A Framework for Monitoring Cargo Movement using Virtual Reality

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ABSTRACT

This research focuses on developing an architecture for monitoring the location and status of entities within a real-world environment and representing this in a virtual or augmented reality environment. The primary objective was to create an application that enables real-time monitoring of cargo movement in a port setting, demonstrating this architecture. By establishing communication with a server storing entity data, accurate information display and updates are ensured. The research presents a preliminary project that showcases the feasibility of the proposed architecture, demonstrating the connection between the application and server to display updated data in a VR environment. Results indicate successful real-time synchronization and data exchange, highlighting the benefits of such an architecture in enhancing logistics operations and providing a comprehensive understanding of entity movement. This research sets the foundation for future endeavors in creating large-scale virtual environments and exploring different communication frameworks, expanding the potential of VR technology in diverse monitoring scenarios.

CCS CONCEPTS

• **Computer methodologies**; • **Mixed / augmented reality.**;

KEYWORDS

Cargo monitoring, virtual reality, logistics

ACM Reference Format:
Carlo Mantovani, Leonardo Pavanatto, and Márcio Sarroglia Pinho. 2023. A Framework for Monitoring Cargo Movement using Virtual Reality. In *Symposium on Virtual and Augmented Reality (SVR '23), November 06–09, 2023, Rio Grande, Brazil.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3625008.3625040

1 INTRODUCTION

Virtual and Augmented Reality (VR/AR) technologies have gained significant attention in recent years for their potential to create immersive and interactive experiences. These technologies have various applications in fields such as gaming, education, training, and simulation. They offer new possibilities for the monitoring of a real environment through a virtual environment that represents it in real-time.

The primary objective of this research endeavor is to develop an architecture that supports the monitoring of the location and status of entities through a virtual environment. Therefore, by creating an application that, for example, enables the monitoring of cargo movement within a port, a preliminary usage for this architecture can be demonstrated. The application will communicate with a server that stores data about the entities, ensuring real-time updates and accurate information display.

To accomplish this objective, the project leverages VR technologies and establishes a connection between the application and the server. Given that the server stores a variety of data about the entities, an enhancement of the logistics operations within a specific setting can be achieved.

The remainder of this paper is organized as follows: Section 2 provides an overview of related work in the field of VR/AR environments and the monitoring of cargo in port settings. Section 3 presents an application scenario for the suggested architecture. Section 4 demonstrates the proposed architecture, outlining its objectives and scope. Section 5 discusses the implementation of the preliminary project, highlighting the key details necessary for the established architecture. Section 6 presents potential avenues for future research and development. Finally, Section 7 concludes the paper, summarizing the findings and discussing their implications.

2 RELATED WORK

Several studies have explored the utilization of Virtual and Augmented Reality (VR/AR) environments for various applications [1][2]. In the logistics domain, researchers have proposed innovative solutions that combine VR technology with logistics operations to enhance efficiency and safety.

F. Shu et al [3] presented an interactive logistics center information integration system that employed virtual reality technology to address traceability and safety supervision in the logistics industry. The system utilized the immersive nature of virtual reality to simulate realistic logistics center scenes, allowing operation staff to conduct safety supervision training without regional restrictions. By incorporating sensor data and video surveillance, the system could simulate disaster emergency situations and analyze personnel operation data to improve training efficiency. The study demonstrated the potential of VR-based solutions in enhancing safety and information integration within logistics centers.

SVR '23, November 06–09, 2023, Rio Grande, Brazil

ACM ISBN 979-8-4007-0943-2/23/11…$15.00
https://doi.org/10.1145/3625008.3625040

In a similar vein, another research project, by Hong, S. and Mao, B. [4], presented a comprehensive system, it simulated a port environment using VR that emphasized the importance of information management in container terminals, highlighting the need for an effective and systematic strategy. Their proposed solution involved the development of a VR-based information-sharing infrastructure, which aimed to serve as a logistics information system for container terminal operation and control. For that purpose, real time information exchange and coordination between different entities was needed, including terminals, shipping companies, custom inspectors, and administrative departments.

Beyond that, a study by Wang, W. et al [5] analyzed the application of AR technology in in-house logistics operations. Their research delved into the principles and technical characteristics of AR technology and examined its advantages in optimizing in-house logistics processes.

Additionally, a study by Mourtzis, D. et al [6] proposes a framework for warehouse design that utilizes Augmented reality (AR) to maintain a high degree of service. This framework had the objective to minimize inventory cost and its AR aspect was used to provide significant information for an effective management of operations within the warehouse.

Also, a study by Wang, K. [7] examined the benefits of VR technology in logistics education, highlighting its positive impact on students' learning interest and achievements. The study emphasizes how VR-based teaching methods have the potential to revolutionize the logistics curriculum by providing a dynamic and immersive learning environment that surpasses traditional teaching techniques. This research underscores the potential of VR technology to overcome the limitations of time, space, and equipment availability in logistics education, paving the way for a more engaging and effective teaching approach.

These studies highlight the potential of virtual and augmented reality technology in the logistics industry, and, building upon these insights, the proposed research project aims to leverage the potential of virtual reality technology by exploring real-time communication between applications and focusing on the location and status monitoring of various entities in a virtual environment.

3 APPLICATION SCENARIO

For illustrative purposes, consider a 3D application that simulates a port environment, featuring numerous cargo containers positioned throughout the virtual space. These containers would be assigned predetermined locations and will contain various internal information. In contrast, another application would serve as a 2D graphical representation of the environment, allowing users to observe changes that occurred within the virtual environment, secondarily, it allows the placement of containers freely within the virtual setting.

These containers would be instantiated in real time within the 3D immersive application, and their positions and internal contents would be sourced from a server that contained all data associated with them, such as position and internal contents. Additionally, the virtual environment would undergo periodic updates at predetermined intervals, ensuring that any modifications made to the containers would be reflected in their positions and contents accordingly. Therefore, the 3D Virtual Environment Application serves as a dynamic representation of an environment that underwent real-time changes.

Regarding the 2D application, it offers an overhead representation of the environment. Its primary objective is to serve as a user-friendly monitoring tool, allowing users to observe real-time data from sensors placed on the containers. However, this 2D interface also possesses a secondary function, empowering users to manually modify the environment whenever necessary. This manual alteration capability provides added flexibility in scenarios where adjustments are required, for instance, it proves useful when the monitoring process of container items is conducted by a human.

Both applications would be synchronized to ensure that any modifications made in the 2D interface would be reflected in the corresponding 3D virtual environment, ensuring consistency between the two applications.

This type of scenario could also be applied to a parking lot. In this case, a combination of sensor devices could be deployed to observe the environment from different angles. Each vehicle within the parking lot would be associated with a unique identifier, such as a QR code or a beacon. The identifier contains essential information about the vehicle, including details like the brand, color, and other relevant attributes, depending on the specific context of the environment.

In terms of hardware requirements, the 3D application relies on a compatible VR Headset, such as the HTC Vive or Oculus Quest, along with its controllers to enable general movement and interaction within the virtual environment.

In contrast, the 2D application, being a lightweight graphical interface, is designed to be compatible with a wide range of devices, including personal computers or mobile phones. Additionally, if needed, the 2D application could also be utilized on mobile devices for added flexibility and accessibility.

4 ARCHITECTURE

A generic architecture has been established for use in various scenarios requiring monitoring, such as parking lots, warehouses, and other similar environments. Therefore, this research serves as a representative sample, providing valuable insights into the potential of scaling up the project for larger applications.

To establish a clear understanding of the architectural choices made, it is crucial to identify the core requirements of this architecture. Firstly, there is an emphasis on the necessity for the accurate representation of the physical environment within a virtual setting. This requirement is fundamental because the system operates in a domain where precise real-world replication is essential. Without this fidelity, the system's effectiveness in monitoring and tracking real-world movements would be compromised. Setting a high bar for accuracy ensures that the system can reliably fulfill its intended purpose.

Furthermore, it's important to note that defining precise architectural requirements is contingent on a comprehensive understanding of the application's context and its various demands. These requirements transcend the realm of virtual reality and are, in fact, foundational for any software system.

Additionally, to ensure that real-world changes are accurately reflected in the virtual realm, seamless connectivity between monitoring equipment and the virtual environment application is essential. Typically, this connection is established, either directly or indirectly, through a server.

4.1 Communication

In this project, the communication within the architecture is supported by the PUN2 framework [8], which plays a crucial role in facilitating real-time data exchange through a server and interaction between the 3D virtual reality environment and the real-world monitoring application. PUN2's concept of "rooms" is central to its networking capabilities. A room can be thought of as a virtual space or container where multiple users or applications can be grouped together, creating a shared environment for real-time interaction and data exchange.

When both the monitoring application and virtual reality applications join the same room, they become part of the same networking ecosystem, allowing them to communicate and synchronize their data effectively. In the specific context of this research, this communication mechanism allowed a 2D graphical interface application to not only serve as a clear visualization of the environment's state, but also transmit edited arrangement data (when simulating changes to the environment) to the virtual reality application, which in turn utilized the updated data for further update of its own environment.

This was achieved by utilizing the concept of "Custom Properties" within the framework. Custom properties refer to room-specific properties that are not predefined within the framework. By assigning a label to a custom property, various types of data can be stored with that specific label and subsequently accessed by other applications within the same room. Therefore, the edited arrangement data was stored as a custom property of the room.

When the monitoring application observes a change within the real environment, it changes its arrangement data, updating the corresponding custom property. The virtual reality application, utilizing the capabilities of the PUN2 framework, detected changes in the room's custom properties and observed this modification. Subsequently, the virtual reality application retrieved and saved the received data in response to the observed change.

This implementation, seen on Figure 1, allowed for efficient and synchronized data exchange between the monitoring application and the virtual reality applications, demonstrating the practical utilization of custom properties within the PUN2 framework for achieving proper communication.

4.2 Arrangement Data

The arrangement data represents the spatial organization and positioning of containers within the physical environment. This data is essential for accurately reflecting the current state of the physical environment in the corresponding virtual environment.

The data is stored and transmitted in JSON (JavaScript Object Notation) format [9]. JSON provides a lightweight and flexible structure for organizing and exchanging data. It allows for easy serialization and deserialization of the container arrangement information, making it suitable for real-time communication between the graphical interface and virtual reality applications.

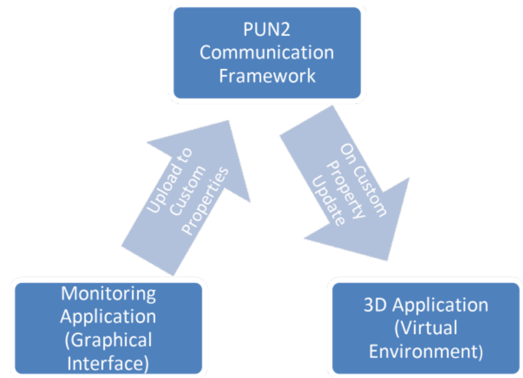

Figure 1: Communication Diagram

The JSON structure for the arrangement data includes relevant attributes such as ID, position coordinates, orientation, and any additional metadata associated with each entity, such as its internal contents. This structured representation ensures that the virtual environment can accurately replicate the spatial distribution and organization of entities within a given environment.

By transmitting the arrangement data through the communication mechanism facilitated by the PUN2 framework, the monitoring application can update and transmit changes in the container positions and organization to the virtual reality application. The virtual reality application, in turn, receives and processes this data to update its own environment, ensuring synchronization between the physical and virtual representations.

5 DEVELOPED APPLICATION

The developed application in this research endeavor consists of two interconnected components: the 3D Virtual Environment Application and a 2D Interface Application that allows the simulation of cargo movement. These applications work together to establish real-time monitoring and synchronization between the physical and virtual environments.

5.1 3D Virtual Environment Application

The 3D Virtual Environment Application simulates a port environment in a virtual space. Currently, it runs on HTC VIVE and Oculus Quest platforms, but can be easily ported to other hardware because it is based on the Unity Framework.

This application dynamically represents the physical environment by reflecting corresponding changes in real-time. The virtual environment can be observed on Figure 2 which reflects the real-world position of the containers.

Within the virtual environment, users can navigate using the VR headset's controller and interact with the containers to access internal information about each of them. Figure 3 illustrates the user's perspective while engaging with the containers.

The 3D Virtual Environment Application instantiates cargo containers, which are positioned throughout the virtual space based on the container arrangement data received from the server. This data would establish the containers' locations and their internal contents. To ensure that any modifications made to the containers

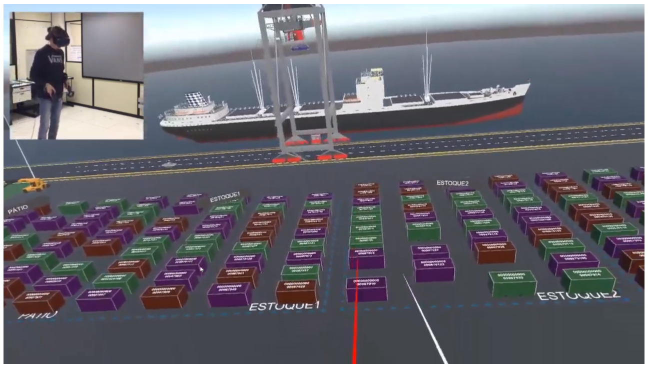

Figure 2: Visual Representation within the Virtual Environment

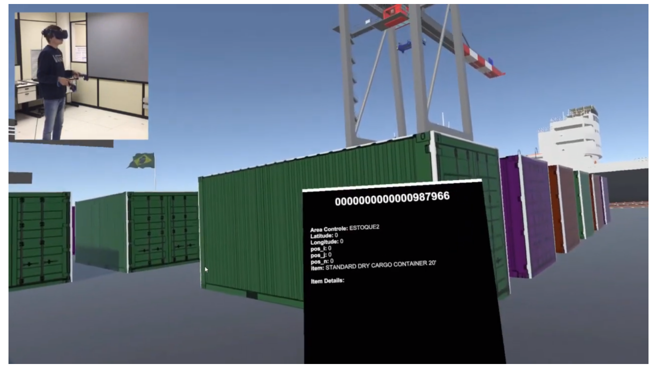

Figure 3: User Perspective within the Virtual Environment

are accurately reflected, the application periodically updates the virtual environment.

5.2 2D Interface Application

The developed 2D Interface Application serves as a user-friendly graphical representation of the virtual environment when viewed from above (Figure 4). While the primary purpose is to display real-time data from sensors placed on the containers, it also offers a flexible manual manipulation feature, allowing users to alter the environment if necessary.

The interface presents rectangular areas representing potential container positions, enabling users to interactively move and arrange the containers manually. Figure 4 represents this developed interface with its various areas and potential container positions. These areas would be colored based on the state of occupation of that position within the environment with green representing an "unoccupied" position and red an "occupied position". When a given user were to click a specific area, its state would change, and the change would be reflected in the referenced virtual reality environment.

5.3 Integration and Communication

To ensure proper communication between the two applications, both applications are connected to the same room within the PUN2 framework so that changes within this room are observable by both applications.

The arrangement data, which represents the spatial organization and positioning of containers within the physical environment, is transmitted in JSON format.

The JSON structure includes attributes such as container ID, position coordinates, orientation, and additional metadata. This data would be stored and transmitted by utilizing a labeled custom property within the shared room.

When changes are made in the 2D Interface Application, such as positioning a container, the corresponding custom property is updated. The 3D Virtual Environment Application, also utilizing the PUN2 framework, detects changes in the room's custom properties and retrieves the updated data to reflect the modifications in its own environment.

Figure 4: Monitoring Application of the Virtual Environment

6 CONCLUSION

In conclusion, this research project aimed to explore the potential of an architecture that monitors the location and status of entities within a real environment to then be represented in a Virtual or Augmented Reality (VR/AR) environment. The development of a preliminary project demonstrated the feasibility of representing a real environment by establishing real-time communication and synchronization between interconnected applications. The implementation within this project successfully simulated a port environment and provided a graphical interface for monitoring and visualization of this virtual environment and, secondarily, the manipulation of container placement in the virtual setting.

Through the utilization of the Photon Unity Networking 2 (PUN2) framework, synchronous communication was achieved, allowing for fluid data exchange and interaction between applications. The practical utilization of custom properties within the PUN2 framework showcased the efficiency and effectiveness of real-time communication in VR/AR environments.

The findings of this research contribute to the understanding of how the proposed architecture enhances monitoring and interaction within VR/AR environments. With this successful implementation, it is highlighted the benefits of real-time communication, including improved collaboration, enhanced user experiences, and increased realism.

Moving forward, future projects can expand upon these findings by creating large-scale virtual environments that accurately mirror real-life models, such as parking lots, and leverage multiple capture devices for real-time synchronization. Additionally, exploring different communication frameworks and integrating features like real-time physics simulations and multi-user collaboration can further enhance the capabilities of VR/AR environments.

In conclusion, this research project demonstrates the feasibility and practical implications of an architecture that monitors the location and status of entities in VR/AR environments. The successful implementation and insights gained lay the foundation for future projects aiming to leverage these technologies for enhanced monitoring and interaction in various domains.

7 FUTURE WORK

In the context of the preliminary project, a similar framework can be used for an expanded and comprehensive project. This project involves creating a large-scale virtual environment that accurately simulates a detailed real-life setting, monitored in real-time using a variety of capture devices like cameras, GPS units, and sensors. These devices are then placed in the physical environment to track positions of relevant entities.

The virtual environment encompasses a range of positions to accommodate various types of entities represented by digital models within the virtual space. Each entity has an identifier that contains essential information pertaining to it depending on the context of the environment. Within a port, for example, it could contain information such as its internal contents and total weight.

When an entity occupies a specific position within the real-life model, this occupancy is instantly reflected in the corresponding location within the virtual environment. This synchronization is achieved by leveraging the information obtained through scanning the identifier associated to the entity. The identifier is scanned, and the extracted data, typically in JSON format, is utilized to represent the entity's occupation within the virtual environment.

Consequently, any new entity entering the physical environment will be promptly updated in the virtual environment, thereby establishing a seamless and real-time correlation between the real-life model and the virtual simulation. This synchronization process ensures that the virtual environment accurately mirrors the current state of the physical environment, enhancing the overall realism and fidelity of the virtual experience.

This architecture can be utilized in a diverse variety of environments, including ports with their containers, parking lots with vehicles, warehouses with various products, and other applicable scenarios. It enables real-time monitoring, synchronization, and tracking between the physical and virtual realms, providing a comprehensive understanding of the state and movement of entities within these environments.

ACKNOWLEDGMENTS

Our research is partially funded by (a) the National Institute of Science and Technology in Medicine Assisted by Scientific Computing (Grant CNPq 465586/2014-7).

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