A Novel Immersive Digital Twin Architecture for Rescue Mission Automated Guided Vehicle with VR Capabilities

The American University in Cairo

SIEMENS

KNOW Center

Mokhtar Ba Wahal, Maram Mahmoudi, Ahmed Bahssain, Ikrame Rekabi, Abdelhalim Ali, Mohammed Al Zarif

Supervised by Eng. Mohamed Leithy, Dr. Mohamed Abd El Salam, Dr. Neven ElSayed, Dr. Tamer ElBatt

Abstract

Digital twins are advanced virtual replicas of physical assets capable of mimicking their behavior through bidirectional communication in real-time to improve human understanding of complex systems. Supplementing digital twins with Virtual Reality (VR) capabilities is a step towards easing human interaction by elevating the situational awareness of the user.

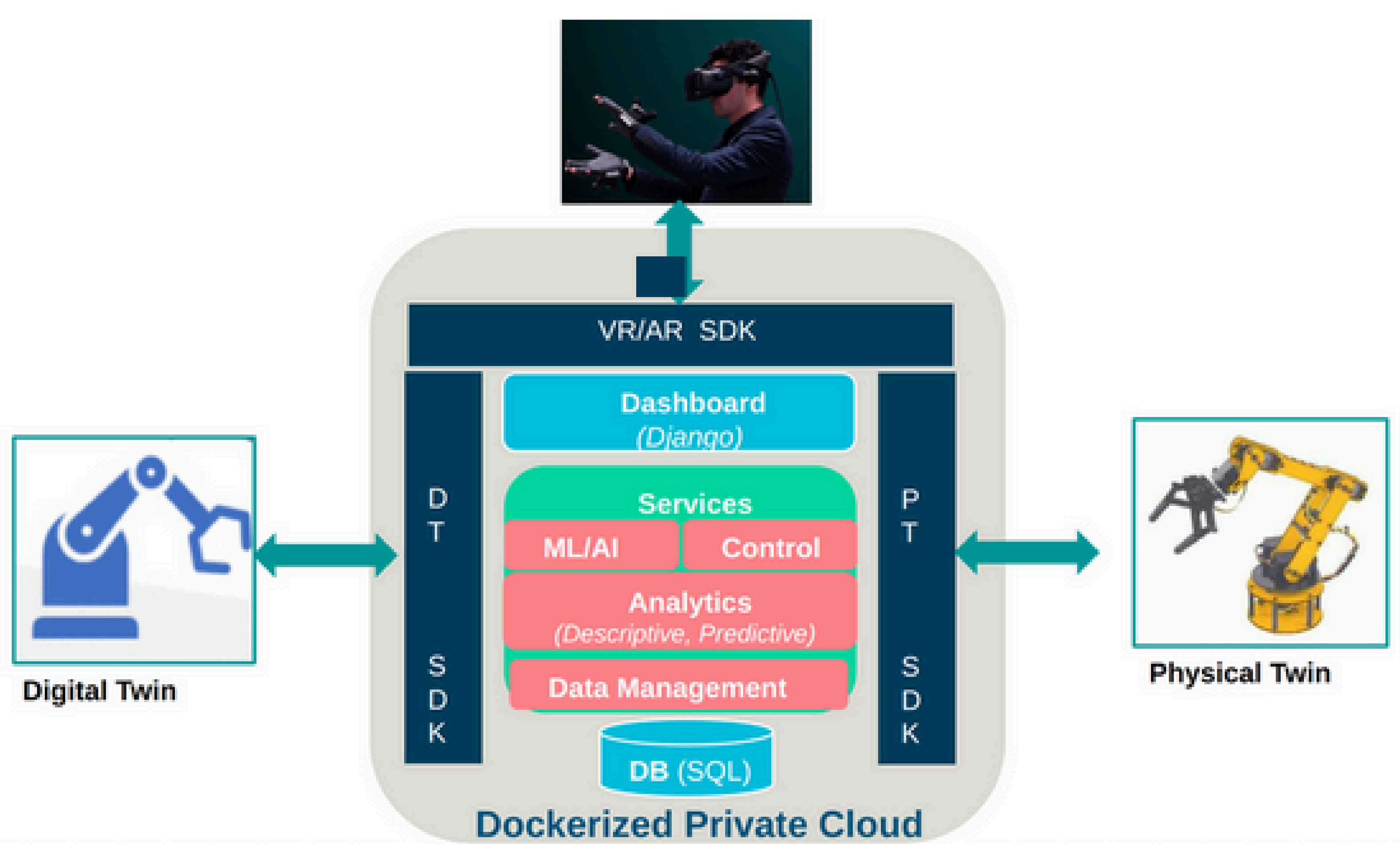

Fig. 1 : Architecture Diagram

This paper presents a comprehensive framework integrating VR with Dockerized private cloud infrastructure to enhance human interaction with Digital Twins in rescue missions. The system utilizes a Robotic Operating System (ROS) based architecture to integrate robotics applications with VR, incorporating innovative techniques such as proximity heat maps and VR-based hand-gesture controls. The system was tested using a Turtlebot3 robotic kit augmented with a robotic arm, demonstrating significant improvements in human interaction and situational awareness.

Methodology

Our approach integrates VR and Dockerized private cloud with ROS to enhance human-robotic interaction. Key techniques include a proximity heat map and VR-based hand-gesture control, validated through user studies using a TurtleBot3 with a robotic arm.

SYSTEM INTEGRATION

The integration process commenced with establishing a connection between ROS and Unity through the utilization of the ROS-TCP connector package. Publishers and subscribers were used to transmit essential data to ROS topics from the Unity side to the Ubuntu side. To imporve the situational awareness of the user, a heat map was implemented using ultrasound sensors. The heat map adjusts dynamically based on the distance of the surrounding object. Additionally, hand gestures actuation methods were implemented to control both the AGV and the robotic arm.

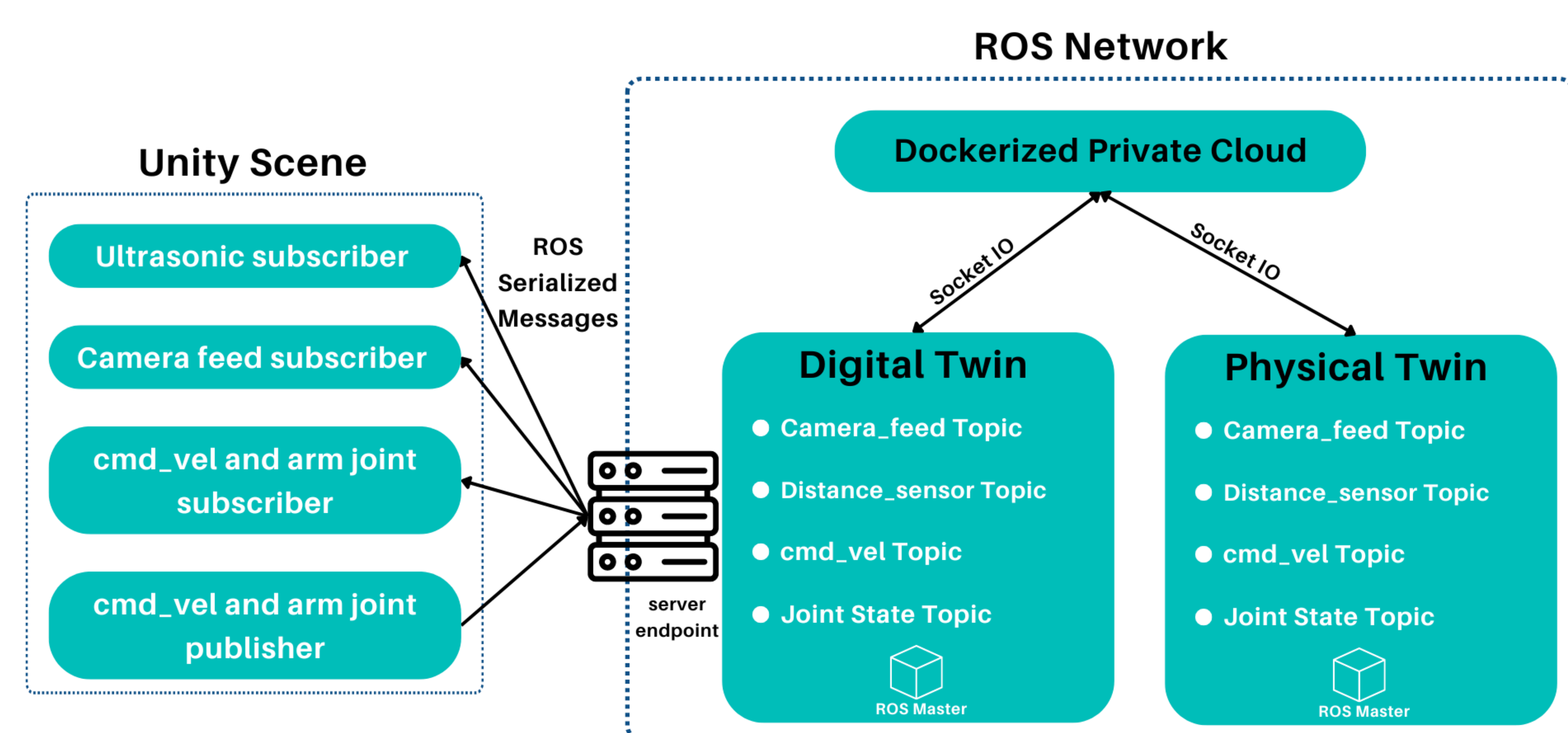

Fig. 2: Data flow between ROS and Unity

USER STUDY

In order to identify the most effective and immersive actuation method, a user study with 15 volunteers was conducted to evaluate the VR integration and compare the three actuation techniques for controlling the robotic arm. The volunteers tested the methods using a sequence of tasks while wearing a Quest Headset. Metrics were collected on task completion time, offset error, and user feedback on accuracy, intuitiveness, and satisfaction.

Discussion

User studies demonstrated improved situational awareness and interaction efficiency with our methods. Volunteers found the VR hand-gesture control intuitive, leading to better performance metrics compared to traditional methods.

The third method that mimics the movement of the hand provides the most effective and immersive experience as it has shown superior results in all of the five specified metrics.

Fig. 3: : Mixed Selection and Actuation

Task	Compl. Time	Offset	Sat.	Int.
Sequential	03:36	6.67	3.83	3.34
Numerical	03:34	7.72	3.58	3.56
Mixed	01:28	2.2	4.55	4.9

Table 1: Evaluation Criteria

SYSTEM LATENCY

Private cloud outperforms public cloud, with lower latency (9.6ms vs. 52.737ms) and faster object detection (157.67ms vs. 1444.13ms), making it better for real-time applications.

Acknowledgments

- Project supervisors
- AUC, Siemens, Know Center.
- Contributors of tools we used.