared view feature between multiple headsets could not be tested or implemented. Since this research aimed to evaluate the suitability of mixed reality in neonatal intensive care, the participant requirements had to be very specific, which reduced the number of possible participants for the design workshops and user evaluations. This could have potentially limited the idea generation process, meaning further use cases for mixed reality in neonatal intensive care could have been overlooked.

7.2 Future Work

This research describes the process and outcome of a single design cycle. To continue this research forward, a continuous cycle of design and evaluation should be carried out to further improve the prototype designs. Additional data blocks should be developed for the MED-MR-Desktop application to provide a richer data experience. This could include a PDF file reader and more in-depth data input forms. Once multiple fake patients have been created, there should be a list of all available patient notes. To improve the experience of finding the relevant patient, a search bar could be incorporated which allows the user to search for a patient by saying their name or cot number. For the MED-MR-Ward application, further research and experimentation should be conducted to determine the requirements of the reference images for image detection. Additional iterations of the 3D entity should be created, and then evaluated by the clinical specialists to decide the most suitable design. More specific information about the content of the pop-up windows should be researched to optimise the usefulness of the application.

To further assess the suitability of mixed reality in neonatal intensive care, an additional application should be developed. This would be called MED-MR-Parent and would be used by parents as they walk around a neonatal ward. Using the user's location relative to the cot location their baby is in, the 3D object detection API from Apple could be used to identify medical devices. As the pieces of equipment are detected, a label of what they are could appear above them, which when clicked on would provide summary information about that device. This would hopefully improve the experience for the parents by familiarising them with the devices being used to care for their child. The idea for this application was discussed multiple times during the design workshops and user evaluations but was not developed due to time constraints.

Chapter 8

Conclusion

This research aimed to develop a collection of novel proof-of-concept mixed reality applications for displaying patient data in neonatal intensive care. User-centred design workshops were conducted to discuss the potential benefits and limitations of using mixed reality in the ward, which allowed a list of functional requirements to be determined. Two prototype applications were developed to showcase a combination of these defined design requirements. The suitability and effectiveness of the prototypes were analysed through user evaluations with the original participants from the design workshops. All of the participants said they loved the concept of both applications and that they could greatly benefit neonatal care once the hardware improves. The size, appearance, and cost of the headset were noted multiple times as being major limitations of actually using them in the ward. However, the participants also highlighted that the ability to view quick patient data without the infection risk of using shared computers and keyboards could greatly improve the quality of patient care. They described how combining all existing software packages into a single interface, with the addition of speech dictation for text input could improve the efficiency of patient monitoring, and make it easier to document more detailed notes. This research has highlighted that although hardware limitations are preventing the current use of mixed reality in neonatal care, there is great potential for spatial computing to be utilised in the future.

Bibliography

Amuso, V., Poletti, G. and Montibello, D., 2021. Virtual, augmented and mixed reality: What are the benefits for smes? *Global policy, 12(1)*, pp.167–170.

Apple, 2023. Introducing apple vision pro: Apple's first spatial computer [Online]. Available from: https://www.apple.com/uk/newsroom/2023/06/introducing-apple-vision-pro/ [Accessed 09 April 2024].

Apple, 2024a. Apple vision pro [Online]. Available from: https://www.apple.com/apple-vision-pro/ [Accessed 09 April 2024].

Apple, 2024b. Apple vision pro unlocks new opportunities for health app developers [Online]. Available from: https://www.apple.com/newsroom/2024/03/apple-vision-pro-unlocks-new-opportunities-for-health-app-developers/ [Accessed 08 July 2024].

Bajura, M., F.H. and Ohbuchi, R., 1992. Merging virtual objects with the real world: Seeing ultrasound imagery within the patient. *Acm siggraph computer graphics, 26(2)*, pp.203–210.

Banchi, Y., Ohira, Y., Ito, M. and Kawai, T., 2024. Comparative analysis of user experience in virtual reality (vr) and mixed reality (mr) systems using eye-tracking measurements. *Electronic imaging, 36*, pp.1–4.

Barsom, E.Z., Graafland, M. and Schijven, M.P., 2016. Systematic review on the effectiveness of augmented reality applications in medical training. *Surgical endoscopy, 30*, pp.4174–4183.

Bender, D. and Sartipi, K., 2013. Hl7 fhir: An agile and restful approach to healthcare information exchange. *In proceedings of the 26th ieee international symposium on computer-based medical systems*, pp.326–331.

Billinghurst, M. and Kato, H., 1999. Collaborative mixed reality. *In proceedings of the first international symposium on mixed reality*, pp.261–284.

Braun, V. and Clarke, V., 2006. Using thematic analysis in psychology. *Qualitative research in psychology, 3(2)*, pp.77–101.

Carmigniani, J. and Furht, B., 2011. Augmented reality: an overview. *Handbook of augmented reality*, pp.3–46.

Chuah, S., 2018. Why and who will adopt extended reality technology? literature review, synthesis, and future research agenda. *Literature review, synthesis, and future research agenda (December 13, 2018)*.

Condino, S., Turini, G., Parchi, P., Viglialoro, R., Piolanti, N., Gesi, M., Ferrari, M. and Ferrari, V., 2018. How to build a patient-specific hybrid simulator for orthopaedic open surgery:

benefits and limits of mixed-reality using the microsoft hololens. *Journal of healthcare engineering, 2018*.

Dolin, R., Alschuler, L., Beebe, C., Biron, P., Boyer, S., Essin, D., Kimber, E., Lincoln, T. and Mattison, J., 2001. The hl7 clinical document architecture. *Journal of the american medical informatics association, 8(6)*, pp.552–569.

Edwards, W., Bellotti, V., Dey, A. and Newman, M., 2003. The challenges of user-centered design and evaluation for infrastructure. *In proceedings of the sigchi conference on human factors in computing systems*, pp.297–304.

Fatima, A. and Colomo-Palacios, R., 2018. Security aspects in healthcare information systems: A systematic mapping. *Procedia computer science, 138*, pp.12–19.

Fraune, M., Komatsu, T., Preusse, H., Langlois, D., Au, R., Ling, K., Suda, S., Nakamura, K. and Tsui, K., 2022. Socially facilitative robots for older adults to alleviate social isolation: A participatory design workshop approach in the us and japan. *Frontiers in psychology, 13*, p.904019.

Gausepohl, K., Winchester, W., Smith-Jackson, T., Kleiner, B. and Arthur, J., 2016. A conceptual model for the role of storytelling in design: leveraging narrative inquiry in user-centered design (ucd). *Health and technology, 6*, pp.125–136.

Gritzalis, D. and Lambrinoudakis, C., 2004. A security architecture for interconnecting health information systems. *International journal of medical informatics, 73(3)*, pp.305–309.

Gulliksen, J., Lantz, A. and Boivie, I., 1999. User centered design—problems and possibilities: a summary of the 1998 pdc cscw workshop. *Acm sigchi bulletin, 31(2)*, pp.25–35.

Hou, Y., Lin, Y., Shi, J., Chen, H. and Yuan, W., 2018a. Effectiveness of the thoracic pedicle screw placement using the virtual surgical training system: a cadaver study. *Operative neurosurgery, 15(6)*, pp.677–685.

Hou, Y., Shi, J., Lin, Y., Chen, H. and Yuan, W., 2018b. Virtual surgery simulation versus traditional approaches in training of residents in cervical pedicle screw placement. *Archives of orthopaedic and trauma surgery, 138*, pp.777–782.

Hua, H., Brown, L.D. and Zhang, R., 2011. Head-mounted projection display technology and applications. *Handbook of augmented reality*, pp.123–155.

Khor, W., Baker, B., Amin, K., Chan, A., Patel, K. and Wong, J., 2016. Augmented and virtual reality in surgery—the digital surgical environment: applications, limitations and legal pitfalls. *Annals of translational medicine, 4(23)*.

Kozareva, V., 2022. Healthcare software challenges and their solutions in 2022 [Online]. Available from: `https://dreamix.eu/insights/healthcare-software-challenges-and-their-solutions/` [Accessed 12 April 2024].

Mekni, M. and Lemieux, A., 2014. Augmented reality: Applications, challenges and future trends. *Applied computational science, 20*, pp.205–214.

Meta, n.d. Meta quest 3: New mixed reality vr headset – shop now [Online]. Available from: `https://www.meta.com/gb/quest/quest-3/` [Accessed 09 April 2024].

Microsoft, n.d. Hololens 2: Find specs and features – microsoft hololens 2 [Online]. Available from: `https://www.microsoft.com/en-gb/d/hololens-2/91pnzzznzwcp?activetab=pivot:overviewtab` [Accessed 09 April 2024].

Milgram, P., Takemura, H., Utsumi, A. and Kishino, F., 1995. Augmented reality: A class of displays on the reality-virtuality continuum. *In telemanipulator and telepresence technologies (vol. 2351)*, pp.282–292.

Morimoto, T., Kobayashi, T., Hirata, H., Otani, K., Sugimoto, M., Tsukamoto, M., Yoshihara, T., Ueno, M. and Mawatari, M., 2022. Xr (extended reality: virtual reality, augmented reality, mixed reality) technology in spine medicine: status quo and quo vadis. *Journal of clinical medicine, 11(2)*, p.470.

Munzer, B.W., Khan, M.M., Shipman, B. and Mahajan, P., 2019. Augmented reality in emergency medicine: a scoping review. *Journal of medical internet research, 21(4)*, p.e12368.

Narayana Samy, G., A.R. and Ismail, Z., 2010. Security threats categories in healthcare information systems. *Health informatics journal, 16(3)*, pp.201–209.

Rajan, A., Nassiri, N., Akre, V., Ravikumar, R., Nabeel, A., Buti, M. and Salah, F., 2018. Virtual reality gaming addiction. *2018 fifth hct information technology trends (itt)*, pp.358–363.

Ricci, S., Mobilio, G., Calandrino, A., Pescio, M., Issa, E., Rossi, P., Chessa, M., Solari, F., Chirico, M. and Casadio, M., 2021. Rineo mr: A mixed-reality tool for newborn life support training. *In 2021 43rd annual international conference of the ieee engineering in medicine biology society (embc)*, pp.5043–5046.

Roberts, D.W., Strohbehn, J.W., Hatch, J.F., Murray, W. and Kettenberger, H., 1986. A frameless stereotaxic integration of computerized tomographic imaging and the operating microscope. *Journal of neurosurgery, 65(4)*, pp.545–549.

Ruthberg, J., Tingle, G., Tan, L., Ulrey, L., Simonson-Shick, S., Enterline, R., Eastman, H., Mlakar, J., Gotschall, R., Henninger, E. and Griswold, M., 2020. Mixed reality as a time-efficient alternative to cadaveric dissection. *Medical teacher, 42(8)*, pp.896–901.

Sirimsi, M., De Loof, H., Broeck, K. Van den, De Vliegher, K., Van Royen, P., Pype, P., Driessens, K., Verté, E., Remmen, R. and Van Bogaert, P., 2023. Development of a toolkit to improve interprofessional collaboration and integration in primary care using qualitative interviews and co-design workshops. *Frontiers in public health, 11*, p.1140987.

Slater, M. and Sanchez-Vives, M., 2016. Enhancing our lives with immersive virtual reality. *Frontiers in robotics and ai, 3*, p.74.

Sutherland, I., 1965. The ultimate display. *In proceedings of the ifip congress (vol. 2)*, pp.506–508.

Tanbeer, S. and Sykes, E., 2024. Mivitals–mixed reality interface for vitals monitoring: A hololens based prototype for healthcare practices. *Computational and structural biotechnology journal*.

Teng, C., Redfearn, B., Nuttall, C., Jarvis, S., Carr, J., Jensen, J., Kanuch, S., Peterson, J. and Taylor, D., 2019. Mixed reality patients monitoring application for critical care nurses. *In proceedings of the 3rd international conference on medical and health informatics*, pp.49–53.

Tepper, O., Rudy, H., Lefkowitz, A., Weimer, K., Marks, S., Stern, C. and Garfein, E., 2017. Mixed reality with hololens: where virtual reality meets augmented reality in the operating room. *Plastic and reconstructive surgery, 140(5)*, pp.1066–1070.

Viglialoro, R.M., C.S.T.G.C.M.F.V. and Gesi, M., 2021. Augmented reality, mixed reality, and hybrid approach in healthcare simulation: a systematic review. *Applied sciences, 11(5)*, p.2338.

Wish-Baratz, S., Gubatina, A.P., Enterline, R. and Griswold, M.A., 2019. A new supplement to gross anatomy dissection: Holoanatomy®. *Medical education, 53(5)*, pp.522–523.

Wohlgenannt, I., Simons, A. and Stieglitz, S., 2020. Virtual reality. *Business information systems engineering, 62*, pp.455–461.

Xu, T., 2021. Data requirements make healthtech an interesting puzzle for developers [Online]. Available from: `https://builtin.com/software-engineering-perspectives/healthtech-software` [Accessed 12 April 2024].

Appendix A

Source Code

The source code for the MED-MR-Desktop application can be found here:

https://github.com/joebadger24/MED-MR-Desktop

The source code for the MED-MR-Ward application can be found here:

https://github.com/joebadger24/MED-MR-Ward

The project repositories can be cloned and run using the XCode IDE, however, to run the application using the Vision Pro simulator, a Mac with Apple Silicon and with macOS Monteray or later is required.

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