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To Integrate and Optimize the Use of Programmable Logic Controller in Development of Horizontal Flow Wrap Packaging Machinery for Industry Needs

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A B S T R A C T

This paper focuses on the use of PLC and HMI in the automation industry for a highly effective and versatile horizontal flow wrap plastic film packaging solution. The machine's functioning and efficiency are thoroughly evaluated through extensive testing and validation procedures across multiple criteria. The main aim of this paper is to do the automatic plastic film packaging of any product with packaging dimensions of 4cm X 5cm. For the process automation the FX5U 32MT PLC of Mitsubishi is used for controlling and automating the system using ladder logic. The result shows that the developed system provides fully automatic wrap packaging of products and able to do automatic packaging of 24 packets in one minute. Additionally, the results show the increased efficiency of product rate in less time for automatic packaging system. Finally, it has been observed that the system is very beneficial for the automatic packaging process using PLC and the process can be monitored and visualized on a display screen using HMI. Future advancements are required in the system to meet industry4.0 needs. By incorporating some smart technologies, deeper integration with Industry 4.0 principles could boost capabilities in data analytics, connectivity, and remote monitoring for predictive maintenance.

1. INTRODUCTION

As industrial automation emerges as a worldwide manufacturing trend, the process of packaging stands out as one of its most prevalent applications. An increasing number of industries are transitioning to automation. This paper focuses on implementing an automatic packaging control system within a process machine system, where the control system will have a significant role in managing all aspects of the system. The paper explains the use of programmable logic controller in development of horizontal flow wrap packaging machine [1]. The horizontal flow wrap machine is a type of packaging machinery used extensively in the food, pharmaceutical, and cosmetic industries for wrapping products in a flexible material such as plastic film [2]. These machines automate the process of wrapping individual or multiple products in a continuous motion, creating a sealed package around the contents. Horizontal flow wrap machines, also known as horizontal form fill seal (HFFS) machines or flow wrappers, are designed to package a wide variety of products, including bakery items, confectionery, snacks, frozen foods, hardware, and medical devices. Such mechanism guarantees product safety, sanitation, and display by providing effective, quick packaging solutions. Horizontal flow wrapping originated in the mid-1900s, as packing methods changed. Demand for automated and effective packing led to the development of flow wrapping technology, however it pioneered flow wrapping with their packing technology [3]. Typically to boost productivity and speed automation is useful in the horizontal wrapping process. Horizontal flow wraps machines have evolved to meet industry demands for efficiency, versatility, and speed. Horizontal flow wrap machine frames are shown in figure 1, usually made of stainless steel or other durable materials whereas such machines are stable, durable, and corrosion-resistant, making them suited for many manufacturing situations [4].

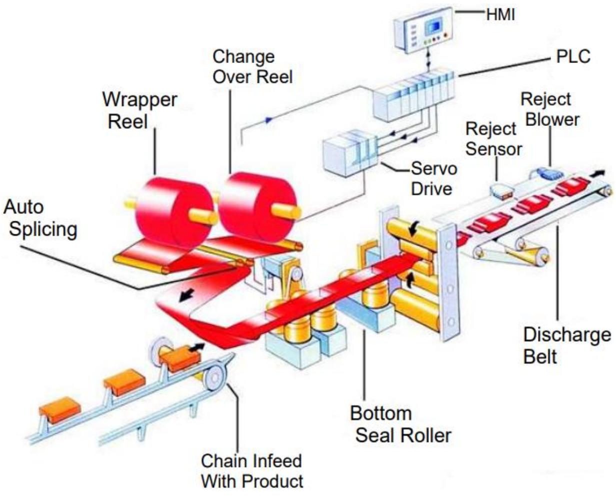

Fig. 1. Processes of Horizontal Flow Wrap Machine.

Products are fed from the production line to packaging material through this equipment. Feeding systems may use conveyors, belts, or infeed systems adapted to the wrapped products. Flow wrap machines unwind and feed packing film. Rolls or reels of film are unwound to guarantee continuous material supply during packing [5]. A rectangle shaped enclosure is formed by the film around the product as it passes through the packaging process thanks to the horizontal flow wrapper. Afterwards, the film is sealed longitudinally and transversely using heat sealing techniques, guaranteeing the package's integrity [6]. In order to create nicely wrapped packages, the extra film is trimmed or cut to size after sealing. The application and packing requirements determine whether cutting mechanisms such as reciprocating blades are used [7,8]. Contemporary horizontal flow wrap machines are outfitted with sophisticated control systems, frequently incorporating PLCs and HMIs [9,10]. By allowing users to adjust variables including manufacturing rates, sealing temperatures, and package sizes, these systems guarantee accurate and reliable packing outcomes [11]. Flow wrap machines are designed with safety as their top priority. To shield operators from dangers and stop mishaps while in use, technically in design it includes guards, sensors, and emergency stop devices [12]. Completely automated packaging lines that include both upstream and downstream machinery including product feeders, fillers, and labelling systems can incorporate horizontal flow wrappers [13,14]. Overall, the design of horizontal flow wrap machines continues to evolve in response to technological advancements, market demands, and regulatory requirements, aiming to deliver reliable, versatile, and high-performance packaging solutions for a wide range of industries [15]. Automation enhances productivity, reduces labor costs, and improves overall efficiency [16,17].

2. LITERATURE REVIEW

There are a great number of publications that are being examined, and the contributions that have been enumerated are available in Table 1.

Table 1. Related Contribution of Authors.

Author's Name	Work description
Baroro, M.M., 2014	The packaging and material handling processes were executed utilizing a PLC and an HMI was suggested for the purpose of control.
Algitta, A.A., 2015	Deployed an automated packaging machine by regulating the conveyor belt with a PLC.
Giberti, H., 2015	This study focuses on the kinematic and dynamic synthesis of a flying machining device, specifying the drive system and design parameters to ensure flexibility and large production volumes. The paper incorporates a flexible design into a horizontal wrapping machine.
Gupta, T., 2018	Proposed a solution for reprogramming the PLC involves interconnecting SCADA and PLC. The design of a packaging process utilizing Programmable Logic Controllers (PLC) and Supervisory Control and Data Acquisition (SCADA) for remote control and monitoring, along with a software interface for process visualization, is proposed.
Gupta, T., 2018	This study examines the control specifications of an automated capping machine, determines the input/output configuration of the system, constructs a flowchart depicting the primary and secondary programs of the system, and finalizes the program and monitoring interface designs in accordance with the flowchart.
Ashhab, S., 2020	In order to accurately count the diapers, a PLC-based precise sensor system was created. The developed packaging machine for diapers expedites the production of diapers while reducing expenses.
Sobh, A. S., 2021	Presented a manufactured automatic feeding system for a manually run flow-packing machine. Automation of the feeding system replaced manual placement of pieces on the conveyor. Resulting in increased product waste and occupational injury risk. Automatic feeding mechanism design addresses these issues.

Based on the above discussion and related literature survey, this research focuses on the successful integration and optimisation of HMI and PLC technologies to enhance control, monitoring, and user interaction within the machine [18]. But during the literature and discussion of this horizontal flow wrap packaging machine we also come to know that this paper can also be useful to achieve some following objectives also.

- Minimize initial investment: Reduce initial costs for the Horizontal Flow Wrap Packaging Machine to widen its accessibility to various businesses.
- Enhance maintenance and repair efficiency: Improve processes to minimize downtime and ensure continuous, reliable operation of the machine.
- Address environmental concerns: Explore and implement sustainable alternatives to mitigate environmental impacts associated with plastic packaging materials.

3. METHODOLOGY

3.1 Description of System

Each component in a PLC-based horizontal flow wrap packaging machine is essential to the effective and dependable operation of the system. The power supply provides electrical energy to all components of the machine and ensures the power requirements for proper operation. The relay module serves as an interface between the PLC and high-power devices such as motors, heaters, and solenoid switches. it enables the PLC to operate these devices safely and effectively. The PLC controls the packing machine by carrying out preprogrammed instructions to synchronize the functions of different parts. It receives sensor input data, processes them using logic that has been designed, and outputs signals to operate heaters, actuators, motors, and other devices. Pneumatic components including solenoid switches, cylinders, and actuators receive compressed air from the air compressor. These pneumatic tools are necessary for operations including cutting, sealing, producing films, and feeding products. The heat controller controls the temperature of heating components used to seal packaging film, such as rod and circular heaters. The products are transported into the packaging machine by the infeed conveyor and then moved through the packaging process by the motor conveyor. These conveyors guarantee a steady, regulated flow of goods, facilitating reliable, effective packing processes. Pneumatic systems, solenoid switches regulate the compressed air flow to different pneumatic actuators and parts. Sensors identify the existence, location, and condition of goods, packing materials, and machine parts, however based on the sensor feedback the PLC allows the machine for immediate supervision and control of the packing process. Sensors guarantee precise product placement, appropriate film tension, and prompt execution of diverse machine operations. Products are inserted into the film, the edges are sealed to produce individual packages, and the film is folded or unfolded as required. When these systems are operating correctly, products are packaged precisely and efficiently while retaining their integrity and aesthetic appeal. The discharge conveyor moves packaged goods to the next section of the production line or to packaging for distribution after receiving them from the packaging machine.

A continuous wrapping material, commonly a roll of flexible packaging film, is used by the flow wrap packaging equipment in this system to enclose the product in a shut-off package. Automating and regulating the operation of the horizontal flow wrap packaging machine is dependent on the PLC. Executing a programmed designed particularly for this purpose, the PLC regulates the entirety of the machine's operation. The programmed dictates to the PLC the timing for starting and stopping the motors that power the machine's components, including those that unwind films, input products, cut, seal, and move the conveyor. To monitor the process and make necessary adjustments to guarantee consistent packaging quality and efficiency, the PLC may also integrate feedback mechanisms and sensors. To accommodate various products and packaging materials, PLC programming permits the modification of machine parameters including package size, speed, and closure temperature. Design and development of the packaging system were conducted utilizing FX5U 32MT series PLCs. The FX5U 32MT PLC series, which is utilized in this system, is depicted in Figure 2.

Mitsubishi Electric manufactures the robust and small-sized FX5U line of programmable logic controllers. It controls a variety of operations and is commonly utilized in industrial automation. FX5U PLC programming and configuration are done with GX Works3 software. GX Works3 is a software application utilized for the purpose of program creation and modification, PLC system monitoring and debugging, as well as various setup chores. The software has an interface that is easy to navigate and is compatible with various programming languages, including structured text, ladder logic, and function bar diagrams. The GX Works3 software is utilized for the purpose of designing control logic, specifying input and output devices, configuring communication parameters, and conducting program simulations prior to deployment on the FX5U PLC.

Fig. 2. Photograph of FX5U 32MT PLC.

The integration of these components enables the effective development and management of a PLC control system. Table 2 presents the technical specifications of the PLC FX5U.

Table 2. Specifications of FX5U-32MT PLC.

Features of FX5U PLC	
No. of inputs and outputs	16 (maximum)
Power supply	100-240 VAC
Type of output	Transistor
Consumption of power [W]	30
Weight [Kg]	0.7
Size in Width [mm]	150

3.2 Flow Chart of Methodology

Figure 3 displays a flow chart that offers a concise summary of the consecutive procedures required for the functioning of a PLC-based horizontal flow wrap packaging machine. Each step interacts with various components to ensure efficient and reliable packaging of products.

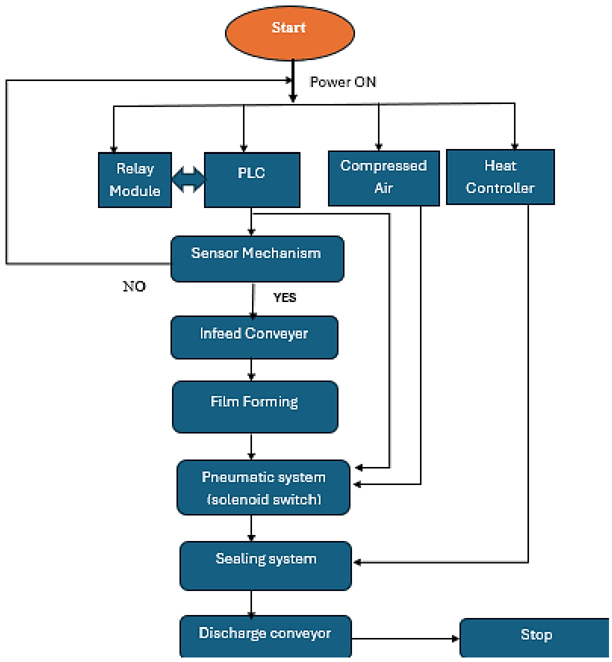

Fig. 3. Flow Chart of the Process.

The flow chart describes that the packaging process starts with the power supply, ensuring all components are operational. Then proximity sensors detect product presence on the infeed conveyor, moving products towards film forming. Film is unwound and formed into a tube around the product. The horizontal pulling motor controls film movement. Solenoid switches manage pneumatic tasks like sealing. Sealing system activates to seal film edges, regulated by heaters. Film folding/unfolding creates desired package configurations. Packaged products are transferred to the discharge conveyor. The packaging area provides space for loading and maintenance. The air compressor ensures pneumatic component operation. Heat controller maintains sealing temperature. PLC signals the relay module for device activation. The process stops once packaging is complete. Each step ensures efficient and reliable packaging.

4. RESULTS ANALYSIS AND DISCUSSIONS

This section offers an analysis or interpretation of the results obtained from the proposed research objectives. In this section, hardware model of the experimental setup of the developed system has been described. Also discussed the detailed overview of the PLC and HMI integrated horizontal flow wrap packaging machine, including its components, functionality, and specifications.

4.1 Experimental Setup (Hardware Model)

The proposed system has been developed as a result for optimizing the use of PLC and HMI in horizontal flow wrap packaging machine. This hardware description outlines the essential components of a PLC-based horizontal wrap packaging machine. Depending on specific requirements and features, additional components have been included in the setup. Figure 4 illustrates the complete hardware model of the experimental setup.

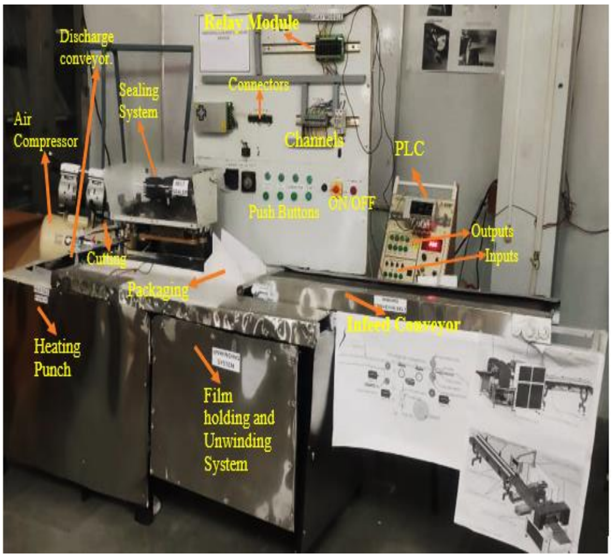

Fig. 4. Photograph of experimental setup.

The working of the whole system and function operation of each component are described as follows:

Power supply activation starts the packaging process by powering all packaging machine components. The packaging operation requires motors, heaters, controls, and other electrical components.

Once the power supply is on, infeed conveyor sensors detect items. These proximity sensors can detect packaged products. The system delays packing until a product is found. This prevents empty packages and maximizes material consumption. The machine's film-forming segment receives items identified by the sensors. After unwinding from a roll, the film is shaped around the product. The product is safely enclosed in the packaging material by making a tube or sleeve. While packing, the horizontal pulling motor moves the film. It ensures the film flows horizontally at a predetermined speed, making packing alignment and sealing easier. Sealing is controlled by solenoid switches in pneumatics. Switches control cutting and sealing pneumatic actuators. Programmable logic in the PLC activates solenoid switches to precisely control pneumatic processes. After placing the product in the film tube, the sealing mechanism seals the film edges lengthwise. Circle and rod heaters manage sealing temperature to ensure film adherence and a tight seal around the product. By folding or unfolding the film, film folding and unfolding technology determines packing designs. This stage may require folding arms or guides to form the film.

PLC and HMI signal relay module for device activation, controlling numerous components based on preset logic. After packaging, the process concludes, and the products are ready for distribution. From product detection to sealing and discharge, the process provides efficient and reliable packing.

4.2 Software Simulation Results

The entire programming for the developed system is conducted exclusively on the FX5U 32MT PLC platform using the GX Works3 simulation software. The selection of the PLC FX5U series is motivated by its incorporation of simulation capabilities, which streamline the monitoring process for the diverse parameters inherent in the proposed model. Ladder logic, a programming language employed, accommodates graphical representation of programming functions, closely resembling the symbols utilized in conventional hardwired control diagrams. For the completion of the implemented system, multiple ladder networks or rungs are used. There are also many instructions are used for the input and output module. Input module has some push buttons, toggle switches and sensors. And in output module some motors, actuators, conveyor system and many more are present. Implementing networks for all these, many instructions are used like timer, counter, holding, set, and reset etc. Mitsubishi's HMI/GOT2000 controls and monitors the system's ladder logic, which GT designer3 software visualizes. The HMI system may monitor and control hardware model operation with marked start and stop buttons. Connecting the PLC and HMI requires these steps:

Open the GX Works3, start a new project and configure PLC FX5U. Designed a ladder logic for proposed problem in GX Works3 and keep the programmed in simulation mode. Using similar input/output addressing, HMI screen was designed in GT designer3 environment. After labelling the similar input/output and tags, interface the HMI and activate the simulation mode for the designed HMI screen. The IP addresses of HMI and personal computer or laptop should be same. Every memory location and element on the PLC is given a tag name during coding, and these tag names are connected to various HMI screen events and properties. It is possible to add and edit every PLC tag. The all the PLC tags and switches, which are used in the coding are shown in table 3.

Table 3. PLC tags and switches.

Tags/switches	Description
X0	START (whole system)
X1	Start
X2	Stop
Y1	Infeed conveyor
Y2	Belt Sealer
Y3	Solenoid valve upper
Y4	Solenoid valve down
Y5	Output conveyor
T0	On delay belt sealer
T1	On timer, solenoid valve up
T2	Dealy timer for solenoid valve down
T3	Sealing delay timer
T4	Conveyor timer lower
M0	Internal relay

After completing the ladder programming, it is required to establish communication between the PLC code and HMI for similar input/output tags. The ladder logic programming has been implemented by using above similar I/O addressing, tags and switches for specified task. The PLC program is shown figure 5.

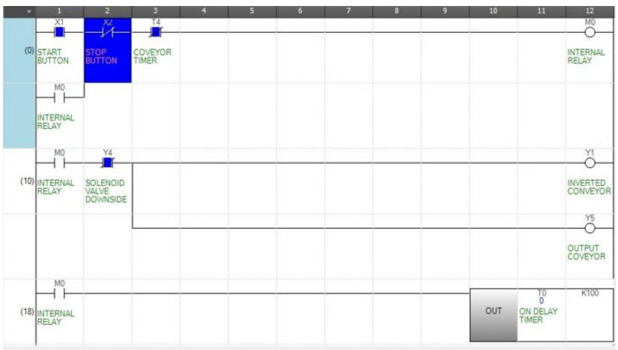

Fig.5. PLC program in GX Works3 simulation software.

Once the hardware connection between the PLC and HMI has been successfully established, the simulation phase can be conducted to simulate the I/O addressing. This will allow for easy monitoring and control of the specified logic, as illustrated in figure 6.

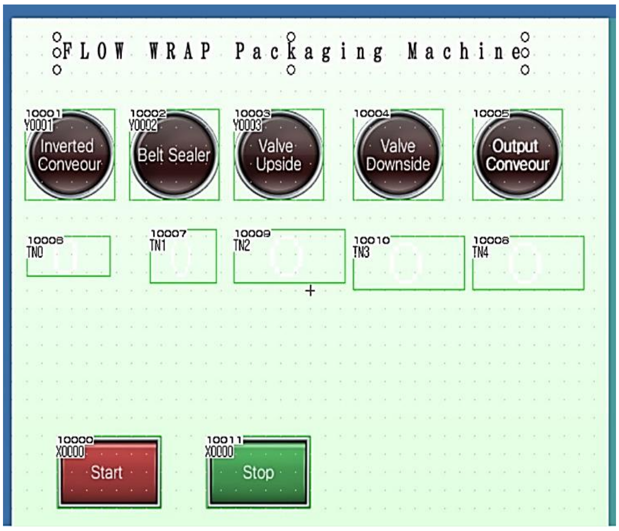

Fig. 6. Connection between PLC and HMI/GOT2000

Push Buttons (X0) and (X2) activated and deactivated the Packaging system. The upper motor of the infeed conveyor (Y0) moves the upper conveyor belt, which sequentially transfers plastic materials to the desired place. Sensor mechanism and other component functions commence when pushbutton (X1) is pressed. After detecting plastic at the designated spot, the sensor stops the lower conveyor belt and activates the upper belt to seal and sever the plastic. The infeed motor drives the infeed conveyor belt (Y0) to package products, which are sealed, sliced, and dumped in the collection point. The instruction (M0) acts as an internal relay to demonstrate memory bit function throughout this operation. This process takes one minute and counts sample packaging. Disconnect at completion of process till pushbutton (X2) pressed.

This program uses timing to delay component activation and measure product packing time. This method produces four packets of 4cm X 5cm plastic packing products in 10 seconds. Plastic packet packaging takes 2.5 seconds for 01 package. Manual packaging requires at least 4 seconds and must be done continuously. The HMI controls and visualizes the entire system. It was observed during the procedure that the designed system performs accurately and precisely. All system components are well-interfaced, efficient, performing properly, sequenced well, and synced with code instructions. Table 4 compares manpower-based and PLC-based automatic packaging system product rates over time.

Table 4. Product rate comparison

Time	Product packaging (with manpower)	Product packaging (Automatic)
10 seconds	2.5	4
1 minute	15	24
1 hour	900	1440
1 day	21600	34560

The packaging machine's effectiveness, speed, and efficiency increase when PLC and HMI are added to make it automatic. In conclusion, the Horizontal Flow Wrap Packaging Machine met objectives well. It exceeded speed and throughput targets while retaining precision. The machine's fast changeover mechanisms minimized downtime and accommodated goods of varied sizes and forms. Seal integrity was maintained, with robust seals across materials. Operators needed less training due to the simple interface.

5. CONCLUSION

The integration and effective use of PLC and HMI enabled horizontal flow wrap automatic packing machines. This study presents a highly efficient and adaptable plastic film packaging system using a Programmable Logic Controller (PLC) and Human Machine Interface to fulfil the urgent demand for automation in diverse industries. By detailing the design, development, construction, and testing processes, a horizontal flow wrap packaging machine with PLC integration was created. This system uses GT designer3 for HMI visualization and monitoring and the FX5U 32MT series PLC for ladder logic design. Multiple evaluations showed the machine's excellent performance. It automated 4cm x 5cm wrap wrapping at 24 packets per minute. The employment of PLC and HMI technology improves control, monitoring, and human interaction.

The machine also smoothly transitions between product shapes and sizes, so efficiency can be improved. Further development could improve the machine's ability to handle fragile or sensitive products. The system should be updated to comply with Industry 4.0, focusing on data analytics, networking, and remote monitoring for predictive maintenance. This revolutionary packaging automation approach improves efficacy and output while reducing manual labor and production time.

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