Electromagnetic Goggles for NAVAID Antenna Pattern Visualization

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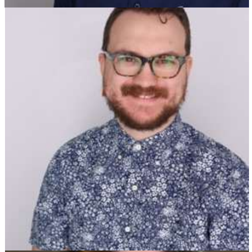

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ABSTRACT

The Ohio University Navaid Performance Prediction Model (OUNPPM) is a safety and compliance tool for airports and air safety organizations. This paper presents recent advancements, including development on a new extended reality interface. This research explores the integration of the visualization component of OUNPPM into mixed-reality environments and explores the related benefits. The mixed reality interface visualizes the radiation pattern of the navigational aids and allows users to view and interact with these waveforms in full scale via mixed reality goggles. By providing users with tools to view these waveforms in full scale 3D these navigational aids can be visualized, in person, at real-life airports, in conjunction with existing computer simulations. This approach allows important navigational aid visualization and planning to occur in a way that is more intuitive and natural for users. By introducing this new integration, the project offers a new and improved experience that positively impacts safety and productivity for a variety of public, private, and military airports across the world.

INTRODUCTION

Ensuring airport navigational aid (NAVAID) equipment is constructed and configured for optimal performance and compliance with safety regulations is of the utmost importance. NAVAIDs are integral to the safe operation of aircraft, providing crucial information for navigation and landing, especially under adverse weather conditions. The Ohio University Navaid Performance Prediction Model (OUNPPM) is a multipath modelling software package and includes a visualization tool that allows researchers to view and simulate NAVAID arrangements. By predicting the performance of navigational aids for new constructions before they are built, OUNPPM assists in maintaining safety standards and operational efficiency at airports globally.

Recent improvements to OUNPPM have begun expanding its visualization features to include an extended reality (XR) medium. Throughout this paper, the authors explore the integration of an XR interface into OUNPPM, and the potential benefits of the tool. The research represents a step forward in the visualization and interaction with electromagnetic waves emitted by airport antennas. This new interface allows users to engage with the NAVAID environment in an extended-reality setting, using advanced goggles to perceive and interact with electromagnetic waveforms in real time. This immersive experience extends the capabilities of conventional computer NAVAID visualizations, providing a tangible, real-world context to the NAVAID predictions offered by OUNPPM. Users can now visualize and manipulate the electromagnetic fields that are critical to NAVAID performance, leading to a more intuitive understanding of the complex multipath interactions at play. This capability is particularly beneficial in real-life airport settings, where immediate and practical insights into NAVAID performance can significantly improve field-testing for technicians, reducing costs and improving operational efficiency. By engaging directly with the extended reality environment, users can identify potential issues, test configurations, and explore solutions in a manner that was previously unattainable.

This paper will start with a Background section that highlights the importance and evolution of extended reality technology, as well as the development of the Ohio University Navaid Performance Prediction Model (OUNPPM). Following the background, the Methods section will detail the design and construction of the extended reality tool, including technical specifications, as well as details about software and hardware integration. It will also cover the process of integrating extended reality with the OUNPPM. The results section will explore the benefits of the research, featuring preliminary graphics from the extended reality application. The discussion section will provide an analysis of these results, comparing them with the initial objectives, and addressing the benefits, challenges, and limitations of the extended reality integration. The paper will then touch on future work and implications, including plans for further testing, potential enhancements, broader applications, and the long-term impact on global airport safety standards. Finally, the work will conclude with a summary of key findings and their significance, followed by acknowledgements of contributors and bibliography.

BACKGROUND & DEFINITIONS

To provide a background on the technologies and themes relevant to this work, this section shall touch on both OUNPPM and Extended Reality (XR).

OUNPPM

The Ohio University Navaid Performance Prediction Model (OUNPPM) is a multipath modelling software package used to certify airports around the world (Figure 1). Multipath effects [1] are introduced when the signal of an antenna interferes with other signals via reflections or diffractions from other surfaces. These surfaces can include terrain, buildings, telephone wires, wind turbines, passing aircraft and vehicles [1]. By calculating multipath effects, users can effectively model and simulate airport NAVAID arrangements. These multipath simulations are frequently used for airport certification and ground plane estimates. Recently, developments and optimizations have been made that make the visualization component of the tool more suitable for XR integration.

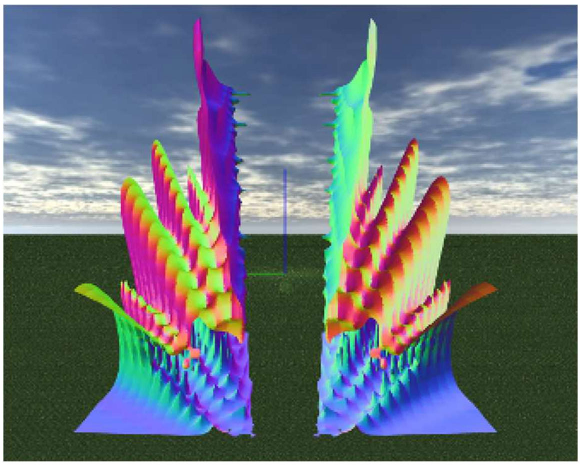

Figure 1. Pictured is a direct view of a standard Wilcox-14 antenna pattern in ideal conditions that was generated using OUNPPM.

At IFIS 2022 Mourning and Odunaiya introduced a new feature in OUNPPM [2] to visualize the isosurfaces of NAVAID antenna patterns. A rectilinear set of samples of the pattern are generated, and then the isosurface is extracted using the standard

Marching Cubes [3] approach. Unfortunately, for very large regions this process can take tens of seconds to generate the surface. Once the isosurface is generated, it can be interacted with at a very high framerate, however, the inability to quickly generate new surfaces dampens the ability of field technicians to rapidly evaluate multiple scenarios.

The inefficiency of the isosurface generation delay caused some users to assume their computer has crashed, or that they were wasting time as the whole program stalls, reducing user satisfaction. A multithreaded approach was implemented which allowed the user to continuously interact with the program while it calculated iterative isosurfaces [4]. This version of the program iteratively displays isosurfaces in an increasingly refined manner; the feature presents in a similar fashion to loading an image on one's phone, or a slow internet connection, appearing in low resolution almost immediately and subsequently being replaced seamlessly with higher detail versions as they become available. This research opened the door to an XR implementation, as stalling in a headset would likely lead to VR sickness [5]. This new feature will allow users of the headset to immediately engage with isosurfaces and continue to have their environment adapt to the position of their body as the calculations occur. Furthermore, additional research on the tool created a parallelized feature for skipping to the highest resolution antenna patterns, saving users who only care about the highest resolution representations approximately 50% of required time [6]. This is the fastest option for rendering arbitrarily high antenna patterns, and serves additional utility in the XR context, as time is increasingly valuable for headset applications.

Extended Reality

Extended reality (XR) is an umbrella term that describes augmented reality (AR), virtual reality (VR), and mixed reality (MR). These immersive technologies are transforming the way we interact with digital information and are finding applications across various fields, including, but not limited to education [7], healthcare [7], entertainment [7].

Virtual Reality

Virtual reality (VR) creates entirely immersive digital environments that replace the user's physical surroundings. Users interact with these environments using VR headsets and motion controllers, which provide a sense of presence and immersion. VR is widely used in gaming and entertainment but is also making significant strides in training and simulation, where it offers safe and controlled environments for users to practice complex tasks [10]. For instance, flight simulators for pilot training use VR to replicate real-world flying conditions without the risks associated with actual flight [11].

The concept of virtual reality has a history which dates back to the mid-20th century. One of the earliest examples is the "Sensorama," developed by Morton Heilig in the 1950s, which provided an immersive experience using a combination of synchronized 3D images, sounds, and smells [12]. In the 1960s, Ivan Sutherland created the *Sword of Damocles*, the first head-mounted display system, which laid the foundation for future VR headsets [13]. The technology faced numerous challenges, including high costs and limited computing power, which prevented widespread adoption.

The 1990s saw a surge of interest in VR, with companies like Nintendo and Sega developing consumer VR products [14][15]. However, these early attempts, such as the Sega VR and the Nintendo Virtual Boy, were unsuccessful due to technical limitations and user discomfort. As a result, VR entered a period of dormancy, with only niche applications in industrial and academic settings.

The re-emergence of VR began in the early 2010s, driven by advancements in computing power, graphics, and display technologies. The launch of the Oculus Rift in 2012, spearheaded by Palmer Luckey, marked a turning point for the industry [16]. Following this, major tech companies such as HTC, Sony, and Google developed their own VR systems, leading to more commercially available devices for consumers. Today, VR is continuously evolving and transforming around us and is increasingly used in a wide variety of disciplines.

Augmented Reality

Augmented reality (AR) overlays digital content onto the real world, enhancing the user's perception and interaction with their environment. AR applications range from simple displays of information, such as text and images, to more complex interactions involving 3D models and animations [17]. Some well-known examples of AR include mobile apps like Pokémon GO [18], industrial applications for maintenance and repair tasks [19] and medical applications where medical professionals can train or have assistive aids during practice [20].

Mixed Reality

Mixed Reality (MR) merges the physical and digital worlds, allowing users to interact with digital objects as if they were part of the real world. MR combines aspects of AR and VR, providing a seamless integration where virtual elements can interact with physical objects and environments in real time. This interaction is made possible through advanced sensors, computer vision, and spatial mapping technologies [21]. Microsoft's HoloLens, Meta's Quest Pro, and Apple's Vision Pro are prime examples of MR devices that enable users to engage with digital content in a more intuitive and immersive manner.

METHODS

Technology Stack

The development of this application uses a combination of software and hardware stacks. The application was built using the AftrBurner engine [22] chosen for its existing integration with the OUNPPM codebase and its low-level control, which provides enhanced manipulation of the engine via manual memory manipulation capabilities and low levels of abstraction. This engine is written in C++23 and uses OpenGL for rendering 2D and 3D graphics. Additionally, the OpenXR API was employed to adapt the original interface to an XR context, enabling the seamless transition from a simulated desktop environment to an extended reality experience.

The Meta Quest Pro was selected as the development device due to its advanced spatial mapping capabilities, high-resolution displays, and XR functionalities such as the ability to create entirely virtual environments or permit passthrough technology for an MR interface. These features made it an ideal choice for accurately visualizing the multipath isosurfaces in a mixed reality environment.

Development

The OUNPPM is split into three, separate, but related, software packages: the Java GUI front end, a C/C++ backend, and the 3D Accelerated Visualization. The GUI communicates with the visualization via a TCP/IP network interface. Typically, the two endpoints are running on the same machine; however, for this project it made more sense to run the visualization software on the XR headset, while the GUI drives the scenario as normal.

For proper construction of a multipath pattern, a user creates an identical environment in OUNPPM on their device to simulate their desired scenario. Then a message can be sent to the remote instance running on the headset to begin generation of the pattern isosurface. Users can then begin to fully interact with the isosurfaces in a VR context.

The initial step for the technician will be to locate the site, or proposed site of the navigational aid to establish an origin. Once placed, the isosurface will be anchored to the ground in the virtual world, and the user can opt to walk around and view the visualization in real time. The headset responds to changes in the position and orientation (pose) by updating the view matrix of the virtual camera. To an outside observer this would appear to be the pattern moving two meters to the left in the virtual world when the user steps two meters to the right in the real world. Similarly, if the user tilts their head up, the pattern will move down, or if the user pans their head left or right, the pattern will move in the opposite direction. By having this new feature, users can potentially discover important issues or reasons for caution that may have otherwise been missed in a simulated environment.

Results

Throughout this research, two interfaces were explored to create an immersive and informative experience for users. These consist of two primary components: the VR interface and the MR interface. Each interface offers distinct advantages, making them ideal for different scenarios. Together, they enhance the value and functionality of OUNPPM.

Isosurface Generation in VR

The first component of the new tool includes an interactive VR application. This application creates entirely virtual environments that users can then explore and interact with in virtual reality. Figure 2 shows the tool being displayed through a virtual reality headset. This feature allows users to explore antenna visualizations in an immersive environment, that fosters additional interactivity and engagement. The feature promises to improve upon safety and current certification methods by introducing this new medium for use of the tool which offers unique user experience benefits.

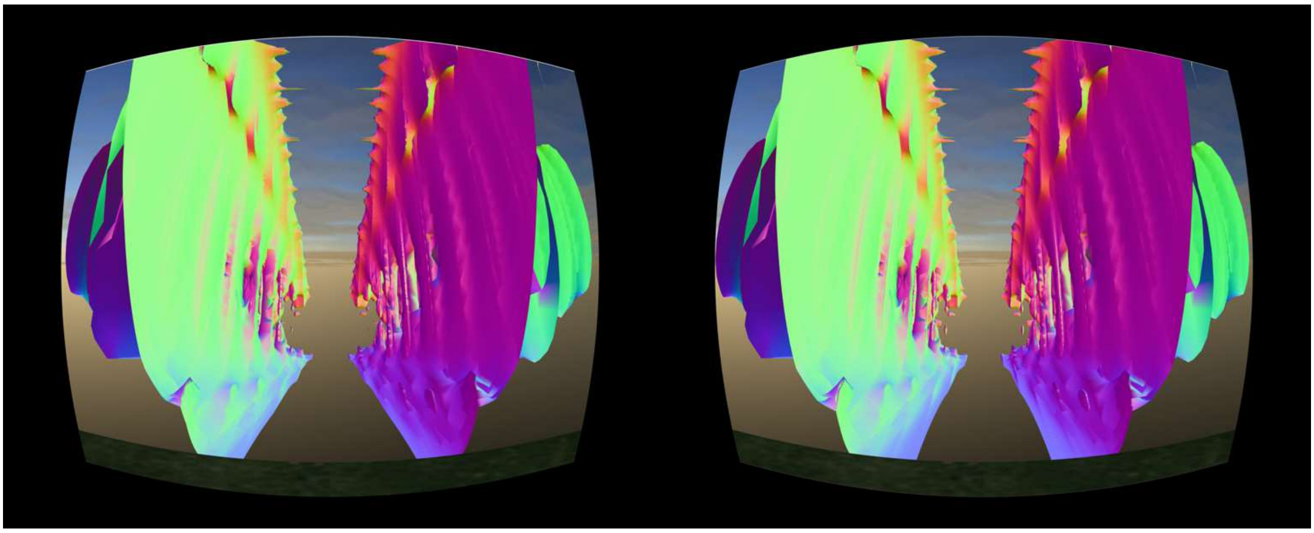

Figure 2. Pictured is a stereoscopic view of the mock OUNPPM VR interface. The left image is sent to the left eye, and the right image is sent to the right eye. The virtual cameras creating these perspectives are separated by the interpupillary distance of the user, creating a crisp, 3D, virtual reality effect.

<u>Isosurface Visualization in MR</u>

The MR interface allows users to examine and interact with antenna patterns in real life. This functionality permits users to view the isosurfaces at runways and explore how they actually behave in the field, as opposed to a purely simulated environment. Figure 2 displays a user interacting with a 3D model of an isosurface in real life. This is from preliminary visual tests, and further development is needed for a finalized version of the tool. The isosurfaces are pinned to a real-world reference point and the user can move around it in physical space. This allows the user to get an intuitive sense of scale, direction, and any potential obstructions.

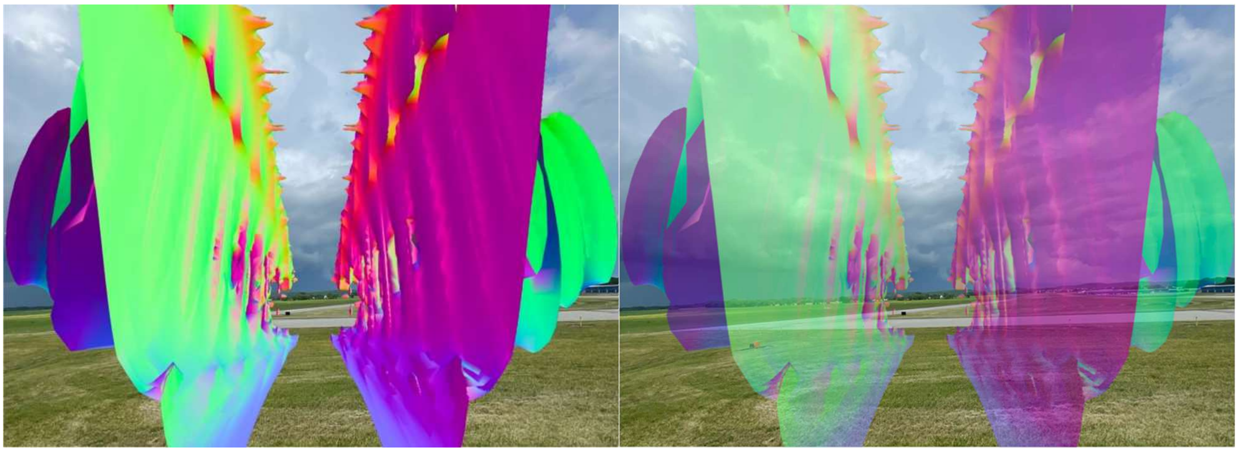

Figure 3. Pictured is a direct view of the OUNPPM MR interface. These serve as a preliminary and highlight certain features such as the opacity configuration. Opacity configuration serves to allow the user to see through the isosurface for improved visibility of the waveform's lobes

FUTURE WORK

The leading cause of VR Sickness is a low or inconsistent framerate, so performance optimizations are an important area for future development. The typical computer monitor has a vertical sync rate of 60Hz; therefore, each frame of the visualization must be completed in 16.67ms. The Meta Quest Pro has two displays each with a refresh rate of 90Hz; which means two perspectives must be generated every 11.11ms. Some work is shared between perspectives, and some of the rendering can be done in parallel; however, this does mean that VR experiences must either be leaner than desktop experiences, or much more optimized.

Expanding the range of visualizations to include other patterns, such as Distance Measuring Equipment (DME) and Tactical Air Navigation (TACAN), could broaden the impact and utility of the tool. These additional visualizations would provide users with a more comprehensive set of tools for analyzing and understanding different navigation systems.

Human subject trials on the effectiveness of the visualization could be conducted to refine the tool. Gathering feedback from the existing pool of users will help identify areas for improvement and discover new features that could enhance the functionality and user experience. Additionally, exploring advanced features such as real-time isosurface calculation using more modern methods such as Flying Edges [23] or Machine Learned approaches such as Neural Marching Cubes [24] or Neural Dual Contouring [25] could significantly enhance the tool's relevance in dynamic environments.

Further development on the tool will also be necessary. This feature is still in development and requires additional testing and augmentation before being ready for certification activities.

CONCLUSIONS

This paper presents a tool that introduces a new and powerful feature to OUNPPM, enhancing user engagement with the program. This new interface enables users to explore antenna patterns in both virtual and mixed reality environments. These capabilities provide users with a heightened sense of immersion, allowing them to discover aspects of the patterns that might have otherwise gone unnoticed. The developments in both VR and MR mediums expand and improve upon prior versions of OUNPPM, offering an advanced level of interaction.

The implications of this feature encompass both safety and compliance; by enabling a more thorough and interactive analysis of antenna patterns, the tool can contribute to the creation of more informed and more robust NAVAID configurations at airports. This advancement holds significant potential for improving the safety and efficiency of navigational aids worldwide. As development on OUNPPM and the XR implementation continues, this feature promises to be a critical component in the refinement of the program, advancing the field of NAVAID simulation through the visualization of electromagnetic waves in virtual and mixed reality.

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