Demonstration of a Digital Twin framework for a two-actuator hydraulic application

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Keywords: Digital Twin, Hydraulic Systems, Mixed Reality, Obstacle Detection, FABRIK

Abstract: This project presents a digital twin framework for controlling a hydraulic crane using AI, mixed reality, and real-time actuation. Leveraging a Jetson Nano and Xbox Kinect for perception and a Raspberry Pi with DRV103 for control, the system enables adaptive motion planning and obstacle-aware navigation. A Unity-based interface integrated with HoloLens2 allows operators to visualize and manipulate the crane through FABRIK inverse kinematics. Real-time environmental mapping from Kinect enables obstacle detection to update the motion path dynamically. Early experiments confirm the ability to compute joint angles in real-time, detect environmental objects, and demonstrate closed-loop control in a virtual-physical hybrid system.

Introduction: Hydraulic machines offer high power density but lack autonomy and adaptability. AI-driven digital twins can bridge the simulation-reality gap to improve safety, training, and productivity. This research aims to prototype an intelligent control system for a hydraulic crane using real-time perception, planning, and actuation. Current methods in socially-aware navigation (SAN) use reinforcement learning and neural networks for human-robot interaction. FABRIK and RRT are popular motion planning techniques, though they lack native support for real-time constraints in hydraulic systems.

Methodology: A mixed reality interface using Unity and HoloLens allows intuitive crane control. Kinect depth sensing feeds obstacle data to Jetson Nano**,** which uses AI models to update a digital twin. FABRIK computes joint configurations to follow targets, and joint references are sent to a Raspberry Pi controlling actuators through DRV103. Feedback is used to update the MR interface in real time.

Results: Simulations confirm FABRIK's suitability for real-time inverse kinematics in planar joints. Kinect-processed depth maps enable successful segmentation and obstacle localization. The crane responds to joint commands from Unity, demonstrating closed-loop functionality between digital twin and hardware. Using Xbox Kinect, both depth and RGB data are captured for environmental understanding. Initial tests confirm accurate depth map generation and spatial object recognition, enabling real-time obstacle detection.

Conclusions and Future work: This project presents a digital twin of a hydraulic crane with AI-driven control and obstacle detection. Initial tests show successful integration of FABRIK for motion planning and Kinect for real-time sensing.

- Implement path planning (e.g., RRT*)
- Add joint constraints to FABRIK
- Close the control loop with sensor feedback
- CNN for Condition monitoring in real-time**.**

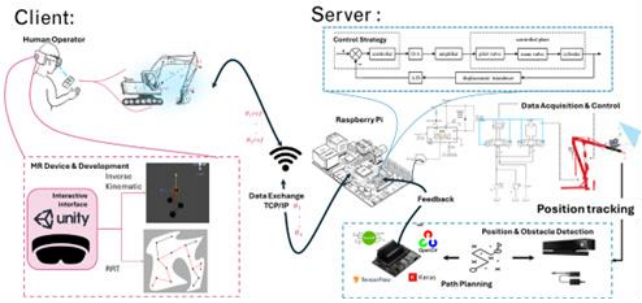

Figure 1 System Overview: Mixed Reality interface, AI planning, and real-time actuation via Jetson and Raspberry Pi