Augmented Reality for Ultrasound Imaging

A Major Qualifying Project
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Abstract

This project explores the integration of augmented reality (AR) technology into ultrasound imaging to facilitate easier interpretation of images for sonographers. Sonographers undergo extensive training, often spanning years, creating professional barriers. The strenuous nature of the work is a physical barrier, leading to the loss of experienced medical personnel due to injury, further straining the financials and abilities of remaining medical personnel and hospitals. In response, our team employed a wireless ultrasound probe connected to an API, where ultrasound data is streamed via TCP connection to a HoloLens 2 headset. We utilized the Unity gaming engine to create the AR interface, displaying ultrasound images in real-time, thereby minimizing delay and providing a user-friendly experience. The displayed images appear as overlays on a virtual plane directly in front of the user, enhancing visualization and interpretation, as well as reducing the physical strain required for sonographers to take and read measurements concurrently. This innovative approach aims to streamline the sonographer's workflow, potentially reducing the learning curve associated with ultrasound interpretation and improving diagnostic efficiency. In the age of exponential technological advancements augmented reality is poised to become a cornerstone in various industries, and already is.

Acknowledgments

We extend our sincere appreciation to Professor Yihao Zheng for his invaluable guidance and support throughout this project. We are also immensely grateful to graduate student Rohit Dey, whose instrumental assistance played a pivotal role in initiating our journey and ensuring our project’s success. Furthermore, we would like to express our gratitude to the Interactive Media & Game Development Association Club for their steadfast support, particularly acknowledging senior student Connor Peavey for his profound expertise of Unity, which significantly enriched our project. Special thanks are also due to the Academic Technology Center for generously providing us with the Microsoft HoloLens 2 AR headset, a crucial asset that propelled our research endeavors forward. Lastly, we would like to thank Barbara Furhman for her assistance in procuring necessary materials, which was integral to the smooth execution of our project.

Table of Contents

List of Figures

Introduction

Ultrasound technology has profoundly transformed medical diagnostics and therapeutic interventions since its inception. Its non-invasive nature, coupled with its versatility and safety, has rendered it indispensable across various medical specialties, including obstetrics, cardiology, and oncology (Rosenberg, 2015). However, despite substantial advancements in ultrasound technology, challenges persist, particularly regarding image visualization during procedures. Technicians typically rely on separate monitors positioned away from the patient to view ultrasound images, necessitating a constant shift of attention between the patient and the display, which can be cumbersome and suboptimal (Hill & Gill, 2020). This orientation poses several health risks. Research conducted from 1985 to 1995 revealed that sonographers experienced increases in carpal tunnel syndrome, shoulder injuries, and other musculoskeletal injuries associated with the profession, with statistics indicating that over 80% of sonographers scan in pain, with pain levels ranging from 75% to 90% (Pike et al., cited in Hogan, 2022).

In addition to these physical limitations, proficiency in ultrasound imaging demands extensive training, often spanning two years or more, due to the complexity of interpreting two-dimensional images in relation to three-dimensional anatomical structures (Gill & Walker, 2016). This necessitates a high level of hand-eye coordination and spatial visualization skills. Simplifying this process could not only streamline medical training but also enhance procedural efficiency and accuracy while eliminating barriers.

Augmented reality (AR) technology offers a promising solution to these challenges by seamlessly overlaying ultrasound images onto the patient's anatomy in real time, directly within the operator's field of view (Wang et al., 2019). AR's capacity to integrate virtual elements with the physical world has garnered attention across various industries, from gaming to healthcare (Fonseca et al., 2021). Leveraging AR in ultrasound imaging has the potential to revolutionize medical practice, offering a more intuitive and immersive experience for technicians while facilitating better patient care.

Our project aims to develop an AR-based solution for visualizing ultrasound images alongside the positioning of the ultrasound probe, laying the groundwork for future innovations in internal system imaging. The flexibility of AR technology allows for endless possibilities in expanding its capabilities, promising a transformative impact on medical imaging and beyond.

Literature Review

Ultrasound imaging, also known as ultrasonography or sonography, is a non-invasive medical imaging technique widely used for diagnostic purposes, fetal monitoring during pregnancy, and guiding interventional procedures. It utilizes high-frequency sound waves to create real-time images of internal structures, offering valuable insights into organ function and pathology. Its safety profile and versatility make it indispensable in various clinical settings, including obstetrics, cardiology, and musculoskeletal imaging. Continued advancements in technology are expected to further enhance its diagnostic capabilities and applications in clinical practice.

Ultrasound Imaging

Ultrasound imaging, also known as ultrasonography or sonography, is a non-invasive medical imaging technique widely used for diagnostic purposes, fetal monitoring during pregnancy, and guiding interventional procedures. It utilizes high-frequency sound waves (typically between 2 and 18 megahertz) to create real-time images of the internal structures of the body. These sound waves are emitted by a transducer and then reflected back to the transducer after encountering tissue interfaces with different acoustic impedance. One of the key advantages of ultrasound imaging is its ability to produce images in real-time, allowing for dynamic assessment of organs and structures. This real-time capability is particularly valuable in various clinical settings, including obstetrics, cardiology, and musculoskeletal imaging.

According to D. Cosgrove and M. Lassau (2010), ultrasound imaging has evolved significantly since its inception, with advancements in transducer technology, signal processing, and image reconstruction algorithms. These advancements have led to improvements in image resolution, penetration depth, and the ability to visualize subtle anatomical details. Furthermore, ultrasound imaging is considered safe, as it does not involve ionizing radiation, unlike other imaging modalities such as Xrays and computed tomography (CT) scans. Furthermore Liao, Y. K., et al. (2020) conducted a retrospective cohort study evaluating the clinical outcomes of ultrasound-guided interventions in a diverse patient population. The study demonstrated that ultrasound guidance improved the accuracy and safety of procedures such as biopsies and injections, leading to better patient outcomes and reduced complication rates. This safety profile makes ultrasound imaging suitable for use in vulnerable populations, including pregnant women and pediatric patients.

In obstetrics, ultrasound imaging plays a crucial role in monitoring fetal development, assessing fetal anatomy, and diagnosing abnormalities. According to J. Abramowicz and R. T. Deter (2014), prenatal ultrasound has become a standard component of antenatal care, enabling clinicians to detect fetal anomalies early in pregnancy and provide appropriate counseling and management. In addition to its diagnostic utility, ultrasound imaging is also used for guiding interventional procedures, such as biopsies, aspirations, and injections. Real-time visualization provided by ultrasound allows for precise needle placement, reducing the risk of complications and improving procedural outcomes.

Overall, ultrasound imaging is a versatile and indispensable tool in modern medicine, offering clinicians valuable insights into the structure and function of internal organs and facilitating timely diagnosis and treatment. Continued research and technological innovations are expected to further enhance the capabilities and applications of ultrasound imaging in clinical practice.

Ultrasound Training

Ultrasound imaging is a valuable diagnostic tool in various medical specialties, including radiology, obstetrics, cardiology, and emergency medicine. Proficiency in ultrasound interpretation and technique is essential for healthcare professionals to effectively utilize this modality in clinical practice. Therefore, comprehensive training programs are necessary to ensure that clinicians acquire the necessary skills and knowledge to perform ultrasound examinations accurately and safely. The training pathway for ultrasound varies depending on the clinician's specialty and level of expertise. For medical students and residents, ultrasound training often begins with didactic lectures and hands-on workshops covering basic ultrasound physics, anatomy, and scanning techniques. These introductory sessions provide learners with foundational knowledge and skills necessary for performing basic ultrasound examinations under supervision.

As learners progress in their training, they typically participate in more advanced ultrasound courses and clinical rotations focused on specific applications and specialties. These courses often include simulation-based training using ultrasound phantoms and simulators, allowing learners to practice scanning techniques and interpret ultrasound images in a controlled environment. According to a study by J. D. Rabinowitz et al. (2016), simulation-based training has been shown to improve novice learners' ultrasound proficiency and confidence, leading to better performance in clinical settings. Virtual reality (VR) and augmented reality (AR) technologies are also increasingly being integrated into ultrasound training programs, providing learners with immersive and interactive learning experiences. A systematic review and meta-analysis done by Jiang, H., et al. (2022) examining the effectiveness of virtual reality-based ultrasound simulators in medical education. Their analysis revealed that simulation-based training using virtual reality platforms significantly improved learners' ultrasound skills and confidence levels compared to traditional training methods.

In addition to simulation-based training, supervised hands-on experience in clinical settings is essential for consolidating ultrasound skills and applying theoretical knowledge to real patients. Mentored practice under the guidance of experienced ultrasound practitioners allows learners to refine their scanning technique, interpret complex cases, and develop proficiency in ultrasound-guided procedures. Continuing medical education (CME) courses and workshops offer practicing clinicians opportunities to enhance their ultrasound skills and stay abreast of advances in ultrasound technology and imaging protocols. These courses often focus on advanced topics, such as ultrasound-guided interventions, point-of-care ultrasound (POCUS), and specialized ultrasound modalities.

Furthermore, certification programs and credentialing bodies play a crucial role in establishing standards of competence and ensuring quality assurance in ultrasound practice. Organizations such as the

American Registry for Diagnostic Medical Sonography (ARDMS) and the American Institute of Ultrasound in Medicine (AIUM) offer certification exams and educational resources to support ongoing professional development in ultrasound imaging. In summary, ultrasound training is a multifaceted process that encompasses didactic instruction, simulation-based learning, mentored clinical experience, and continuing education. By providing learners with comprehensive training opportunities and access to advanced technologies, healthcare institutions can empower clinicians to effectively utilize ultrasound imaging in patient care and improve diagnostic accuracy and patient outcomes.

Work Related Musculoskeletal Disorder

Work-related musculoskeletal disorders (MSDs) represent a significant occupational health concern worldwide, encompassing a range of conditions affecting muscles, tendons, ligaments, nerves, and other soft tissues. MSDs are often associated with repetitive tasks, awkward postures, forceful exertions, and prolonged periods of sedentary work, commonly found in various industries such as manufacturing, construction, healthcare, and office-based occupations. According to the National Institute for Occupational Safety and Health (NIOSH), MSDs account for a substantial portion of work-related injuries and illnesses, resulting in significant economic costs, lost productivity, and decreased quality of life for affected workers. These disorders can manifest as localized pain, stiffness, numbness, tingling, weakness, and reduced range of motion, impacting an individual's ability to perform job tasks and activities of daily living.

Epidemiological studies have identified several risk factors associated with the development of work-related MSDs, including repetitive motion, prolonged static postures, heavy lifting, vibration, and poor ergonomic design of workstations and equipment. Additionally, psychosocial factors such as job stress, job dissatisfaction, and lack of social support have been implicated in the onset and progression of MSDs. Preventive measures aimed at reducing the risk of work-related MSDs encompass a comprehensive approach addressing both ergonomic and psychosocial factors in the workplace.

Ergonomic interventions focus on optimizing workstation design, modifying work processes, implementing job rotation, providing ergonomic training, and utilizing assistive devices to minimize biomechanical stressors and promote neutral body postures.

Psychosocial interventions aim to mitigate job-related stressors, improve job satisfaction, foster supportive work environments, and promote employee participation in decision-making processes. According to a systematic review by D. C. Pillastrini et al. (2007), psychosocial interventions, such as cognitive-behavioral therapy, relaxation techniques, and organizational interventions, have shown promise in reducing pain intensity, improving functional outcomes, and preventing disability in workers with MSDs. Furthermore, early detection and management of work-related MSDs are critical for preventing progression to chronicity and reducing the burden of disability. Multidisciplinary approaches involving healthcare providers, occupational health specialists, ergonomists, and employers are essential for implementing comprehensive prevention and rehabilitation programs tailored to the needs of individual workers and specific occupational settings. A different study by Mahmud,N.,. et al. (2011) conducted a longitudinal study assessing the effectiveness of ergonomic interventions in reducing the incidence of work-related musculoskeletal disorders among office workers. The study found that ergonomic modifications to workstations and equipment significantly decreased the prevalence of musculoskeletal symptoms and improved employee productivity.

In conclusion, work-related musculoskeletal disorders represent a multifaceted public health challenge, necessitating proactive efforts to address ergonomic and psychosocial risk factors in the workplace. By implementing evidence-based prevention strategies, promoting worker health and safety, and fostering a culture of wellness, organizations can effectively reduce the incidence and impact of MSDs, thereby enhancing the well-being and productivity of the workforce.

Augmented Reality

Augmented reality (AR) is a cutting-edge technology that overlays digital information onto the real world, thereby enhancing the user's perception and interaction with their environment. In recent years, AR has gained significant attention and adoption in various industries, including healthcare and medical imaging. AR technology enables the integration of virtual elements, such as 3D models, annotations, and real-time data, into the clinician's field of view, typically through head-mounted displays (HMDs) or handheld devices. This integration allows healthcare professionals to visualize and interact with medical images and patient data in a more intuitive and immersive manner.

According to a study by B. Ploderer et al. (2018), AR has the potential to revolutionize medical imaging by providing clinicians with enhanced visualization tools, improving diagnostic accuracy, and facilitating surgical planning and execution. By overlaying anatomical structures from medical imaging datasets onto the patient's body during surgery, AR enables surgeons to better understand the patient's unique anatomy and precisely navigate surgical instruments. Moreover, AR can be used to enhance medical education and training by creating immersive simulations of surgical procedures and anatomical structures. A study by T. B. Schwaab et al. (2019) demonstrated the effectiveness of AR-based training modules in improving medical students' spatial understanding and procedural skills. To further support this claim Tang, K. S., et al. (2020) investigated the educational benefits of augmented reality technology in medical training, particularly its impact on knowledge retention and procedural skill acquisition. Their findings demonstrated that immersive AR simulations enhanced learning outcomes and provided learners with valuable hands-on experience in a controlled environment.

In radiology and diagnostic imaging, AR technology can assist radiologists and clinicians in interpreting medical images by providing contextual information and highlighting relevant anatomical landmarks or pathological findings. For example, AR can superimpose 3D reconstructions of MRI or CT scans onto the patient's body, allowing for better visualization and localization of abnormalities. Furthermore, AR has shown promise in patient education and shared decision-making, enabling healthcare providers to communicate complex medical information more effectively. By visualizing medical images and treatment options in real-time, AR empowers patients to better understand their conditions and participate in treatment planning. Despite its potential benefits, the widespread adoption of AR in medical imaging still faces several challenges, including technical limitations, regulatory hurdles, and concerns regarding data privacy and security. However, ongoing research and development efforts are aimed at addressing these challenges and unlocking the full potential of AR technology in healthcare.

In conclusion, augmented reality holds tremendous promise for transforming medical imaging and healthcare delivery by providing clinicians with advanced visualization tools, enhancing medical education and training, and improving patient outcomes. Continued innovation and collaboration between technology developers, healthcare providers, and regulatory agencies are essential to realize the full benefits of AR in clinical practice.

Clarius Application Protocol Interface

The ultrasound probe used was an L7 Gen1 created by Clarius and connected to an iOS application. To connect a PC to this iOS application, we used an API developed by Clarius and available for free download and use through their GitHub page. An application program interface is “a set of rules or protocols that let software applications communicate with each other to exchange data, features and functionality.” (IBM, 2024) Specifically, it enabled the one-way transmission of image data from the iOS application to the API through a direct TCP connection. The Clarius API offers various functionalities beyond data transfer, including adjusting settings on the ultrasound probe, capturing specific types of images, and controlling different aspects of the device.

Transmission Control Protocol (TCP)

Transmission Control Protocol/Internet Protocol is essentially a set of standard rules for communication between two host computers on a network. “TCP is one of the main protocols in TCP/IP networks. Whereas the IP protocol deals only with packets, TCP enables two hosts to establish a connection and exchange streams of data. TCP guarantees the delivery of data and also guarantees that packets will be delivered in the same order in which they were sent.” (*Guide to OT Security*, 2023). This architecture organizes communication tasks into five independent layers: application layer, transport layer, internet layer, link layer, and physical layer. Each layer has their own set of protocols. First is the Application layer, where user data is generated by applications like the ultrasound probe.

This data is then passed down to the Transport layer, who is responsible for all things transported and connected from one host to another. It deals with segmentation and reassembly of data from the application layer, end-to-end connections, establishing, maintaining and terminating logical connection between sender and receiver, regulating the flow of data, as well as error detection and correction. It should be noted that packets in this layer are referred to as segments.

Next is the internet layer and it is responsible for moving network layer packets from one host to another host. Packets in this layer are referred to as datagrams. This layer ensures reliable data transmission and is tasked with assigning logical addresses (IP addresses) to devices connected to a network, enabling them to be identified and reached within a network. In addition, it determines the optimal path for the datagrams to travel from the source to the destination based on network conditions, topology, and routing protocols. Finally, it can break down large data packets into smaller fragments, based on Maximum Transmission Unit sizes, and reassemble them at the destination.

The link layer solves the problem of exchanging data between two or more directly connected devices (PC, routers, etc.). The transmission tag or MAC address is used to identify the host devices to ensure correct access points with relation to data packets/frames. MAC addresses are unique to each device on the same network. This layer is also responsible for error detection and correction within the data transmission.

Finally, the physical layer sends individual bits of data from one node to another. This layer is also responsible for the physical interface between the data transmission device such as a PC and the transmission medium. That medium being either ethernet or wireless LAN. – A study conducted by Olmedo, G., et al. (2020) conducted a usability study evaluating the performance of Transmission Control Protocol (TCP) in healthcare data transmission, particularly its reliability and efficiency in transmitting medical imaging data. Their findings highlighted the robustness of TCP in ensuring timely and secure delivery of healthcare information, making it a suitable protocol for medical applications. Overall, it proves the level of efficiency and security of using TCP.

Unity Gaming Engine

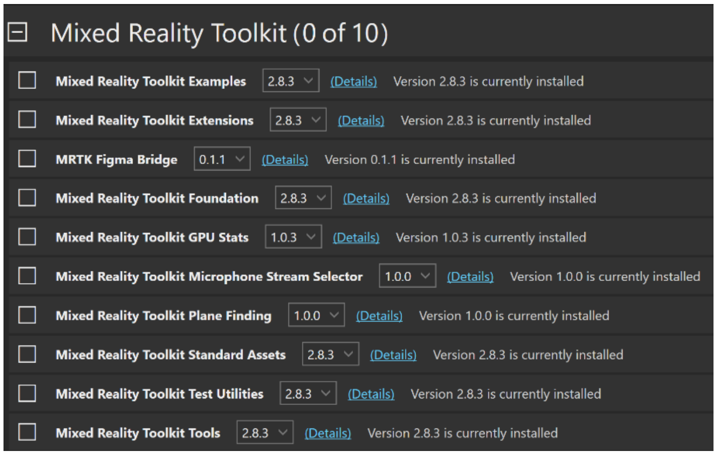
Unity gaming engine emerges as a highly suitable software platform for our project, drawing upon insights from research by Evans, Miller, Pena, MacAllister, and Winer (2017). This choice is underscored by Unity’s robust development capabilities, which enable the creation of immersive and interactive AR experiences essential for enhancing ultrasound interpretation. With Unity’s intuitive interface and extensive documentation, our team can efficiently implement complex features such as real-time streaming of ultrasound data and rendering AR overlays, aligning with the demands of our innovative project.

The cross-platform compatibility offered by Unity is particularly advantageous, facilitating deployment across various devices including the HoloLens 2 headset. This versatility ensures broad accessibility and usability of our AR ultrasound solution across different medical settings, contributing to its scalability and potential impact. Moreover, Unity’s strong community support and extensive asset store accelerate development by providing access to pre-built assets, plugins, and scripts tailored to specific requirements of AR.

Furthermore, Unity’s advanced rendering capabilities in real-time physics simulation play a pivotal role in enhancing the realism and effectiveness of AR. Leveraging Unity’s rendering engine, a visualization of ultrasound images can be overlaid on a virtual plane in front of a user, improving visualization as well as interpretation of medical data. This functionality can help minimize delay, provide user-friendly experiences, and ultimately enhance diagnostic efficiency.

Mixed Reality Toolkit

The Mixed Reality Toolkit (MRTK) stands as a comprehensive framework designed to expedite the development process for mixed reality (MR) applications, offering a suite of tools, components, and resources. At its core, MRTK merges various functionalities crucial for creating immersive experiences, blending the physical and digital realms seamlessly. Leveraging the power of MRTK, developers can efficiently craft applications that transcend conventional boundaries, encompassing virtual, augmented, and mixed reality landscapes.



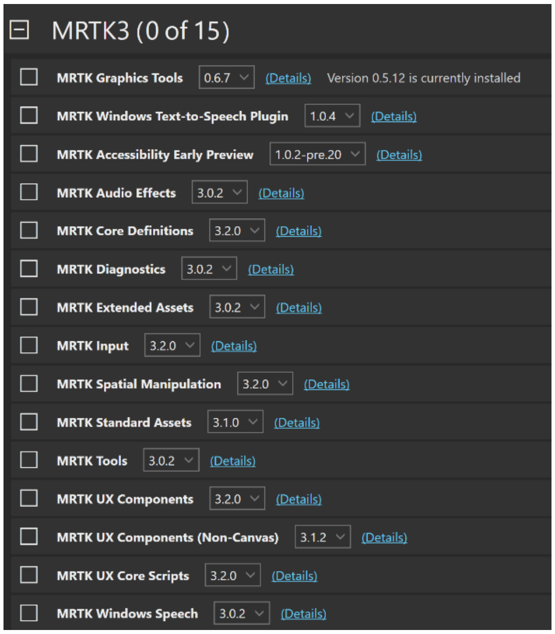
Mixed Reality Toolkit (0 of 10)

☐	**Mixed Reality Toolkit Examples**	2.8.3	(Details)	Version 2.8.3 is currently installed
☐	**Mixed Reality Toolkit Extensions**	2.8.3	(Details)	Version 2.8.3 is currently installed
☐	**MRTK Figma Bridge**	0.1.1	(Details)	Version 0.1.1 is currently installed
☐	**Mixed Reality Toolkit Foundation**	2.8.3	(Details)	Version 2.8.3 is currently installed
☐	**Mixed Reality Toolkit GPU Stats**	1.0.3	(Details)	Version 1.0.3 is currently installed
☐	**Mixed Reality Toolkit Microphone Stream Selector**	1.0.0	(Details)	Version 1.0.0 is currently installed
☐	**Mixed Reality Toolkit Plane Finding**	1.0.0	(Details)	Version 1.0.0 is currently installed
☐	**Mixed Reality Toolkit Standard Assets**	2.8.3	(Details)	Version 2.8.3 is currently installed
☐	**Mixed Reality Toolkit Test Utilities**	2.8.3	(Details)	Version 2.8.3 is currently installed
☐	**Mixed Reality Toolkit Tools**	2.8.3	(Details)	Version 2.8.3 is currently installed

Figure 1: Displays Mixed Reality Toolkit components which can be imported directly into any unity project.

The integration of MRTK with the HoloLens 2 headset underscores its prowess in augmenting user experiences within mixed reality environments. Equipped with advanced sensors, gesture recognition capabilities, and a high-definition display, the HoloLens 2 harnesses MRTK’s capabilities to render holographic imagery and interact with virtual elements intuitively. MRTK streamlines the development process for HoloLens 2 applications, offering pre-built components tailored to the devices specifications, thus empowering developers to focus more on innovation and less on mundane implementation details (see Figures 1 and 2 for prebuilt MRTK components). Consequently, MRTK facilitates the creation of immersive applications that capitalize on the unique features of HoloLens 2, ranging from industrial simulations to interactive design prototyping.

Moreover, MRTK's synergy with the Unity gaming engine amplifies its utility manifold, providing developers with a robust platform to materialize their creative visions. Unity's intuitive interface coupled with MRTK's extensive library of prefabricated assets expedite the development cycle, enabling developers to prototype, iterate, and deploy MR applications with unparalleled efficiency. The seamless integration between MRTK and Unity empowers developers to leverage Unity's rice ecosystem of plugins, shaders, and scripting tools, augmenting the fidelity and functionality of their MR experiences. MRTK's compatibility with Unity empowers developers to push the boundaries of MR innovation, ushering in a new era of interactive digital experiences.



MRTK3 (0 of 15)

☐ MRTK Graphics Tools 0.6.7 (Details) Version 0.5.12 is currently installed
☐ MRTK Windows Text-to-Speech Plugin 1.0.4 (Details)
☐ MRTK Accessibility Early Preview 1.0.2-pre.20 (Details)
☐ MRTK Audio Effects 3.0.2 (Details)
☐ MRTK Core Definitions 3.2.0 (Details)
☐ MRTK Diagnostics 3.0.2 (Details)
☐ MRTK Extended Assets 3.0.2 (Details)
☐ MRTK Input 3.2.0 (Details)
☐ MRTK Spatial Manipulation 3.2.0 (Details)
☐ MRTK Standard Assets 3.1.0 (Details)
☐ MRTK Tools 3.0.2 (Details)
☐ MRTK UX Components 3.2.0 (Details)
☐ MRTK UX Components (Non-Canvas) 3.1.2 (Details)
☐ MRTK UX Core Scripts 3.2.0 (Details)
☐ MRTK Windows Speech 3.0.2 (Details)

Figure 2: Displays MRTK3 components ranging from basic scene features like spatial manipulation and input to speech and audio capabilities.

Figure 3: The photo above displays the hardware in which our team used to integrate, aside from our own personal computers, ultrasound imaging into augmented reality. On the left, the white wire and black adapter are used to as a wired connection to send data from Unity to the Hololens 2 headset through the holographic remoting application. In the middle is the Clarius wireless ultrasound probe. Finally, on the right is the Microsoft Hololens 2 augmented reality headset.

Methodology

Once we had familiarized ourselves with the previous group's project the first step was to get the code they provided to compile. Due to a lack of documentation of the code as well as explanation of methods, our team decided it was better for us to start from scratch rather than spend a significant amount of time and resources to make sense of the information given to us.

First, we identified the Clarius Cast API on GitHub, wherein many versions of their API were available for download. The version with a GUI IDE was preferable for our purposes, so we opted for that. This version used the QT software to facilitate the UI, as QT project files specified the working directories, files to include, and compiler specifications. Upon opening the project from Clarius, we encountered many errors that required different libraries to be specified before compiling. This was our first major hurdle as there was no documentation on which libraries we needed. After some research we discovered the C "Boost" libraries. It took some time to reduce the number of errors, but we still could not compile the code. Eventually we discovered that the Boost libraries were not going to work, as instead the issue was our 'includes' within the QT project file.

While we attempted to fix this, we also began to familiarize ourselves with Unreal Engine, a 3D gaming engine software used by the previous group to display images in an augmented reality environment. By researching various gaming engines, we found that Unity was preferred by many Hololens developers and included an existing embedded data pipeline with the HoloLens 2 headset (runs on Windows holographic OS). As Unity has had native Hololens support for several years longer than Unreal, the developers had more time to polish the overall experience. While Unreal Engine and Unity had many of the same features for Hololens development, with both having official documentation from Microsoft, the support for Unity was better documented and overall, more straightforward. A significant amount of documentation for Unity development was vital as we had not been left with any documentation of the previous group's experiences with Unreal. We found that mixed reality experiences using Unreal were often built upon using the cutting-edge graphical capabilities the engine is known for, which would not apply to our goals with this project. Another benefit of using Unity was its ease of use compared to Unreal. While Unity is almost entirely based on C#, Unreal uses a combination of C++ and blueprints, a proprietary visual scripting language. This made Unreal more challenging to work with for beginners, as there was a much higher learning curve. It was later discovered that the only reason the previous group had decided to use Unreal is because of previous experience with the software.

The specific tool that helped us the most was the Mixed Reality Tool Kit (MRTK). This tool is a Microsoft-driven project that provides a set of features used to optimize cross platform mixed reality app development within the Unity engine. It allows for a cross platform input system and the basis for spatial interactions and UI. Another amazing feature of the MRTK is rapid prototyping which allows developers to make real-time changes to a scene. For example, while one person could be manipulating objects and buttons in the AR headset, another person could be adding/changing objects within the same scene on the host computer.

Once we had the Clarius API code in QT showing no more errors we discovered the "kit" aspect of QT. Each kit consists of a set of values that define one environment such as specific compilers, debuggers, and version of QT to complete compilation with. The computer we first solved the previous problems on had compilers installed from previous computer science classes, so we opted for the MinGW compilers for C and C++. The same situation was true for the debugger, which we used GNU Debugger for.

IP Address: 192.168.1 .1

Port: 41299

SW Revision: Mismatch

Text:

Overlay: Use right mouse button to draw

Raw Data: 0%

☑ Use LZO Compression

Connection successful, streaming port: 49665

Figure 4: The Caster API user interface utilizes the IP address from IOS/Android device in addition to port number information given on the mobile application to receive ultrasound images as seen in the top of the screen.

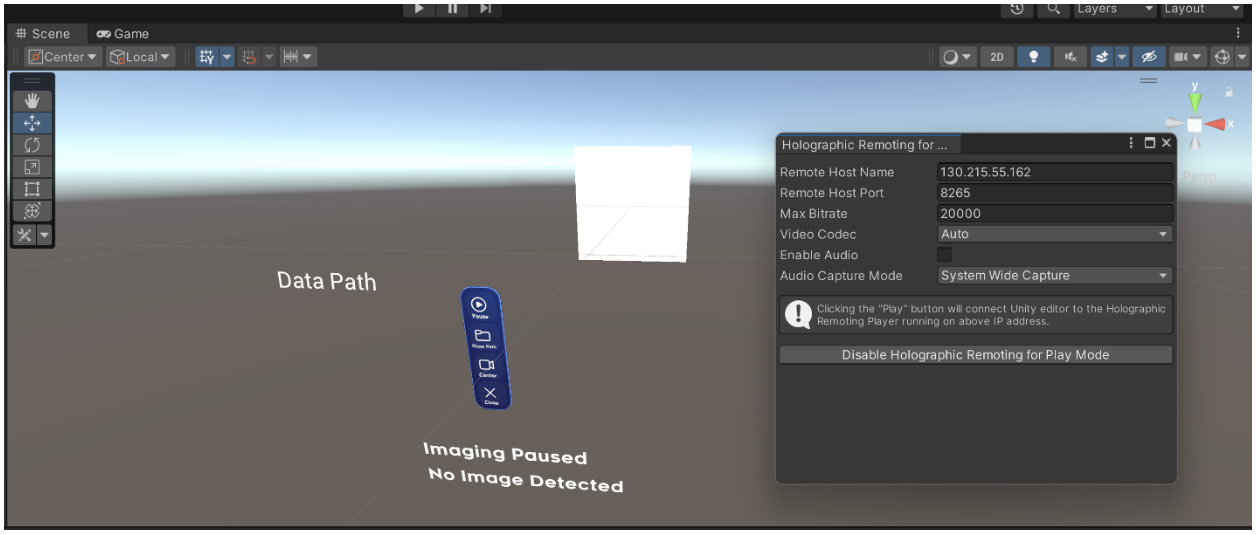
Lastly, the specific version of QT 6.5.3 was needed due to it being the version the Clarius API-supplied code was designed for. With all of that out of the way we finally had a functional API to interact with the Clarius ultrasound probe and its associated iOS application (see Figure 4 for Caster API user interface). To establish a successful connection over a basic TCP link facilitated by the Clarius iOS application, we required the laptop to connect to the Wi-Fi signal emanating from the probe. One hiccup was that the default Windows firewall didn’t let the images through but thankfully that was something that the previous team had mentioned in their report meaning we solved that issue and had images streamed from the probe to the device running the application and to the laptop running the API.

One thing to note is McAfee, even with the firewalls turned off, would not allow for the images to go through. To fix this we had to uninstall the McAfee application from all workspace devices. Since we now had the basic information exchange set up it meant we could start adding our own functionality to the API for our own purposes. This took the form of additional code which allowed us to download the ultrasound frames to a folder on the host laptop. Upon scrutinizing our additions to ensure they would not jeopardize the code, we swiftly discerned that the read/write speeds, even on a solid-state hard drive, proved inadequate to support the live-streaming objective of the project. It was clear that we needed to find an alternative solution to be able to get a “live stream” frequency of frames to update.

Upon the start of C-term, we really began to familiarize ourselves with the process of creating Unity applications. Specifically, we began to utilize the MRTK provided by Microsoft for HoloLens AR development. This toolkit enabled us to stream our Unity project from the laptop to the headset itself, also through a TCP connection. It was then we encountered the issue of needing to connect to multiple Wi-Fi signals at once on the host laptop, which we circumvented by using an ethernet connection for the internet access to send the Unity project to the headset and connecting through regular Wi-Fi to the Clarius probe’s signal. From here we needed to create C# scripts for Unity to display the images streamed to it onto a texture. This version functioned more like a slideshow in its refresh rate for ultrasound frames, as well as leaving much to be desired for usability within Unity.

Realizing the complicated nature of Unity, we decided to pursue some assistance from the Interactive Media and Game Development (IMGD) department. After attending a meeting for WPI's chapter of the International Game Developers Association, we deepened our understanding of what was possible in Unity and recruited an IMGD major to assist us in our efforts. With his involvement, we significantly accelerated our advancement in designing fundamental UI elements and comprehending how our scripts could be modified to generate a live stream of the images, rather than a disjointed slideshow. Using Unity's persistent data path functionality, we could more directly feed the image data into Unity rather than waste valuable time writing hundreds of images into a file and trying to read them in the correct order. Instead, the images would be sent to a directory Unity had access to, and when a new image is generated it would replace the previous one in this directory. Soon after this we finally had a full livestream from the probe to the HoloLens headset and we just needed to keep adjusting settings, so the images could come through clearly. The streaming method had some troubles leading to some investigation into emulation rather than streaming but we managed to get the streaming to work again but kept the emulation method on the backburner in case we needed it.

After managing to stream the images into Unity, the first step was displaying these images to the user. We started by building a test program designed just to run on a local computer without any mixed reality support. This allowed us to plan out what features we wanted the application to have, and how we would go about achieving them. Once we were satisfied with the direction, we built a



Remote Host Name 130.215.55.162
Remote Host Port 8265
Max Bitrate 20000
Video Codec Auto
Enable Audio ☐
Audio Capture Mode System Wide Capture

Clicking the "Play" button will connect Unity editor to the Holographic Remoting Player running on above IP address.

Figure 5: This screenshot from Unity shows our scene setup. To the right of the screen is the holographic remoting display. This enables Unity to stream the scene directly to the Hololens via TCP connection. In fact, if need be, it allows for changes to be made in real time so that the computer user can input and adjust components in the scene while the Hololens user is viewing said components. The white square in the middle of the screen is the plane in which ultrasound images are being sent via persistent data path. The blue rectangle on the left is the hand-initiated user interface with recenter, show data path, pause/play, and close options. A better image of this UI can be found in Figure 6.

new Unity project using the MRTK framework. A small hurdle we had to overcome was that Unity's mixed reality features were designed first and foremost for manipulating 3D models, not 2D images. To circumvent this, we created a 3D quad and set the images being loaded in to act as textures for the model. We then wrote a script to adjust the rotation of the quad as the user moves their head, making it always face forward. This gives off the illusion of looking at a 2D image, while also allowing the user to have a clear view from any angle.

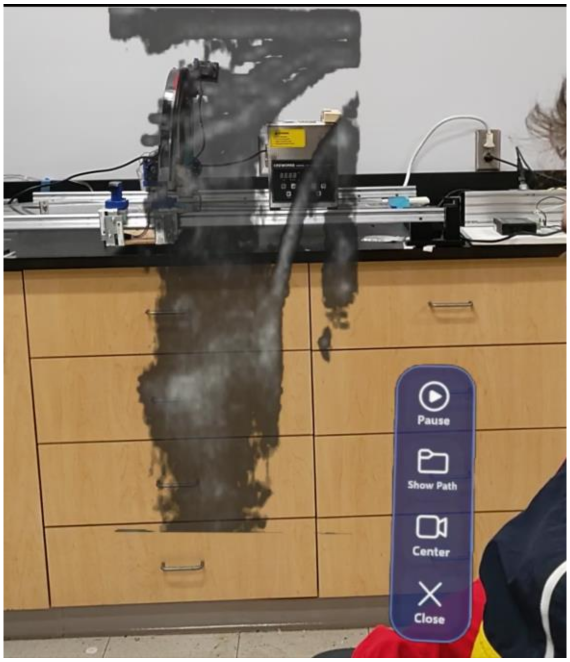


Figure 6: The blue interface on the right appears after the user raises either hand, palm facing user. The image to the left is an ultrasound frame of the patients forearm. It should be noted that the video rendering of the Hololens, when screen recording, eliminates the black background associated with the ultrasound images. However, when viewing the images in the Hololens 2, the black background is still present.

A tougher hurdle we had to overcome were the various menu options the user needed access to. We wanted people to be able to easily recenter the image, pause the image feed, and show the desired data path. We created an interactive menu to accomplish this, but as the user moved around, the menu would become less visible, and depending on their positioning the buttons could be difficult to accurately press. Our first attempt to fix this was allowing the user to move the menu around just like they could with the image. However, this made the program feel confusing to maneuver, as keeping track of both the image and menu could be a hassle, and needing the often-misplaced menu to recenter everything was clearly not an intuitive solution. After reading up on some different options, we decided to convert the menu into “hand menu,” meaning it would appear whenever the HoloLens detected a specific hand movement, in our case, a flat palm. This solved the issue of the user losing track of the menu as it would always appear next to their hand (see Figure 6 for hand interface display). However, this brought up a new issue specific to how our application worked. The built-in hand menu functionality would make the menu appear when a specific hand movement is detected, then disappear once the hand shape had changed. The intention was that as the user had one hand in the trigger position, the other would be used to select the menu options. However, if the user had the probe in one hand, they would only then have one free hand to be able to select options. Our first attempt to remedy this was to adjust the hand menu functionality to make the menu stay visible until the user shows their palm again. This way the user could show their palm to see the menu, select the desired options, then show their palm again to disable the menu. While this functionally worked, it was not the most intuitive, as Unity would sometimes register the hand entering the trigger position unintentionally as they selected options, making the menu occasionally disappear while the user was still using it. To accommodate this, we took a simpler approach and added a close button to the menu. This allows the user to show their palm to bring up the menu, which will stay open until they press the close button, greatly reducing the risk of error.

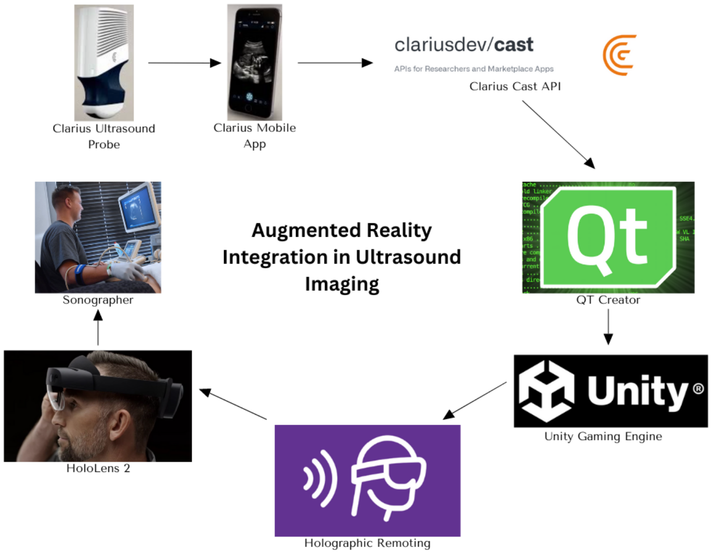


Figure 7: The chart above is a representation of methodology. The Clarius probe connects to the mobile app through WiFi connection. It transmits the ultrasound frames onto the mobile devices screen (IOS/Android). From there the images get sent to the Cast API. QT Creator is a GUI application development software which houses our API code. In our code we send image frames, as they are saved and uploaded, to Unity's persistent data path. This path constantly looks for data to upload to a specific scene component such as our blank plane, as seen in Figure 4. After the images are recognized by Unity, the holographic remoting application built into unity specifically for AR development, sends all scene data directly to our Hololens2 headset. This connection is made possible by another TCP connection. By this point the sonographer is able to view and manipulate the ultrasound livestream coming from the probe, as well as the blue user interface,

Discussion

Achievements and Challenges

The final product from this project was a fully functional livestream of the 2D ultrasound image within an AR environment on a predefined plane within a user's field of view. Within this plane are the zoom, play/pause, and image data path features. We achieved a substantial amount of progress in this project, as we had essentially started with just the idea and an ultrasound probe. From achieving the real time streaming of image data to our devices to the effective integration of this image data into our AR environment and eventual live streaming of said data to an actively running AR environment we managed to hit just about every goal set out for our team. Going beyond our initial expectations we managed to make great strides in the usability of our platform through the development of a comprehensive tutorial for getting the API to run as well as a more user-friendly UI within the AR environment.

As for challenges, we faced a myriad. From the lack of available support for implementing the existing code, to complete changes in what development engine we used there were many hurdles. One of particular note is the use of augmented reality, a very new technology which resulted in more than a few project-breaking errors. We also had no one with any experience in 3D development engines for a substantial portion of the project which led to our time with the substantial learning curve that results from their use.

Throughout this project, we have accomplished remarkable milestones, transforming a mere concept into a fully functional and innovative platform. The focal achievement lies in the successful implementation of a live stream of 2D ultrasound images within an augmented reality (AR) environment, seamlessly integrating this imagery onto a predefined plane within the user's field of view. This feat represents a convergence of cutting-edge technologies, including real-time streaming of image data to user devices, adept integration of this data into the AR environment, and the seamless live streaming of imagery during active AR sessions.

Broader Impacts

Engineering Ethics

In the development of our MQP project, we meticulously adhered to the principles outlined in the Mechanical Engineering Code of Ethics. Specifically, we prioritized user safety and well-being by implementing ergonomic advancements in ultrasound imaging, aiming to reduce the risk of work-related musculoskeletal disorders among sonographers and healthcare professionals. Our project also focused on enhancing diagnostic efficiency and accuracy, aligning with the ethical imperative of ensuring the effectiveness and reliability of engineering solutions in healthcare applications. Furthermore, we recognized the importance of advancing medical education and training, empowering aspiring sonographers and medical students to gain hands-on experience with ultrasound imaging techniques. These efforts align with the ethical responsibility of promoting professional competence and education within the engineering field. The ethical implications of our project on society are profound, as it not only improves healthcare professionals' working conditions but also enhances patient care outcomes, contributing to the overall well-being of society.

Societal and Global Impact

The impact of our project extends beyond individual users to encompass broader societal implications. By promoting ergonomic scanning practices and enhancing diagnostic capabilities, our project directly benefits the health, safety, and welfare of healthcare professionals and patients alike. The reduction of work-related injuries among sonographers not only improves their quality of life but also helps to retain experienced professionals in the workforce, thereby ensuring continuity of care for patients. Additionally, our project has the potential to influence cultural perceptions of healthcare technology, fostering a greater acceptance of innovative solutions in medical imaging and diagnostics. However, we also recognize the need to consider unintended consequences, such as potential job displacement or shifts in traditional healthcare practices and strive to address these challenges through responsible implementation and ongoing stakeholder engagement.

Economic Factors

In considering economic factors, we recognize that the value of our project extends beyond its direct cost or budgetary constraints. While our MQP budget provided resources for development, we also considered the broader economic implications of our project, including its potential market impact and cost-effectiveness. By enhancing diagnostic capabilities and improving workforce retention in healthcare settings, our project can generate significant long-term cost savings for healthcare institutions. Additionally, by empowering medical students and aspiring sonographers with hands-on training opportunities, we contribute to the development of a skilled workforce in medical imaging and diagnostics, thereby fostering economic growth and innovation in the healthcare industry.

Future Extensions

In the pursuit of advancing ultrasound imaging technology, future extensions of our project should be centered around the development of real-time 3D modeling techniques. This extension entails the formulation and implementation of algorithms and techniques designed to facilitate instantaneous 3D modeling directly on the patient’s body. Our aim is to enable the ultrasound probe to capture sequential 2D images, which will then be processed and assembled into a comprehensive 3D model of the scanned area in real-time. This approach not only holds promise for improving the accuracy and efficiency of diagnostic assessments but also offers unprecedented insights into complex anatomical structures and pathological conditions of the unique forms and needs of patients.

Moreover, an essential aspect of our future extensions involves the optimization of rendering methodologies to ensure seamless and precise visualization of 3D ultrasound images. This endeavor will entail revisiting rendering techniques to minimize latency and maximize image fidelity, thereby enhancing the interpretability of the generated 3D models. By leveraging cutting-edge rendering technologies and computational resources, we aspire to achieve a level of image quality and detail that rivals traditional 2D ultrasound imaging modalities.

Another avenue for future exploration lies in the integration of QR code recognition capabilities into our AR framework. By leveraging the advanced features of the HoloLens 2 device, we seek to investigate methods for enabling seamless and accurate positioning of ultrasound images on a patient's body. This extension involves exploring algorithms and techniques for QR code detection and recognition, allowing the AR headset to precisely overlay ultrasound images onto the corresponding anatomical regions indicated by the QR codes. This functionality not only enhances the spatial accuracy of ultrasound image visualization but also streamlines the workflow for healthcare professionals, facilitating more efficient and precise diagnostic assessments. The use of QR codes within an AR environment has potential even outside of our work, as other vital information could be displayed within medical personnel's field of view, further enhancing their efficiency and ability to perform their work.

The technical documentation of our project can be found in Appendix A and, which outline QT Creator and Unity projects respectively.

Conclusion

This project represents a step forward in the process to integrate AR technology into ultrasound imaging, aiming to alleviate many challenges that sonographers face in their everyday practice. The development process involved navigating through substantial hurdles, including exploring different software platforms and engaging with an unfamiliar and relatively new platform, augmented reality.

Initially, the team encountered obstacles with the Clarius Cast API and QT software, which required meticulous troubleshooting to ensure compatibility and functionality, the use of QT made the user experience much cleaner thanks to its UI functionality, despite the additional hurdles it also caused. Additionally, making the transition to Unity as our preferred platform for AR development proved to be a strategic decision, given its robust documentation and better support for HoloLens development compared to alternatives like Unreal Engine. The integration of MRTK provided essential tools for cross-platform mixed reality app development within Unity streamlined our development processes. The collaboration with students from the Interactive Media and Game Development Department further accelerated progress, enabling the implementation of fundamental UI elements along with refining live streaming capabilities of the AR interface. The team was able to do this by adjusting hand gestures for menu interaction and leveraging Unity’s persistent data path functionality.

Ultimately, the culmination of these efforts resulted in a functional AR interface that seamlessly superimposes ultrasound images onto a virtual plane while offering essential functionalities like a recenter button, pause/play button, and more. Beyond its immediate application in medical imaging, this achievement carries profound implications for the fields of ergonomics and patient care. The integration of AR technology holds promise for reducing work-related injuries and improving diagnostic accuracy and clinical outcomes. By facilitating ergonomic scanning practices, this innovative interface not only enhances the wellbeing of sonographers, but it also prolongs their careers ensuring the retention of experienced personnel within the healthcare workforce.

Looking ahead, future extensions of the project should aim to further advance ultrasound imaging technology through innovative avenues such as real-time 3D modeling and QR code recognition for positioning. By capturing sequential 2D images and seamlessly assembling them into comprehensive 3D models, along with leveraging HoloLens 2’s QR code detection capabilities, there is potential to revolutionize diagnostic assessments. offering unprecedented insights into complex anatomical structures for work and education alike.

In summary, this project underscores the transformative potential of AR technology in healthcare, paving the way for enhanced diagnostic capabilities, improved outcomes, improved education/training, mitigation of work-related injuries, and continued innovation in medical imaging. As technology continues to evolve, the integration of AR with ultrasound imaging emerges as a pivotal advancement, poised to shape the future of diagnostic practices and patient care.

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Appendices

Appendix A: Related files and instructions for successful compilation of QT Creator with the Clarius ultrasound API.

https://github.com/kavyamani02/Augmented-Reality-of-Ultrasound-Imaging-MQP-

Appendix B: Augmented reality for ultrasound imaging Unity project documentation.

https://github.com/Brian-DeFlaminio/Unity_Project