Development of a Custom Embedded Control Architecture for Wireless Electro-Hydraulic Operation of an Omni-Directional Diesel Forklift

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Standard diesel forklifts rely on manual hydraulic valves and fixed steering, which limits their use in confined industrial spaces and slows the adoption of automation. While existing retrofits usually address remote operation or directional flexibility separately, the main objective of this study is to develop a low-cost embedded control system that upgrades standard hydraulic forklifts to feature both wireless and Omni-directional capabilities without replacing legacy hydraulic components. The proposed system uses an ESP32 microcontroller to regulate hydraulic fluid by actuating standard spring-return spool valves with stepper motors. An Android mobile application provides remote control via a TCP/IP network, maintaining command latencies under 100 milliseconds within a 30-metre radius. The firmware uses mecanum wheel kinematics to convert operator inputs into precise valve movements across four independent hydraulic wheel motors. This enables full-plane mobility, including lateral travel, diagonal movement, and stationary rotation. Testing was conducted at operating pressures up to 20.7 MPa using a 1/16-step motor resolution and auto-calibrating neutral valve positioning. Valve accuracy was maintained within ±2%. Safety features, such as automatic valve centering on signal loss and network watchdog monitoring, were successfully verified in over 50 test sequences. Finally, an economic analysis demonstrated that the proposed retrofit costs approximately 500,000 LKR—achieving an estimated 75% cost reduction compared to equivalent commercial electro-hydraulic systems (approx. 2 million LKR), while providing superior functional integration. This work provides a practical, straightforward, and affordable method to introduce digital control and remote operation to legacy hydraulic equipment, directly supporting sustainable industrial automation in resource-constrained environments.

Keywords: electro-hydraulic retrofit, Omni-directional mobility, ESP32 microcontroller, mecanum wheel kinematics, industrial automation