Pnevmatic system production line

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0 Abstract

This project focused on programming a Beckhoff CX7000 PLC to control a production line (Pneumatic system) as part of the laboratory sessions of the course Process Automation. The production line was designed to simulate automated manufacturing processes and included components such as a compressor, piston, rotating table, press, and a conveyor belt. The objective was to implement and integrate three operational modes: manual control, automatic control, and SCADA-based monitoring and control.

In manual mode, each component could be individually operated. Automatic mode enabled the sequential operation of the system, where a piston moved an object from the starting position to a rotating table. The table transported the object to a midpoint, where a press applied force for a specific duration. The object was then moved to a conveyor belt by a piston. Finally, the conveyor belt transported the object to the end of the production line. The SCADA system provided real-time monitoring, remote control, and data visualization.

In addition to documenting the project's development, this report also serves as a user manual for operating and controlling the system. It includes instructions for utilizing manual and automatic modes and the SCADA monitoring system, making it a practical guide for replicating the system.

Contents

1 Introduction

This project focuses on the development and implementation of an industrial automation system using Beckhoff PLCs. The system replicates a simplified production line (Figure 3). The project encompasses programming and integrating components such as an compressor, pistons, rotating table, press, and conveyor belt. The project includes manual and automatic modes and the SCADA monitoring and control system to enhance functionality and usability.

Modern industries rely heavily on automation to optimize efficiency, reduce costs, and ensure consistent quality in production processes. This is where this class and project becomes very useful and fun for students because they can gain hands-on experience with such industry problems. The motivation behind the project was to learn something new, to make the production line work properly, and of course to pass the class.

The primary objective of this project is to develop and implement a fully functional production line. The system must:

- Enable manual control to control all components separately
- Enable automatic control, for sequential and automatic operation of the line
- Integrate SCADA functionality for remote control, real-time monitoring, and data visualization

The scope of the project includes programming Beckhoff PLCs to operate the production line components whether it's with manual or automatic control, creating a SCADA system for enhanced control and monitoring, and documenting the project as a comprehensive user manual.

2 Project Description

2.1 Description of the Task

The goal of the project is to have a working production line that satisfies all the requirements.

Pneumatic System requires a control mode that can be toggled between manual and automatic using a switch on the panel (Figure 2). In manual mode, the operator will control the system via buttons, selecting the active function and controlling the press cycles. Rapid direction changes must be blocked with a delay (e.g., 1 second) to prevent damage to the actuators, and the relay should only be triggered when the direction changes, not when the motor stops.

In automatic mode, the pneumatic system should behave similarly to manual mode, including safety timing and relay power-saving mechanisms. When switching between manual and automatic modes, the system should stop in manual mode and resume processing in automatic mode.

The recipe for the pneumatic system should define the press operation, including the number of presses and possibly the press duration. The SCADA system should allow users to adjust the recipe parameters, with real-time updates reflected in the automation model. The SCADA system should also provide clear visualization of the pneumatic system's state, including ongoing press cycles, and handle alarms with appropriate severity levels.

2.2 Overview of the System

The pneumatic system comprises several components, including valves to control the actuators, sensors like photoelectric and position sensors for feedback, and motors for driving compression, table movement, and conveyor belt movement. Relays are used to direct the actuation of motors and valves, while lights indicate the operational status of the system. Manual inputs are facilitated through various switches and buttons. The system is controlled through a central control panel that includes an embedded PLC, specifically the CX7000 model, which manages the operations.

2.3 Process Description

The Pneumatic System production line is designed to process an object, that is dropped into the waiting chamber by the user. The object waits in the chamber until there is an empty spot on the rotating table, at which point it is pushed onto the empty spot by a pneumatically powered piston. The rotating table then rotates the object to the next stage where it is pressed by a pneumatically powered press for a user-defined period of time. After the object has been pressed, it advances to the next stage with the help of the rotating table where it is unloaded from it, with the help of a pneumatically powered piston to the conveyor belt that then takes it to the end of the production line. At the end of the production line, there is a photoelectric sensor that stops the entire production line when it detects an object. At this point, user has to unload the processed object from the end of the production line in order for it to resume production. All of the objects are given an ID at the beginning of the production line, which allows us to track each object's position and display it to the user.

3 Control System Design and Implementation

3.1 Control Hardware

The hardware used consisted of the Beckhoff CX7000 PLC [1] and the production line, which includes the following components: one compressor, one rotating table, one conveyor belt, two pistons, one press, three motors, two photocells, four switches, and five valves [2].

3.2 Control Software

3.2.1 The Programming Environment

The programming environment used for the project was Microsoft Visual Studio, integrated with Beckhoff's TwinCAT 3. Two types of projects can be created within TwinCAT 3: the TwinCAT HMI Project, which is used for the SCADA HMI interface, and the TwinCAT XAE Project, which is used to program the PLC. TwinCAT 3 supports multiple programming languages, including four graphical languages: Function Block Diagram (FBD), Ladder Diagram (LD), Continuous Function Chart (CFC), and Sequential Function Chart (SFC). It also supports two textual languages: Instruction List (IL) and Structured Text (ST). For this project, we used Ladder Diagram and Structured Text, the latter being the closest to a 'traditional' programming language within the PLC domain.

3.2.2 Implementation of Manual and Automatic Modes

The manual mode is implemented in a straightforward manner. First, all devices are turned off. Then, an if statement checks which device the user wants to control. This is achieved using a CTUD counter that can count both up and down. The counter increments when the upper-right black button on the control panel is pressed and decrements when the upper-left black button is pressed. If the selected device is one of the two pistons or the press, it is simply activated (set to true). If the selected device is the rotating table or the conveyor belt, a motor object is initialized for control. The motor object is provided with the following attributes:

- Direction of movement: Controlled by the bottom-left black button (for backward) and the bottom-right black button (for forward) on the control panel.
- Block time: Prevents rapid switching between directions.
- Motor selection: Specifies whether to control the rotating table or the conveyor belt.

The automatic mode sequentially calls four functions, each controlling a specific part of the production line:

- First Function: Controls the initial stage of the production line, where the first piston pushes an object onto the rotating table.
- Second Function: Manages the rotating table, which moves the object around. This includes operating the press located in the middle of the table to apply pressure to the object for a specified duration.
- Third Function: Controls the second piston, which pulls the object from the rotating table onto the conveyor belt.
- Fourth Function: Operates the conveyor belt, transporting the object to the end of the line and stopping the production process once the object reaches its destination.

3.3 SCADA Integration

The SCADA control (Figure 1) and monitoring system has the following feature:

- Overview of tracking and active logic: The tracking logic displays the current location of specific objects on the production line by showing their IDs. The active logic indicates which locations on the production line are currently active (operational).
- Alarm and warning display: Displays alarms and warnings that occur on the production line.
- Recipe parameter management: Allows setting and resetting recipe parameters, which are used for the press operation (specifies the amount of time the press is active).
- Control panel mirroring: Provides a visual representation of the control panel for remote monitoring.

3.4 Implementation Steps

The process of developing the production line was divided into four parts. We firstly developed the manual controls because of the requirement and for the testing purposes. Then followed the development of the automatic controls, which took the most time because they were the most complex. The third part was the development of the SCADA monitoring system which was the simplest and fastest. Lastly we developed the errors and warnings part where we have an overview of possible mistakes that can go wrong. We then integrated the errors and warnings part into the SCADA monitoring system and that marked the end of the project.

4 Instructions for Use

4.1 System Startup and Shutdown

Before turning on the system, make sure that it is in manual mode (turn the toggle switch on a control panel to the right). Next, you have to turn on the compressor by pressing the green button on the control panel. Now you can use the production line in manual mode or switch into automatic mode by switching the toggle switch to the upright position.

To turn off the system, first put it into the manual mode and then turn off the compressor by pressing the red button on the control panel.

4.2 Manual Mode

In manual mode, you control all of the devices in a production line through a control panel. While green and red buttons are used to turn the compressor on and off, black buttons are used to pick and control any other device attached to the production line. More specifically, the top two black buttons are used to choose which device you want to control. Imagine every device has an ID. The left button decrements the ID by one and the right increments it by one, and based on your chosen ID, the device is chosen. The bottom two black buttons are then used to control the device. Based on what device is being controlled you will either use both or just the left button. In case you want to control a piston or a press you will only use the left button to activate them. They will be activated for as long as you hold the left button. On the other hand, if you want to control motors for the belt or rotating table, you will use both bottom buttons one for each direction, right being forward and left being backward.

4.3 Automatic Mode

To switch to automatic mode, you need to turn the toggle switch on the control panel upright, at which point the rotating table will start to turn and other devices will get activated by the sensors. In this mode user has two jobs to put in an object at the beginning of the production line and to take the processed object off the production line at the end of it. It is important that you take the object off the production line otherwise it will stop and wait until the object is removed.

4.4 Alarms and Troubleshooting

Production line also implements a warning and error system. Whether there are any warnings or errors, they can be seen in SCADA interface of the production line. Below are listed possible errors and warnings, and what they mean:

- **Compressor turned off** - ERROR! Your compressor is turned off which makes the entire production line non-operational
- **Line backed up** WARNING! There is an object waiting at the and of the line, you need to remove it to resume operation
- **Belt wrong direction** WARNING! Belt is moving into a wrong direction and may cause problems or damage
- **Table wrong direction** WARNING! Table is moving into a wrong direction and may cause problems or damage

5 Implementation Challenges and Solutions

The biggest challenge was the implementation of tracking logic, since logic of each device runs in parallel it was hard get all the timings and conditions right. The solution was to make a separate function block for tracking objects which gave us more control over the logic.

6 Conclusion

The development and implementation of the pneumatic system for a simplified production line has successfully demonstrated the integration of industrial automation principles using Beckhoff PLCs. By incorporating both manual and automatic control modes, as well as SCADA for real-time monitoring and control, the project achieves a high degree of functionality and usability. The system provides hands-on experience in programming, hardware integration, and troubleshooting. The inclusion of safety mechanisms, such as delays to prevent rapid actuator changes and a comprehensive alarm system, ensures reliable and efficient operation. Additionally, the object tracking logic and SCADA visualization enhance the user's ability to monitor and manage the production line effectively. Through this project, we have not only created a functional production line but also gained valuable insights into the complexities of industrial automation. Everything we made during the project was done together so each team member contributed equally to the final result. We also learned how to work together and how to communicate efficiently.

7 Appendices

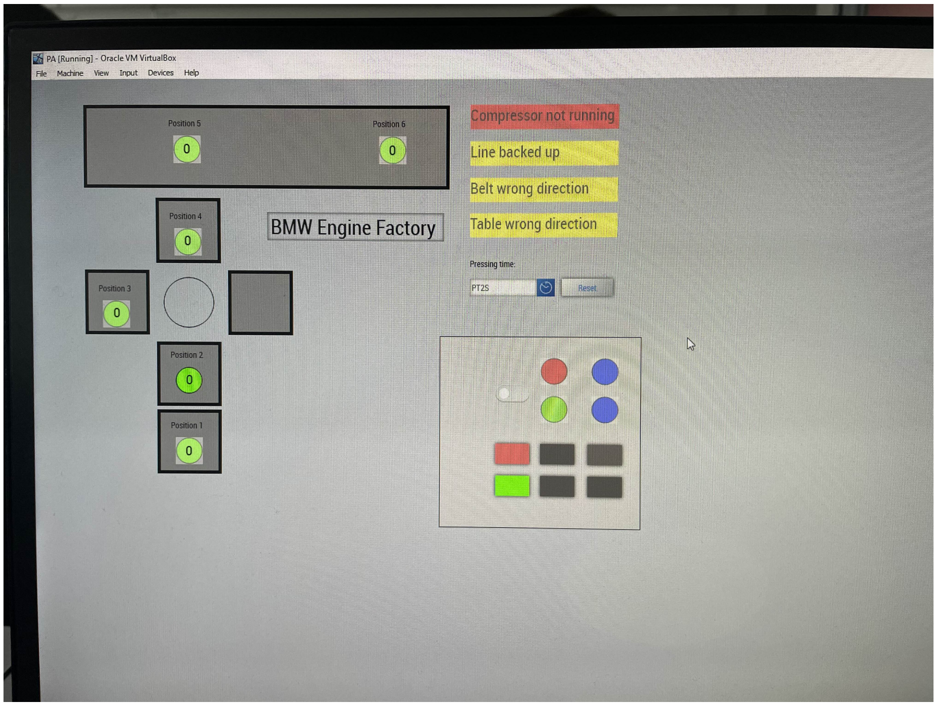

Figure 1: SCADA interface

Figure 2: Control panel

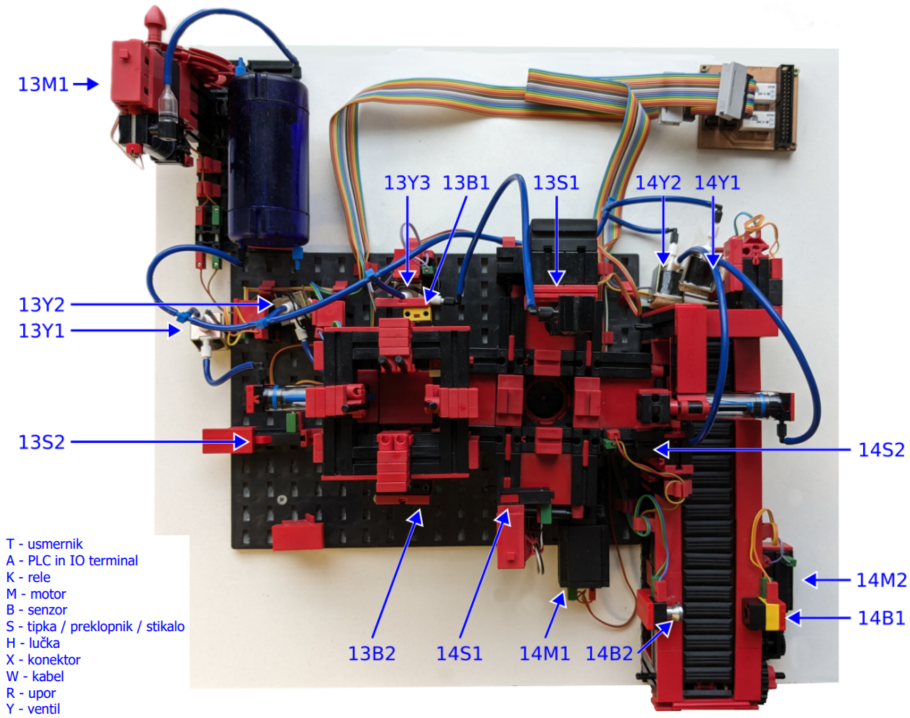

Figure 3: Production line

References

[1] *Beckhoff CX7000 Documentation*. URL: https://www.beckhoff.com/en-en/products/ipc/embedded-pcs/cx7000-arm-r-cortex-r/cx7000.html.

[2] *PA-PS*. URL: https://ucilnica.fri.uni-lj.si/pluginfile.php/214459/mod_resource/content/3/PA-PS-2023-10-19.pdf.