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Mixed Reality Platform for PLC Operation in Academy and Industry Environment

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Abstract **-** This paper describes an mixed reality (MR) platform for the industrial automation that is used to control and monitor, in real-time, the movement of a conveyor belt, with a Horner XL4 PLC (connected via Modbus protocol) and a frequency inverter. The system, powered by IoT-cloud based connectivity and augmented / virtual reality (AR/VR) interfaces, provides a mechanism for operators to engage remotely with physical equipment (e.g., change motor speed) within virtual environments. Combining PLC data (transmitted in Modbus via Python) with MR visualization to boost operational efficiency, minimize downtime, and increase safety—doubling as a control tool for industry and a training simulator for academia. Its effectiveness is shown by experimental results bridging digital-physical systems for Industry 4.0 applications.

***Keywords*:** Mix Reality, PLC, Industry, virtual environment, IoT, operator, Safety, Modbus, Database.

1. Introduction

The foundations for the development of a mixed reality (MR) platform for industrial automation are established through a theoretical and practical framework. The theoretical approach focuses on analyzing the integration of programmable logic controllers (PLCs) with IoT-cloud systems, real-time data transmission through industrial communication protocols such as Modbus, and the role of immersive mixed reality technologies within industrial environments. [1]

The practical approach proposes a system architecture that enables operators to remotely interact with physical processes in real time through immersive mixed environments, enhancing supervision, operational efficiency, and safety in industrial operations.

To contextualize this proposal, it is essential to define the concepts that support this work. This section introduces the function of programmable logic controllers (PLCs) in industrial control systems, the importance of real-time data acquisition and cloud connectivity, and the potential of MR in creating interactive and intuitive environments for industrial supervision and control.

PLCs are essential in industrial automation, responsible for executing control logic, monitoring process variables, and ensuring operational safety. Traditionally, these controllers are accessed through local HMIs or Supervisory Control and Data Acquisition (SCADA) systems, limiting operational flexibility and restricting access to on-site conditions. By integrating PLCs with IoT-cloud platforms and real-time data communication protocols such as Modbus, it becomes possible to transmit live process data to remote visualization and control systems. [2]

MR merges real and virtual worlds, allowing physical components and digital objects to coexist and interact dynamically in real time. Unlike Augmented Reality (AR) or Virtual Reality (VR), which primarily focus on overlaying or simulating environments, MR creates a bidirectional interaction between digital interfaces and physical systems, offering operators immersive environments to supervise, control, and respond to process conditions remotely.

This paper proposes a mixed reality platform that integrates a Horner XL4 PLC with a frequency inverter to control and monitor a conveyor belt system in real time via the Modbus communication protocol through python. The system leverages IoT-cloud connectivity to synchronize live PLC data with MR visualizations, enabling operators to adjust motor speeds, monitor system status, and perform troubleshooting within immersive environments. By combining real-time data management, cloud connectivity, and mixed reality interfaces, the platform enhances operational efficiency, reduces downtime, and improves safety in industrial processes. Additionally, it serves as a training simulator for academic applications, demonstrating its effectiveness in bridging digital and physical systems within Industry 4.0 environments. [3]

Table 1 presents a comparison between conventional industrial control methods based on local HMIs and SCADA systems, and the proposed Mixed Reality-based platform. The analysis highlights the improvements in user experience, interaction capabilities, flexibility, and remote access provided by integrating PLC control via Modbus, IoT-cloud services, and MR interfaces. [4]

Table 1: Comparison between Conventional Industrial Control Methods and the Proposed Mixed Reality-based Platform

Characteristics	Conventional Methods (HMI/SCADA local)	Proposed Method (MR + IoT-Cloud + PLC)
User Experience	Operators interact through physical HMIs or fixed SCADA terminals located near the process.	Operators interact remotely in immersive, mixed reality environments with real-time process data synchronized to virtual objects.
Interaction with the Environment	Interaction is limited to physical devices (buttons, touchscreens) and 2D graphical interfaces.	Allows dynamic, real-time interaction with both physical and virtual elements, adjusting process variables through 3D MR interfaces.
Level of Immersion and Accessibility	Low immersion — operators must be physically present at control stations or SCADA rooms.	High immersion — operators can access and interact with the system from anywhere using MR headsets and cloud connectivity.
Data Availability and Control	Data and control options are restricted to local networks; remote access requires complex VPN setups or dedicated SCADA servers.	Real-time data synchronized via IoT-cloud platforms and Modbus, enabling secure, direct remote access to process variables in MR environments.
Flexibility and Scalability	Limited flexibility; system modifications and expansions require physical changes in hardware and software infrastructure.	High flexibility; virtual interfaces and data visualizations can be quickly adapted, scaled, or modified without affecting the physical system.

Applications in Training and Simulation	Typically limited to simplified simulators or theoretical instruction disconnected from real equipment.	Enables the creation of realistic, immersive training environments using live or simulated process data, improving both academic and industrial training.

2. Platform development

The graphical interface and programming linking the MetaQuest 3 mixed reality headset with the Firebase real-time database were developed on the Unity platform. The system's primary function is to enable users to remotely operate industrial devices (such as the Horner XL4 PLC) from different locations using TCP/IP and modbus protocols, aligning with the growing interconnectivity of Industry 4.0.

The operator can connect the MetaQuest 3 headset from anywhere, provided they have a stable internet connection. For seamless operation, the database must process data requests in real time, as any delay between the headset's motion inputs and the PLC's response could lead to errors in command execution. Figure 1 illustrates the platform's operational diagram.

The following diagram (Fig. 1) depicts a bidirectional communication system. The platform connects to the cloud via TCP/IP, storing and retrieving data through Firebase. Using the "Get" method, the system fetches data and sends it to the headset, while the "Put" method updates the database with new positional data from the digital twin. This ensures the Horner XL4 PLC receives real-time commands with python while synchronizing feedback to the MetaQuest 3 for an interactive teleoperation experience. [5]

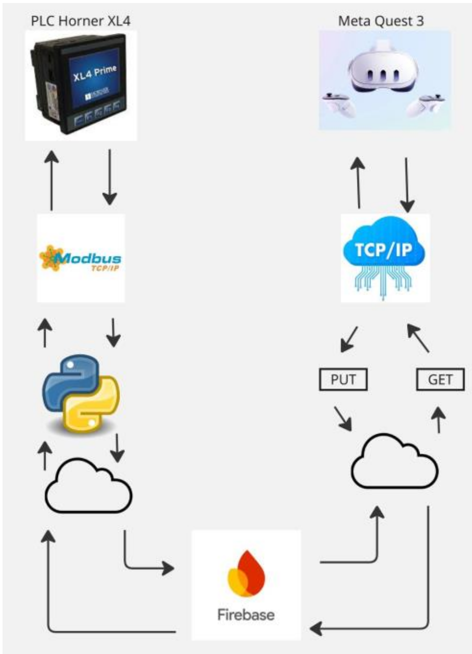


Fig. 1: Representative diagram of bidirectional communication of the MR platform.

2.1. Augmented reality glasses

The Meta Quest 3 delivers mixed reality experiences where digital objects interact with your physical environment while maintaining full situational awareness. Unlike fully immersive VR, this approach lets users see their surroundings clearly while overlaying interactive 3D content, enabling natural movement and real-world interaction. Advanced spatial tracking and passthrough technology ensure holographic elements maintain proper perspective within your workspace [6].

The system leverages the headset's high-resolution lenses and optimized field of view for precise industrial visualization. When combined with spatial audio cues, operators can maintain spatial awareness of virtual control elements even when they're outside direct view. The Meta Quest 3's environment understanding capabilities allow virtual interfaces to anchor securely to physical workstations, creating a seamless blend of digital and real-world components [7].

In this implementation, the Meta Quest 3 connects to Firebase to stream real-time operational data from a Horner XL4 PLC [8]. Operators can visualize the PLC's status and control parameters through an interactive 3D interface superimposed on their physical environment. This creates a virtual control panel that mirrors the actual industrial system, enabling remote monitoring and programming from safe distances.

The digital interface precisely replicates the PLC's logical architecture while maintaining proper scaling of control elements. This accuracy is crucial when mapping ladder logic operations to virtual controls, ensuring there's no discrepancy between the operator's inputs and the PLC's execution. The Firebase integration maintains sub-second latency for real-time synchronization between the virtual interface and physical PLC operations.

2.2. Horner XL4 Programmable Logic Controller

The Horner XL4 is a compact and versatile PLC designed for seamless integration in industrial automation and control systems. Its modular architecture and reduced footprint make it ideal for applications in constrained spaces or embedded within machinery. The XL4 combines robust processing capabilities with a wide range of I/O options, enabling efficient management of tasks such as process control, data acquisition, and equipment monitoring. Additionally, its user-friendly programming environment and scalability have made it a popular choice not only in industrial settings but also in educational contexts for training in automation technologies.

Fig. 2 Horner XL4 PLC [8].

2.3. Platform Menu

The platform's main control allows us to remotely operate a conveyor belt connected to a PLC via a transducer, allowing interaction between a user and various remotely connected devices. The operator can digitally manipulate and observe the behavior of the actual belt. The platform has a menu (see Fig. 1) allowing for different options:

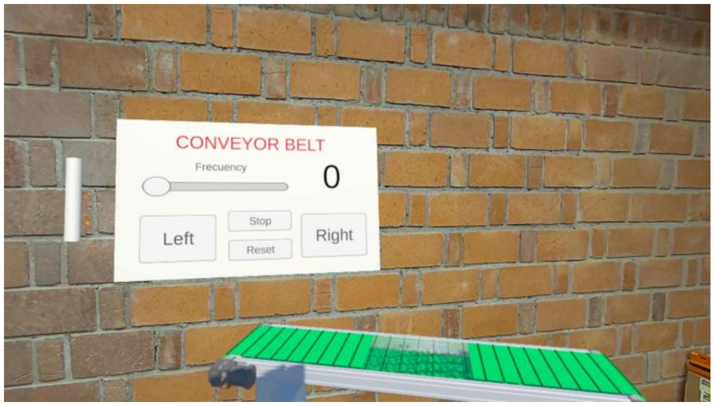


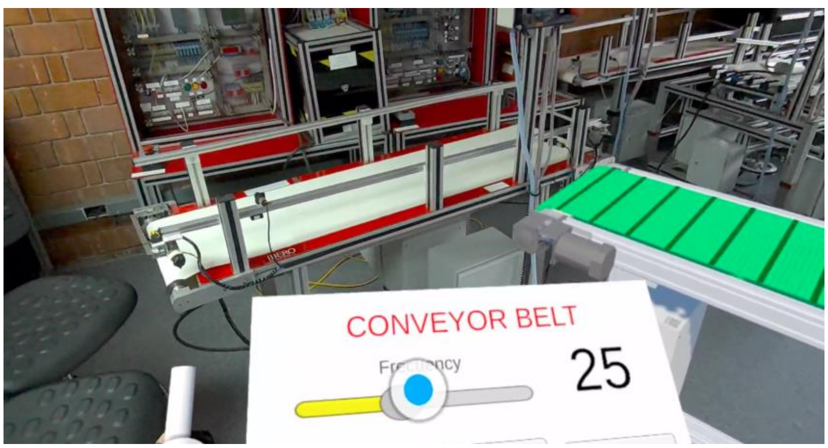
Fig. 1 Menu

The side buttons change direction from left to right as required, connecting to the database in real time. In this model, only direction changes, stopping the belt, and modifying the movement frequency are possible.

In this model, it is possible to spatially move the belt, but rescaling is not possible, allowing for a comfortable operating position.

Being able to observe a moving digital model allows for training an operator without having to be in front of the belt, reducing costs and improving operating efficiency.

It allows for manipulating the frequency at which we want the belt to move, ranging from 0 to 60 speed (see Fig. 2).



Fig, 2 Frequency.

Through a script, communication is established between the virtual twin data, the database, the PLC, and the conveyor belt (see Fig. 3). This allows for complete manipulation of the plant's devices and avoids putting an operator at risk by remotely manipulating different pieces of equipment. This represents a significant improvement in operator safety and reduces training and operating costs for industries.

Fig, 3 Database connection.

This type of operation becomes a strong foundation, allowing for the interaction and control of different plant elements and a safe and user-friendly environment, leveraging the benefits of Industry 4.0 and IoT connectivity (see Fig. 4).

Fig. 4 Operation.

For the connection between the PLC, the conveyor belt, and the cloud database, a Python project was designed with a graphical interface (see Fig. 5) capable of locally viewing or manipulating the data sent to the PLC, connecting to a computer via Ethernet.

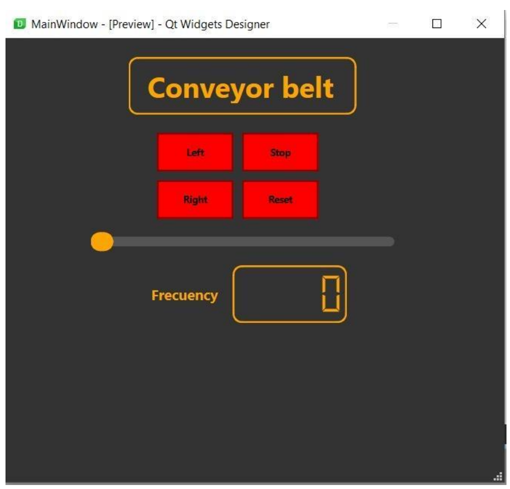


Fig. 5 Operating Interface

4. Conclusion

In conclusion, this MR platform, powered by Industry 4.0 technologies and integrated with the Horner XL4 PLC, represents a significant leap forward in industrial automation and engineering education. The system successfully achieves real-time bidirectional communication between the physical PLC and its virtual twin through the Modbus protocol, enabling remote monitoring and control of industrial processes within an immersive MR environment. This innovation not only enhances operational efficiency and safety but also reduces downtime by allowing operators to visualize and interact with equipment data intuitively.

The platform's adaptability underscores its potential for diverse industrial applications, from assembly line automation to predictive maintenance systems. Additionally, its low-cost architecture and user-friendly interface make it an ideal training tool for academic settings, bridging the gap between theoretical knowledge and hands-on experience with industrial-grade systems. Future work could explore scaling the platform to multi-PLC networks or incorporating AI-driven diagnostics to further optimize process automation.

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