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Mobile mixed reality platform for rapid prototyping

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Abstract

Mixed Reality (MR) represents a revolutionary advancement in computing, poised to transform interactions with the digital world by integrating virtual elements into real-world environments. This technology has the potential to significantly impact prototyping, business operations, and the education sector. Traditionally, the prototyping phase in product development involves sketching designs on paper or using CAD for 3D rendering, followed by manufacturing or 3D printing prototypes—a process that is both costly and time-consuming. MR tools allow developers to augment 3D models of prototypes over surfaces or in midair, enabling designers to modify and refine their designs without the need for repeated printing. In education, MR enhances the presentation of knowledge, moving beyond printed books and 2D screen presentations to create immersive, interactive learning experiences. This facilitates a deeper understanding by allowing users to move around and interact with virtual content. Recognizing the need for virtual object interaction in prototyping and education, we have developed a mobile mixed reality application that seamlessly blends the physical and digital worlds. This application allows users to rotate, scale, translate, and dismantle virtual objects, providing a more intuitive and engaging way to grasp structural concepts.

Keywords: Mixed Reality (MR); Rapid Prototyping; Mobile Applications; Modeling; Augmented Reality (AR)

1. Introduction

Mobile Mixed Reality (MMR) has emerged as a transformative technology in various fields, including design, education, and entertainment. Rapid prototyping, a crucial phase in the development of products and applications, can benefit significantly from the capabilities of MMR platforms. This literature review explores the evolution, current state, and potential future directions of MMR platforms for rapid prototyping, highlighting key studies and technological advancements.

The concept of Mixed Reality (MR) blends the physical and digital worlds, creating environments where virtual and real objects coexist and interact in real time. Early works by Milgram and Kishino (1994) introduced the Reality-Virtuality Continuum, which laid the foundation for MR. The continuum spans from the completely real to the completely virtual environment, including augmented reality (AR) and augmented virtuality (AV) as intermediates. The integration of MR with mobile technology further expanded its applicability, providing a more accessible and versatile platform for various applications. Recent advancements in mobile computing power, sensor technology, and network connectivity have enabled the development of sophisticated MMR platforms. Azuma et al. (2001) described AR systems as immersive and interactive, relying on precise tracking and registration of real-world and virtual objects. Mobile devices, with their built-in sensors and cameras, have become ideal candidates for MR applications. Billinghurst et al. (2015) discussed the evolution of AR on mobile devices, emphasizing their increasing capabilities and potential for widespread use. Rapid prototyping is a methodology that involves quickly creating scale models of a physical part or system using three-dimensional computer-aided design (CAD) data. It allows designers and engineers to test and refine their ideas efficiently. MR platforms can significantly enhance this process by providing an immersive environment where digital

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prototypes can be visualized, manipulated, and tested in real-world contexts. Kaufmann and Schmalstieg (2003) demonstrated the potential of AR for rapid prototyping in the domain of architectural design. Their system allowed architects to overlay virtual building components onto physical models, facilitating a more intuitive design process. Similarly, Funk et al. (2016) explored the use of mobile AR for prototyping interactive systems, highlighting the benefits of real-time feedback and collaboration. Accurate tracking and registration of virtual objects in the real world are crucial for effective MR experiences. Technologies such as Simultaneous Localization and Mapping (SLAM) have been pivotal in achieving this. Davison et al. (2007) discussed the use of visual SLAM in mobile devices, enabling precise tracking without the need for external markers. Natural and intuitive user interactions are essential for the usability of MMR platforms. Hansen et al. (2006) explored various interaction techniques, including gesture recognition and touch interfaces, which allow users to manipulate virtual objects seamlessly. MR platforms offer unique opportunities for collaborative design and prototyping. Billinghurst and Kato (1999) introduced collaborative AR, where multiple users can interact with shared virtual objects in a real-world environment. This approach fosters teamwork and collective problem-solving. The development of a Mobile Mixed Reality (MR) platform for rapid prototyping can significantly benefit from recent advancements in sustainable materials and technologies. Pesode et al. (2023) highlighted the use of sustainable materials in biomedical applications, which can be integrated into MR platforms to enhance durability and environmental friendliness. The study on metal oxide coating on biodegradable magnesium alloys by Pesode et al. (2023) underscores the potential of using advanced materials to improve the lifespan and reliability of MR devices. Additionally, Pawar et al. (2023) demonstrated the importance of precise chemical analysis in optimizing biodiesel's calorific value, a technique that can be adapted to refine energy efficiency in MR applications. The research by Wankhede, Hole, and Patil (2022) on the performance of diffusion absorption air cooling systems emphasizes the significance of energy-efficient technologies, which are crucial for mobile MR platforms. Further, Patil, Hole, and Wankhede's (2023) work on enhancing solar stills can inspire the development of renewable energy sources for powering MR devices. The antibacterial activities of plasma electrolytic oxidation coated magnesium alloys discussed by Pesode et al. (2023) can be pivotal in maintaining the hygiene and longevity of MR hardware. The investigations into manufacturing methods and the reuse, remanufacturing, and recycling of Mg alloys (Pesode et al., 2024; Wankhede et al.) highlight sustainable practices that can be incorporated into the lifecycle management of MR devices. Finally, Wankhede, Lobo, and Pesode's (2023) evaluation of machine learning algorithms for real-time optimization and issue detection in heat exchangers demonstrates the potential for integrating AI-driven analytics into MR platforms, enhancing their functionality and user experience.

The integration of advanced algorithms and machine learning models into a Mobile Mixed Reality (MR) platform for rapid prototyping can significantly enhance its functionality and user experience. Mane and Chavan (2013) demonstrated the effectiveness of median filters in image denoising, a technique that can be pivotal in refining the visual quality of MR environments. Mane and Shinde's (2023) development of StressNet, a hybrid model combining LSTM and CNN for stress detection from EEG signals, showcases the potential of incorporating sophisticated neural networks into MR platforms for real-time user feedback and adaptive experiences. Their earlier work (Mane & Shinde, 2022) on imaging approaches for mental stress detection using EEG signals further underscores the relevance of integrating biofeedback mechanisms into MR applications. Additionally, the evaluation of quality of service parameters for MQTT communication in IoT applications by Pawar et al. (2024) highlights the importance of reliable and efficient communication protocols, which are essential for the seamless operation of MR systems. Mane and Shinde's (2023) research on machine learning methods for diagnosing Alzheimer's disease via EEG signal analysis could inspire the development of MR tools aimed at healthcare and diagnostics. The work by Sabnis, Patil, and Wankhede (2023) on selecting automated guided vehicles using the Weighted Sum Method demonstrates decision-making frameworks that can be adapted for MR applications to optimize user interactions and prototyping processes. Lastly, Mane, Patil, and Shinde's ongoing investigation into neural stress patterns through EEG recordings emphasizes the importance of precise and responsive data analysis, which is crucial for creating immersive and interactive MR environments.

2. Materials and Methods

Mixed reality blends the physical and digital worlds, integrating intuitive human interaction, computing power, and environmental context. It represents an advanced form of augmented reality where users can interact with their surroundings through sophisticated computer vision, processing, and augmentation technologies. To run this application, a device equipped with a camera and robust video processing capabilities is required, such as a smartphone, tablet, or smart AR headset. The application utilizes computer vision models to recognize objects, planes, and features within the environment by analyzing a continuous video stream. The application captures raw images from the camera and processes them using machine learning models. The rendering module then augments the video frames with AR objects, ensuring precise alignment and interaction. This is achieved by determining the 3D position and orientation of objects using computer vision techniques. Given that the application operates in real-time, all these processes must be executed within the timeframe of new frame capture. Typically, smartphone cameras operate at 30 frames per second, allowing only 30 milliseconds to complete all necessary processing tasks.

$$\text{Time between frames} = \frac{1000}{No.of\ Frames\ per\ second}$$

Therefore, Time between frames = 30 ms

In many instances, the camera experiences significant delays (ranging from 50 to 60 milliseconds), but our brain does not perceive this lag, making the application appear to function seamlessly.

There are several types of mixed reality applications, each utilizing different techniques for integrating virtual objects into the real world. Marker-Based Reality employs markers such as images or QR codes that can be scanned by a camera and processed by software to determine the location of virtual objects within a scene. These markers typically consist of black squares on a white background. Marker-Less Reality, on the other hand, does not require a physical marker; instead, it uses images obtained from the internet and places them directly onto a plane rendered through the camera. Projection-Based Reality is a newer form that projects artificial light onto real-world surfaces, augmenting 3D models onto detected plane surfaces or floating them in midair. These applications are designed to detect interactions between objects, adjusting projections based on user interactions. Superimposition-Based Reality replaces the original view of an object with an augmented view. In this case, the virtual object superimposes over the real object, which acts as a marker. Accurate object recognition is crucial in this type, as the application must correctly identify the real object to replace its view effectively.

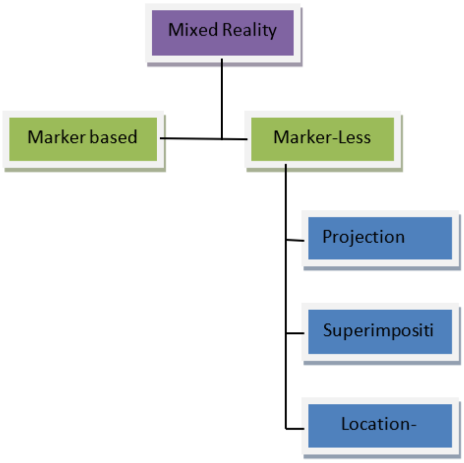

Figure 1 Types of Reality

The application requires various hardware components for proper functioning of MR. It requires a suitable size display, processor, camera, electronic sensors, etc. A smartphone contains all of the above elements along with accelerometer and compass which makes it compatible for MR.

2.1. Hardware requirements

Processor: Minimum Intel Core i5 with 2.8 Ghz or AMD Ryzen 5 or above. It is required mostly for a smooth processing and easy execution of the algorithm.

DDR4 RAM with 8GB or above

Storage: 128 GB of SSD (Solid State Drive). I am using SSD to load the assets

OS: Windows 8 or above.

Graphics Card: Nvidia GTX 1050 with minimum 2 GB memory or above.

Android Device

A Webcam is required to capture pictures and to detect surfaces and objects in real time for testing purpose.

A well working Monitor for displaying the Result.

2.2. Software Requirements

Unity Framework: It is a game development platform which can also be used for building mixed reality applications.

C# (C-Sharp): It is an open source, simple, flexible, and versatile language. The language that is used for the app development in Unity operates with object-oriented scripting technique.

Android NDK: The Native Development Kit consists of tool required for developers to reuse the code in C# and incorporate it into Java.

Android SDK: Software Development Kit is a package consisting of all the development tools and API's for building application.

Visual Studio Code: External editor for creating C# scripts.

2.3. Toolkit's and Packages required

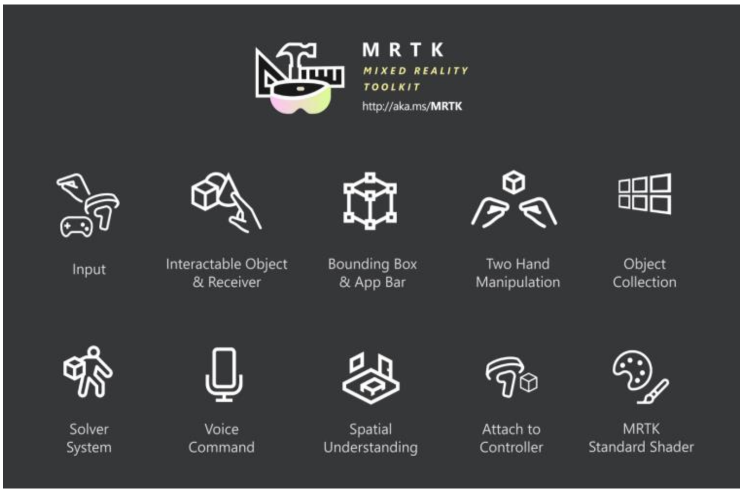

Figure 2 Mixed Reality Toolkit

The Mixed Reality Toolkit (MRTK) is a project by Microsoft that offers a comprehensive set of components and tools designed to accelerate cross-platform mixed reality app development in Unity. Similarly, AR Foundation is a Unity asset store package that enables developers to create mixed reality applications in a multi-platform environment within Unity. Play ARCore, developed and released by Google, is a platform for building augmented reality experiences, utilizing key capabilities such as motion tracking, understanding the surrounding environment, and light and position estimation to create immersive AR experiences.

3. Methodology

In order to augment the 3D models in space, target images with feature points are required which can be easily targeted by the camera. These features points describe that the video frame has enough attributes to track the target image. For the plane detection, it uses these features point having common co-ordinate in space thus recognizing the plane. The development system itself is used for the first test purpose. Therefore, application has to be deployed to Android device with latest version of Android software.

A bounding box in essence, is a rectangle that surrounds an object that specifies its position and confidence. Bounding boxes are mainly used in the task of object detection, where the aim is identifying the position and type of multiple objects in the image. For this application, the bounding box is used in a different manner. With the help of the box the different components of the 3d model can be packed into a single object. It acts a transparent glass cage in which the object is placed. The advantage of doing this is that the user won't be able to interact with the components of the model rather it can interact with the transparent glass cage. When the bounding box is removed, each component of the model can be accessed and interacted individually. An illustration is given in image above, the rectangle is a bounding box that encloses the model in it. Annotator's projects these rectangles over models, outlining the object within each image by defining its X and Y coordinates. This also makes it easier for the machine learning algorithms to find what they're looking for and thus saving valuable computing resources.

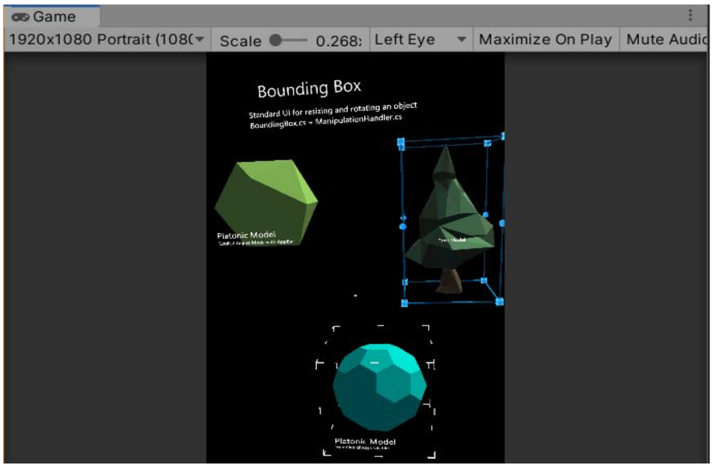

Figure 3 Bounding Boxes

These are the game Objects which is used to add some functionality to this application to make application or game complete. These buttons are custom designed virtual button's and programs are added for require functions. User can also get the sample virtual button from Unity's official asset store which can also be customized to function in a user-defined way. There are in total 3 buttons created as follows:

- Bound/Unbound Boxes: Used to pack or unpack the Game Object (or Virtual objects).
- Reload Scene: Used to reload the entire scene.
- Gravity Component: To add gravity to all the objects in the environment.

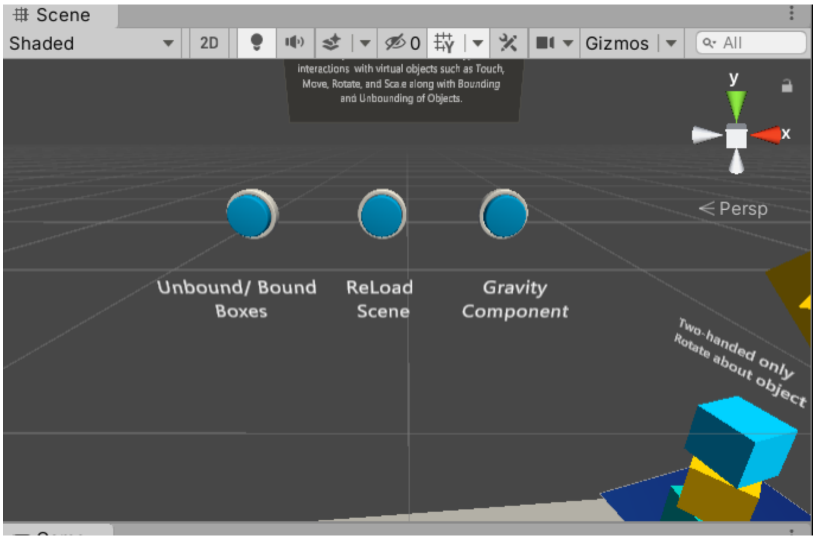

Figure 4 Virtual Buttons in Unity

The reason why the buttons are included is to expand the capability of the application.

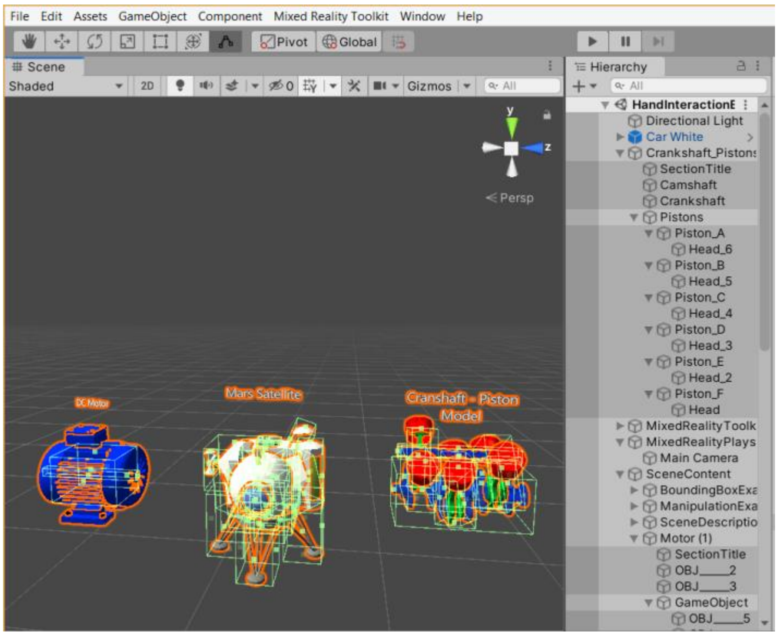

Figure 5 Colliders of Game Object

Collider is a component that defines the physical shape of an object to detect physical collisions. It is an invisible entity, which has either the shape of the object or it need not be same as that of object shape. A rough shape including maximum surface area is also efficient for the process. The simplest colliders are also known as primitive collider types. In 3D, these are the Box Collider, Sphere Collider and Capsule Collider. With proper positioning and scaling, these colliders can take an approximate shape of an object. Colliders interact with each other which are helpful in determining collisions and also human physical touches. It depends upon the configuration of Rigid body component. It helps in maneuvering the virtual objects in physical environment depending upon various touch gestures.

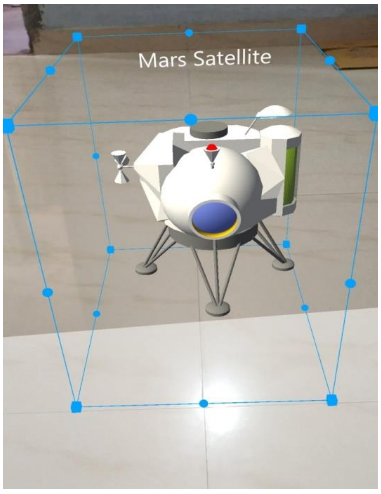

Figure 6 Bounded Satellite Game Object

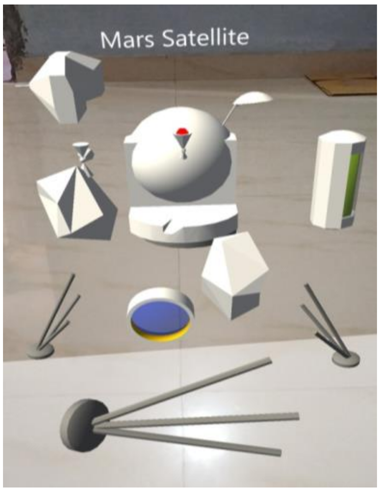

Figure 7 Unbounded Satellite with maneuvered components

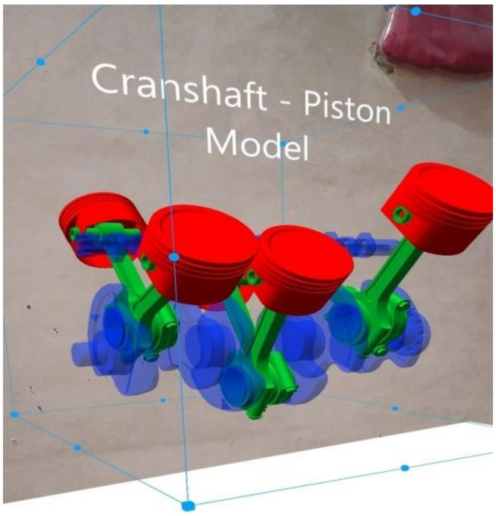

Figure 8 Bounded Crankshaft-Piston Model

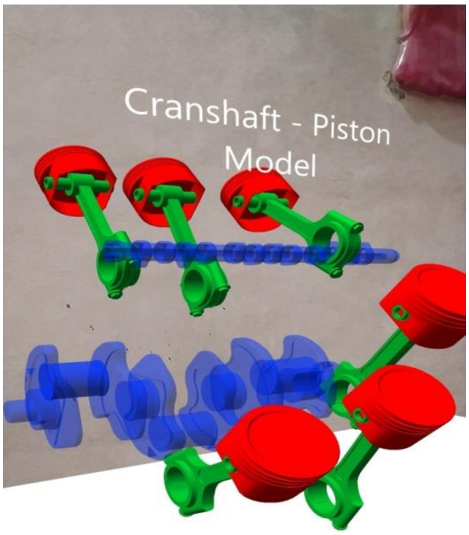

Figure 9 Unbounded Crankshaft-Piston Model (Maneuvered)

4. Conclusion

A mobile mixed reality application was created to blend the physical and digital worlds. This application allows virtual objects to be rotated, scaled, and translated, along with a dismantling feature to better understand their structure. The application overlays 3D objects onto existing ones, enabling designers to modify prototypes without the need to print a new version with each change. It offers an immersive experience for audiences in educational settings, allowing learners to move around a room and interact with content, thus creating more engaging and active learning experiences that enhance knowledge retention and understanding of complex concepts. This MR application streamlines the concepting and prototyping process, saving time and resources. Users can create digital overlays to visualize how features will appear next to real-world objects. The application provides complete in-app interactivity, enabling users to scale, rotate, and walk around virtual models, as well as dismantle them to comprehend their structure more effectively.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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