Prototype of automatic conveyor system using programmable logic controller for educational purpose

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Abstract. The study of conveyor control and programming using PLC (Programmable Logic Controller) has been taught in many universities, especially in the field of Electrical Engineering. Unfortunately, the material obtained by students is only in the form of theory without direct application to the conveyor system in the industry because it is constrained by the company policy. Therefore, it is necessary to build a prototype of automatic conveyor system using PLC for educational purpose. This prototype is owned by the university so that students can directly implement the results of the PLC program design that they have learned in class. The prototype of the automatic conveyor system can increase students' interest and understanding of the industrial automation process so that they will be better prepared when they have implemented it directly to the industry. This research discusses the design and manufacture of a prototype of automatic conveyor system using PLC. The main controlling device used is the FX3U Mitsubishi PLC which is equipped with analogue inputs, analogue outputs, and high-speed counter output as PWM (Pulse Width Modulation) output. The conveyor used is a mini conveyor with a DC motor drive. Conveyor speed control is done by adjusting the rotational speed of the DC motor using direct PWM setting from PLC. To complete the automation system, infrared sensor was added as the input to detect the dummy load. Thus, full automation system of conveyor for educational purpose was done and it showed satisfying results.

Keywords: PLC, automation, prototype, conveyor, pulse width modulation

1. Introduction

Automation is intended so that machines in an industry move automatically without the need to be run by humans. Automation is a technology whose processes and procedures are completed without human involvement [1]. So that in general, an automation system can be defined as a process that can function automatically using technology related to electronic mechanical applications and computer-based systems without human intervention [2]. The use of humans in an automated production process is only to oversee the production process. Thus, the automation of machines in an industry provides an advantage for the company because it can reduce the number of workers which results in the company's low operating costs.

Programmable Logic Controller (PLC) is an automatic control device that is widely used in various sectors, especially the industrial sector. PLC according to Capiel (1982) is an electronic system that operates digitally and is designed for use in industrial environments, where this system uses
programmable memory for internal storage of instructions that implement specific functions such as logic, sequence, timing, enumeration, and arithmetic operations to control machines or processes via digital and analog I/O modules [3]. Programmable Logic Controller (PLC) is an automatic control device that is widely used in various sectors, especially the industrial sector. PLC according to Capiel (1982) is an electronic system that operates digitally and is designed for use in industrial environments, where this system uses programmable memory for internal storage of instructions that implement specific functions such as logic, sequence, timing, enumeration, and arithmetic operations to control machines or processes via digital or analog I/O modules [3].

In general, the PLC functions are as follows [4]:

1. **Sequential Control**
   PLC processes the binary signal input into output which is used for technical processing purposes in sequence (sequential). PLC keeps all steps or steps in a sequential process taking place in the right order.

2. **Plant Monitoring**
   The PLC continuously monitors the status of a system (e.g.: temperature, pressure or altitude) and takes the necessary action in connection with the controlled process (e.g.: value has exceeded the limit) or displays these messages to the operator.

One of the most common industrial implementations of PLCs is its use for conveyor belt automation. In order to do the conveyor can work automatically, it is necessary to design appropriate instruments and control systems using a PLC and its programming. The study of PLCs basically depends on the type and brand of PLC. Different types and brands, different PLC programs are used even though logically the program is still the same. Therefore, before the PLC can be implemented as a controlling device in the production process, it is necessary to do in-depth research and study regarding the PLC itself. This research is related to the syntax and block function of the PLC ladder diagram. Hardware research is also important. In hardware, research is carried out by studying the specifications and maps of the PLC input output pins.

The study of conveyor control and programming using PLC (Programmable Logic Controller) has been taught in many universities, especially in the field of Electrical Engineering. Unfortunately, the material obtained by students is only in the form of theory without direct application to the conveyor system in the industry because it is constrained by the company policy. Therefore, it is necessary to build a prototype of automatic conveyor system using PLC for educational purpose. This prototype is owned by the university so that students can directly implement the results of the PLC program design that they have learned in class. The prototype of the automatic conveyor system can increase students’ interest and understanding of the industrial automation process so that they will be better prepared when they have implemented it directly to the industry.

This research discusses the design and manufacture of a prototype of automatic conveyor system using PLC. The main controlling device used is the FX3U Mitsubishi PLC which is equipped with analogue inputs, analogue outputs, and high-speed counter output as PWM (Pulse Width Modulation) output. The conveyor used is a mini conveyor with a DC motor drive. Conveyor speed control is done by adjusting the rotational speed of the DC motor using direct PWM setting from PLC. To complete the automation system, infrared sensor was added as the input to detect the dummy load.

2. **Research Method**

The research method in this study is divided into several stages, including: Phase I is a literature study related to conveyor mechanisms, infrared sensors, pulse width adjustment on DC motors, PLC programming, and PLC technical specifications. The expected output at this stage is to understand how to program the FX3U type PLC, how the infrared sensor works, adjust the pulse width of the DC motor, and PLC specifications. Phase II is the design stage of an automatic conveyor system including software design, hardware design, and instrumentation.

At this stage, it is hoped that the results of the software and hardware design and system instrumentation will be obtained. Stage III is the prototyping stage for the automatic conveyor system,
including the manufacture of hardware, programs and instrumentation. At this stage it is expected to produce a conveyor system prototype. Finally, Phase IV is testing and correcting the prototypes that have been made. At this stage it also includes drawing conclusions and making scientific articles related to research.

3. Results and Discussion
In this section we discuss the result of each research’s step start from I/O configuration, prototype designing and building, PLC ladder diagram, and the last step is testing section.

3.1. PLC I/O Configuration
The PLC input / output configurations for this conveyor prototype are:

- Power supply : 24 VDC
- Digital input : switch on / off (on pin X000); Infrared sensor (on pin X001)
- PWM output : DC motor (at pin Y000)
- Communication : RS-232 to USB

The pinout of I/O configuration based on the list above can be seen on Figure 1.

![Figure 1. I/O Configuration for conveyor prototype.](image1)

3.2. Prototype designing and building
Prototyping is done in accordance with the research stages. Mini conveyors are made according to the desired dimensions. The DC motor used is a 24 Volt DC motor with a maximum rotation of 100 rpm and a torque of up to 16 kg. Infrared sensor was installed on the conveyor. Figure 2 shows the installed IR sensor. The manufacture of mini conveyors is carried out in a separate workshop. The next step is to install a tachometer as a motor rotation speed sensor / conveyor speed.

The installation of the speed sensor is not the part of the I/O configuration in Figure 1 and the speed sensor itself was not connected with PLC. The need for installing speed sensor is to test the characteristics of the DC motor used as a conveyor drive. After the speed sensor has been installed, the relation of motor voltage according to the motor speed (in RPM) could be get.

![Figure 2. Installed IR sensos](image2)
The next step is the manufacture of a control module consisting of a PLC, switch, infrared sensor, and input/output terminals. The manufacture of the control module needs to be adjusted to the wiring diagram between the PLC and the conveyor. Figure 3 shows the conveyor prototype and control module that has been made.

![Image](image_url)

**Figure 3.** I/O Configuration for conveyor prototype.

### 3.3. Ladder diagram

Ladder Diagram is a programming language for PLC in the form of a ladder diagram. Making ladder diagrams for a prototype automatic conveyor system with speed control based on the FX3U PLC was carried out using special software for the Mitsubishi FX3U type PLC, namely the GX-Developer software. Programming is done on a PC/Laptop that is connected to the FX3U PLC via an RS-232 serial cable.

The programming criteria are as follows:

1. If the switch is ON, the system will turn on, and vice versa.
2. If the infrared sensor detects a dummy load, the conveyor will run until the system is turned off (switch off)
3. The desired conveyor rotation speed is input on the ladder diagram in the "PWM" function. K3810 is the constant value of PWM where the duty cycle is 100%.
4. The output in the form of a high-speed counter on pin Y000 is connected to the DC motor as a conveyor drive
5. Internal memory in the form of M0 and M1 is used for the on/off system and sensor’s latching.

Based on the criteria above, a ladder diagram can be developed using the GX-Developer software. The ladder diagram of the system can be seen in Figure 4.

![Diagram](diagram_url)

**Figure 4.** Ladder diagram

### 3.4. Overall system testing

Testing aims to determine whether the system that has been created is in accordance with the research objectives. System testing is divided into several stages. The first is testing to determine the relationship between the motor voltage and the conveyor rotation speed. The result of this stage is DC motor’s characteristic. Figure 5 shows the process of testing the relationship between motor voltage and conveyor rotation speed using a speed sensor, laptop, and voltmeter.
Figure 5. Measuring motor voltage to get motor’s characteristic

Based on the test results, the results are shown in Figure 6, where the motor voltage is directly proportional to the motor rotation. But there is a DC motor dead-zone, which is at voltages below 6 volts where voltages less than 6 volts will not be able to drive the DC motor. The dead-zone then being the limitation of desired speed input of the system.

Figure 6. Graph of DC motor characteristic

The next testing is for the relationship between the PWM active pulse width and the motor voltage. The equation for motor rotation speed is as the eq. 1:

\[
    n = \frac{E_i - I_a R_a}{c \Phi}
\]

where:
- \( E_i \) = input voltage (V)
- \( L_a \) = armature inductance (H)
- \( R_a \) = armature resistance (Ω)
- \( I_a \) = armature current (A)
- \( \Phi \) = flux
- \( n \) = speed (rpm)

Based on the motor rotation speed equation, it can be seen that the motor rotation speed regulation can be done by changing the magnetic flux or changing the input voltage. Since the permanent magnet motor has a fixed magnetic flux value, adjustments can be made by changing the input voltage \( E_i \). The technique of changing the voltage is done by using PWM, namely by varying the width of the duty cycle.
(active cycle) of the motor input voltage. By setting 3810 ms as a constant 1 cycle, it can be calculated the PWM duty cycle which affects the PLC output voltage to drive a DC motor.

Based on the graph of the results of testing the relationship between the PWM active pulse width and the motor voltage in Figure 7, the results show that the relationship between the PWM active pulse width and the motor voltage is linear.

![Graph of active pulse's width to the DC motor voltage](image)

Figure 7. Graph of active pulse’s width to the DC motor voltage

The last stage is testing the whole system using the ladder diagram that has been made. Selected some of the desired setpoint / conveyor speed with the setpoint limit must be more than 50rpm to avoid dead-zone and no external disturbance of the system. From the final testing, the results were satisfying, and the conveyor prototype worked as the criteria of the system, where the conveyor worked when the switch set to On and the infrared sensor detected the dummy load. The conveyor speed depended on the PWM setting. Then the conveyor would be stop working if the switch turned off. Thus, full automation system of conveyor for educational purpose was done and it showed satisfying results.

4. Conclusion
The design of an Automatic Conveyor System using a Programmable Logic Controller for educational purposes has been successfully made. The main controlling device used is the FX3U Mitsubishi PLC, which is equipped with an analog input, an analog output and a PWM (Pulse Width Modulation) output. The conveyor used is a mini conveyor with a DC motor drive and an infrared sensor. Conveyor speed control is done by adjusting the rotation speed of the DC motor using a PLC-based pulse width setting. The program is created with ladder diagrams using GX-Developer software. Conveyor speed regulation is done using the Pulse Width Modulation (PWM) method found on the PLC programming tool for FX3U PLCs, namely GX Developer. Based on the test data, the relationship between the conveyor motor voltage and the motor rotation speed is directly proportional. Likewise, the relationship between the PWM active pulse width and the motor voltage. System automation is obtained when the conveyor works automatically at the desired speed if the infrared sensor detects a dummy load. From the final testing, the results were satisfying, and the conveyor prototype worked as the criteria of the system, where the conveyor worked when the switch set to On and the infrared sensor detected the dummy load. The conveyor speed depended on the PWM setting. Then the conveyor would be stop working if the switch turned off. Thus, full automation system of conveyor for educational purpose was done and it showed satisfying results.
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