REMOTE CONTROL AND MONITORING OF A PNEUMATIC WORKSTATION USING TWINCAT 3 AND BECKHOFF PLC

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For severe traffic accidents, rapid occupant extrication is crucial. Firefighter hydraulic rescue shears, while essential for this task, are hindered by bulky hydraulic hoses which reduce maneuverability. This research investigates powering these tools with compressed air from a firefighter's self-contained breathing apparatus (SCBA) cylinder. The proposed system utilizes a compact, mobile hydraulic power unit driven by this pneumatic source. A hydraulic rescue shears and review of market solutions are reviewed, and a typical cutting loads are defined. A model of a small, mobile hydraulic power unit powered by an SCBA cylinder is proposed and its performance validated via simulation. This study aims to enhance rescue efficiency and ergonomics by potentially eliminating traditional hydraulic hose constraints.

Keywords:
fluid power,
pneumatic workstation,
remote control,
Beckhoff PLC,
Industry 4.0

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1 Introduction

Remote operation of industrial machinery has become increasingly important in modern manufacturing, driven by the Industry 4.0 paradigm and the need for flexible, decentralized control. Pneumatic systems are widely used in industry due to their long service life and simple maintenance. However, traditionally, direct on-site supervision is required to monitor and control such systems. Recent global events (e.g. the COVID-19 pandemic) have further underscored the value of remote access and control capabilities to maintain production with minimal on-site staffing. This paper addresses the upgrade of an existing pneumatic workstation [1] to enable remote monitoring and control over the Internet. The solution employs a Beckhoff soft-PLC [2] and TwinCAT 3 software to implement control logic and a web-based HMI [3]. With this approach, authorized users can start, stop, and adjust the pneumatic process from anywhere, and also monitor the system's status in real time. Similar approaches have been explored in prior work, but our implementation uniquely emphasizes integrated safety and live process visualization.

2 Methodology

The development of the remote-controlled pneumatic workstation involved both hardware integration and software design. Figure 1 provides an overview of the pneumatic workstation setup, while Figure 2 shows the control architecture of the system. The existing workstation's pneumatic components were leveraged and interfaced with a new Beckhoff PLC and network infrastructure. We followed an Internet of Things (IoT) approach, connecting the workstation to a networked PC controller to allow remote access in line with Industry 4.0 principles.

3 Pneumatic Workstation Design

The base of the system is a pneumatic workstation comprising multiple actuators and modules arranged on an aluminum frame. It includes two orthogonal linear axes (X and Y) and a vertical Z-axis manipulator, enabling 3-dimensional movement of a pneumatic gripper. These axes, driven by pneumatic cylinders, allow pick-and-place handling of workpieces across the workstation. Additional tools on the station include a drilling unit and a stamping unit, which can be applied to the workpieces. Various sensors are installed to ensure safe and precise operation: traditional micro limit switches and inductive proximity sensors detect cylinder end positions, and a magnetic sensor monitors the Z-axis piston position. The station is equipped with a Festo VTUG pneumatic valve island (manifold) with multiple solenoid valves – eight 5/2 bistable valves, one 5/3 centre-closed valve, and two 3/2 monostable valves – that direct compressed air to the actuators. The use of bistable valves ensures that actuators hold position upon loss of power (each valve has a memory function), whereas monostable valves return to a default state with spring return, contributing to fail-safe behaviour. Compressed air at a regulated pressure is supplied to the station and on-board pressure gauge was added. The complete pneumatic workstation is shown in Figure 1.

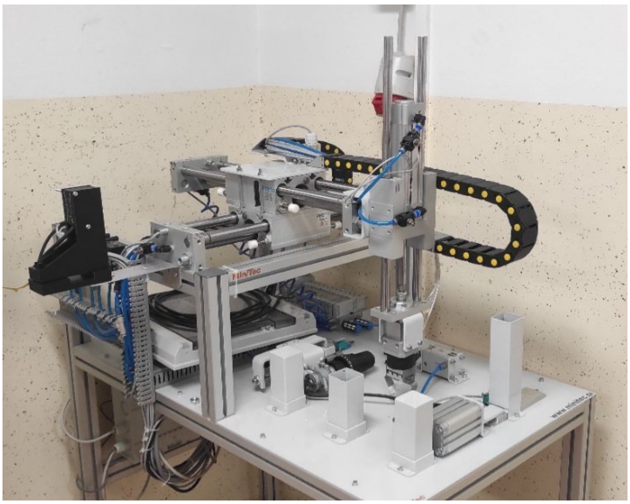

Figure 1: Pneumatic workstation with linear axes, grippers, and tooling. Sensors and valves are installed for position feedback and control.

3.1 Control System Architecture

A Beckhoff programmable logic controller system was used to control the workstation, selected for its high performance and flexibility. The PLC hardware consists of a Beckhoff embedded PC (running TwinCAT 3 in soft-PLC mode) connected to modular I/O terminals via an EtherCAT bus coupler (model EK1100). Digital input terminals (e.g. Beckhoff EL1008) interface with the limit switches and sensor signals, while analog input terminals (e.g. Beckhoff EL3214) read analog sensor values such as pressure. A special communication terminal (Beckhoff

EL6631 PROFINET interface) links the PLC to the Festo valve island, allowing direct actuation of valves via the PROFINET fieldbus. The EtherCAT coupler and I/O modules are all powered by a 24 V DC supply for safety. Figure 2 illustrates the system architecture, including the controller, I/O modules, and their connection to the pneumatic components. An emergency-stop circuit is integrated such that any critical fault will cut power to valve coils and immediately stop all motion.

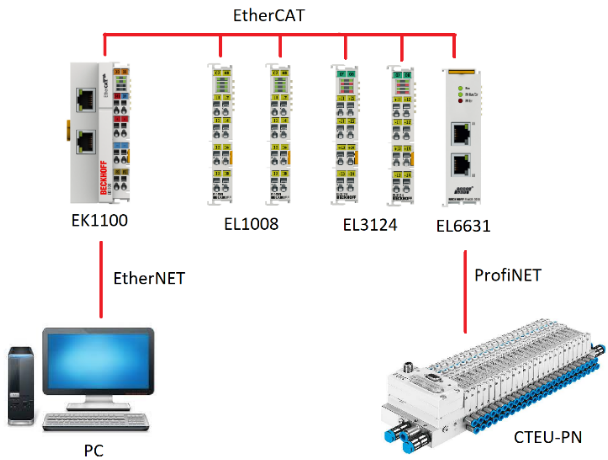

Figure 2: System architecture connecting the Beckhoff PLC (soft-PLC on embedded PC) with EtherCAT I/O modules and the pneumatic valve manifold (via PROFINET).

3.2 Control Software Design

The control logic for the workstation was implemented in the Beckhoff TwinCAT 3 environment. TwinCAT 3 supports programming in multiple IEC 61131-3 languages (Structured Text, Ladder Diagram, Sequential Function Chart, etc.). We partitioned the control program into an initialization routine and three operational modes corresponding to available processes: drilling, stamping, and a combined drill-and-stamp cycle. Upon startup, the system performs an initialization sequence that moves the robotic manipulator to a safe home position. This step prevents collisions in case the system was halted in an unknown state when last used. Operators can then select a mode via the HMI (e.g. drilling only, stamping only, or both). Depending on the selection, the PLC executes the corresponding subroutine to handle the workpiece: retrieving a raw part from a feeder, securing it on the worktable, performing the selected process(es), and finally depositing the finished part into one of three sorting bins.

The program was structured using a combination of Structured Text (ST) and Sequential Function Chart (SFC) languages. Complex logic and data handling (such as mode selection and cycle counting) were written in ST for clarity and flexibility, while the step-by-step operational sequences were implemented as an SFC, which graphically represents states and transitions. This modular approach improved code readability and allowed real-time monitoring of both numeric variables and state transitions during runtime. Figure 3 shows a portion of the SFC implementation of one process cycle, illustrating the sequence of steps and conditions for transitions. Each step (state) triggers specific actions (e.g. move axis, activate drill) and transitions on completion conditions.

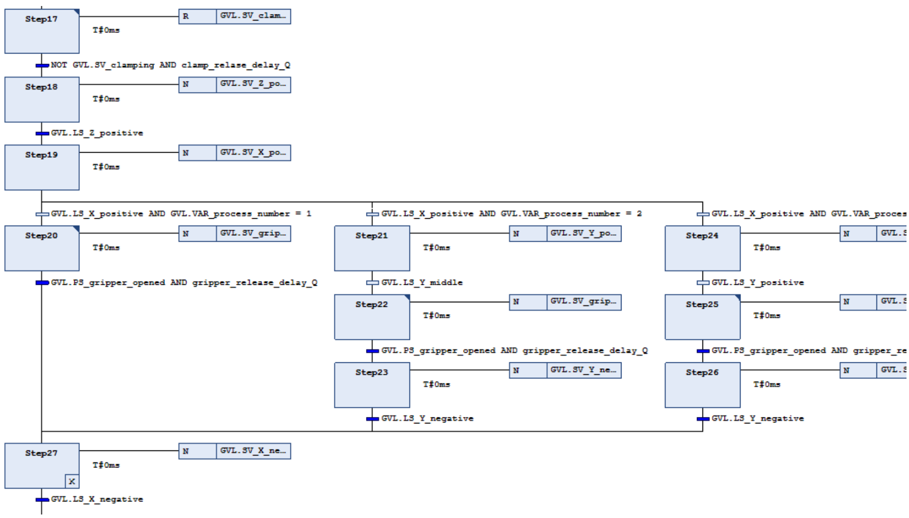

Figure 3: Excerpt of the Sequential Function Chart (SFC) program controlling one operational cycle.

3.3 HMI Development for Remote Control

A critical component of the system is the TwinCAT 3 HMI web interface, which provides remote visualization and control through a standard browser. The HMI was developed as a web application within the TwinCAT engineering environment, using drag-and-drop widgets for buttons, indicators, and displays. We designed the interface to be intuitive and to include all necessary controls and readouts without clutter. Key controls include buttons for starting and stopping the process, selecting the operation mode (drill, stamp, or both), resetting the system, and an emergency stop (E-stop). Status indicators on the HMI show the real-time state of various subsystems (e.g. whether the manipulator is at home position, whether drilling is in progress, etc.), illuminating green when the corresponding function is active. The interface also displays counters that track how many parts have been processed out of the target quantity set by the user. In addition, a gauge widget (barometer) continuously shows the supply air pressure; colored zones on the gauge provide quick feedback if pressure moves outside the normal operating range. For easier remote monitoring of the physical process, a live video camera feed is embedded in the HMI. A normal USB webcam is connected to the controller PC and streams real-time video via an IP camera application, allowing the remote operator to visually observe the workstation during operation.

For security, the HMI requires user authentication upon accessing the page. The interface is hosted on the TwinCAT HMI server running on the controller PC, configured with secure HTTP (HTTPS) on a specified port. We set up the server with the controller's IP address and the HMI's port (3000) as an endpoint so that authorized users can reach the interface via a. The TwinCAT HMI server was configured to require an administrator username and password for login. A login screen prevents unauthorized use, addressing cybersecurity concerns – without valid credentials, no control actions can be sent to the workstation. To deploy the HMI, the project was published from TwinCAT into the runtime server environment.

4 Results

After integrating the hardware and developing the software, the remote control system was thoroughly tested. Initial tests were conducted in manual mode, verifying that each HMI button correctly triggered the corresponding action on the pneumatic station (for instance, the "Initialize" button returned the manipulator to home, and each mode selection button started the correct process sequence). Automatic mode was also tested by setting a desired count of parts and letting the system run through complete cycles; all indicators and counters on the HMI updated appropriately with the process progression. The pressure monitoring feature was validated by artificially reducing the air supply pressure: the on-screen barometer reflected the drop and entered the warning (red) zone as expected.

To evaluate remote accessibility, the HMI was accessed from multiple devices and locations. On the local network, a second PC was used to connect to the interface and successfully start and stop the workstation. The interface was also accessed via a mobile phone over the internet from a different location. In all cases, the system responded correctly to user commands. We observed a small increase in control latency when using a mobile cellular network, but the responsiveness remained within acceptable bounds for safe operation. Throughout testing, the safety features proved effective: for example, pressing the E-stop button (either on the physical station or the HMI) immediately halted the system as intended, and the login requirement successfully barred access when incorrect credentials were entered. Overall, the system meets its design goals: it allows the pneumatic workstation to be operated remotely with real-time feedback, and it includes safeguards to prevent misuse or accidents. Figure 4 shows the final web HMI as seen by the user, with its main components annotated. The interface includes manual controls (top-left), automatic operation settings (top-right), status indicators (centre), counters (bottom-left), a pressure gauge (bottom-right), and a live video feed (bottom-centre). The E-stop and login features enhance operational safety.

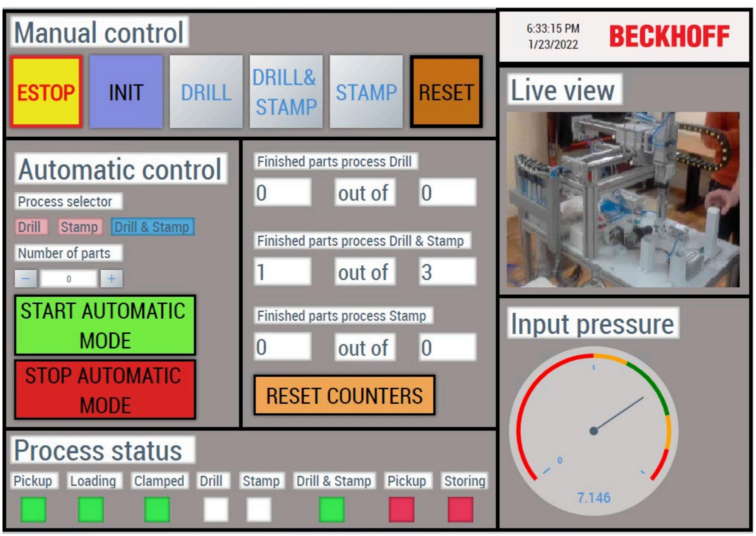

Figure 4: The TwinCAT 3 web-based HMI for the pneumatic workstation.

5 Discussion

The developed system demonstrates how an existing pneumatic workstation can be modernized for remote operation, bringing it closer to an Industry 4.0 "smart factory" cell. Using a soft-PLC running on an industrial PC (instead of a traditional standalone PLC) made it straightforward to integrate advanced features like the web HMI and camera feed. This platform leverages standard IT technologies (Ethernet networks, HTTP/HTTPS protocols) to interface with fluid power equipment, illustrating the convergence of automation and internet connectivity.

The safety measures implemented – specifically the authentication requirement and emergency stop integration – address both cybersecurity and operational hazard concerns. In practice, these measures are essential; an unsecured industrial control interface could be maliciously manipulated, potentially causing equipment damage or safety incidents. By requiring users to log in before granting control, and by designing the interface with clear E-stop functionality and real-time sensor feedback (e.g. pressure and flow sensors signalling abnormal conditions), the system ensures that remote operators have the situational awareness and control authority needed to manage the process safely. The inclusion of a live video feed further aids the operator in verifying actions and preventing potential collisions or errors, essentially serving as the remote "eyes" on the process. This combination of networked control and live monitoring significantly improves the ability to respond quickly to issues, even when off-site.

Overall, the project highlights that with appropriate hardware (modern networked PLCs) and software (web-based HMIs), even traditional pneumatic systems can be successfully integrated into a remote supervision and control framework. This opens opportunities for increased flexibility in managing manufacturing processes and enables rapid expert intervention in system issues without the need for physical presence on the factory floor.

6 Conclusion

In this work, a pneumatic workstation was successfully upgraded for remote monitoring and control. The integration of a Beckhoff PLC and TwinCAT 3 environment enabled the existing system to be controlled via a web browser interface from anywhere with internet access. The implemented HMI provides intuitive control and continuous feedback on the process state, including safety-critical information like emergency stop status and air pressure levels. Testing confirmed that the remote operation functions as intended, with robust performance observed in both local and remote network scenarios. This development demonstrates the feasibility of retrofitting fluid power workstations with modern control technology to meet the demands of distributed and flexible manufacturing.

Future enhancements could include expanding the system with additional sensors or incorporating analytics for predictive maintenance, further aligning the workstation with smart factory principles. Nonetheless, even in its current form, the system provides a clear example of applying IoT and Industry 4.0 concepts to pneumatic automation, significantly enhancing both the usability and safety of the workstation. We believe that such remote-operated pneumatic systems can improve maintenance response times, reduce downtime, and enable new operational models (such as centralized supervision of multiple remote sites), thereby offering substantial benefits in industrial practice.

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