International Journal of Industrial Engineering, 30(2), 435-450, 2023

HUMAN MACHINE INTERFACE DESIGN OF INDUSTRIAL AUTOMATED MACHINE USING SIMATIC SCADA SYSTEM

Houda Meddeb[1, *], Zouhaira Abdellaoui[2], and Olfa Ezzine[2]

[1]Automatic Research Center of Nancy (CRAN)
Nancy, France
[*]Corresponding author's e-mail: meddebhouda@gmail.com

[2]Communication Systems Research Laboratory SYSCOM - LR-99-ES2,
University of Tunis El-Manar, National Engineering School of Tunis – ENIT,
El Manar, Tunisia.

In an industrial world full of technological advancements where competitiveness is the essential objective, automation has become a fundamental necessity to achieve higher productivity with less chance of error in a limited time. Additionally, regular monitoring of processes is required to improve system performance and ensure employee safety. In this paper, a method for realizing an automated weighing and bagging machine is proposed, and special emphasis is placed on the weighing system. A simulated process prototype based on a SCADA (Supervisory Control and Data Acquisition) system and PLC (Programmable Logic Controller) of weighing and bag packing machines is designed to fill and close bags with the product. Operators can monitor the process and control outputs through the HMI (Human Machine Interface) screen.

Keywords: Automation Control; HMI Design; PLC; SCADA System; Weighing and Bagging Machine, Arduino.

(Received on September 4, 2022; Accepted on February 6, 2023)

1. INTRODUCTION

Major developments have taken place in the field of automation in recent years (Cai *et al*., 2011; Ponsa *et al*., 2010; Mich Priyadharson and Surarapu, 2017). The benefits of industrial automation include increased productivity and quality, optimization of time, waste and labor costs, and replacement of operators in hazardous environments such as fire, nuclear and underwater. On the other hand, we cannot ignore the disadvantages of industrial automation, such as high installation costs and rising of unemployment (Normanyo *et al.,* 2014).

An industrial automation system consists of field level (Sensors & Actuators), control level (PLC) and supervisory control level. The latter encompasses SCADA systems (Supervisory Control and Data Acquisition) and Human Machine Interfaces (HMI). The basic function of a SCADA system is to collect information, perform required control operations and display this data on the HMI screen to monitor system information (Agarwal and Fatima, 2002; Bejan *et al.,* 2009; Poosapati *et al.,* 2018).

Automatic weighing and bagging machines are among the most widely used machines in the industry. For example, in agri-food, medical or pharmaceutical industries etc. However, ALMES, a large company in the food industry, still uses manual weighing systems to dose a product called Complement of Mineral and Vitamin (CMV) to improve animal growth and optimize their reproduction.

Generally, in these cases, the operators take a long time to fill and close the bag (including moving the bag to weigh, check and manually adjust the weight). All of these operations lead to measurement uncertainties, quantification errors, a large accumulation of bags waiting to be weighed, and, most importantly, poor management of time and human resources.

In order to improve productivity, quantify production errors, and especially optimize time, a method to realize automatic weighing and bagging machines is proposed, and an HMI interface to supervise and monitor the system using Wincc SCADA system is designed.

DOI: 10.23055/ijietap.2023.30.2.8561 ISSN 1943-670X

1.1. Related Works

SCADA systems are widely used in energy supply, manufacturing and automotive industries (Younas *et al*., 2015; Amditis *et al*., 2010). This technology is used in today's control systems to facilitate production operations, alarms, event recording and remote control.

Recently, several works based on SCADA systems have been proposed, such as (Cai *et al*., 2011), a PLC-based SCADA system was developed to control a subsea BOP stack. Triple redundant control, Ethernet and dual subsea electronic modules are used to implement the system hardware architecture. HMI interface and database were developed to collect data and monitor the system.

Younas *et al*. (2015) proposed a SCADA-based control system for electronic fuel-injected (EFI) diesel engines. A Siemens S7-300 PLC is used as the engine control unit (ECU), which detects the inputs from the EFI engine sensors. HMI screens are developed with WinCC to monitor and control variations of EFI sensors.

Aghenta and Iqbal (2020) proposed a low-cost SCADA system based on an ESP32 micro-controller, Raspberry Pi and the Internet of Things (IoT) to acquire, process, and remotely monitor the current, voltage and power of a standalone solar photovoltaic (PV) system. When the storage battery voltage reaches a threshold, the control and monitoring system generates an alarm to trigger a notification.

In (Bin Mofidul *et al*., 2019), a SCADA system is implemented to monitor and control the automated packaging process based on PLC and Arduino board. An HMI interface is designed with an Android application to ensure communication between the operators and the PLC-based plant. Therefore, the process can be remotely controlled and monitored using a mobile application.

In (Tomar and Kumar, 2020), a simulated prototype of a SCADA system is designed to monitor an automated process of bottle filling in the beverage industry. An OMRON PLC is used to control the system and fill the storage tanks with liquids of different compositions. The visual interface of the operation is implemented in the SCADA software Wonderware Intouch.

In (Chakraborty *et al*., 2020), a PLC-based automation strategy is introduced to control a tank water level. The process is monitored and controlled in real-time with a SCADA system developed using RSLOGIX 5000 software.

1.2. Contributions and Outline

The contributions of this work are summarized as follows:

- A model of an automated weighing and bagging machine is designed with selection of the appropriate components. The proposed system is characterized by its reasonable structure and convenient installation. It can provide simple and fast operations. Moreover, proper selection of components reduces powder residue, facilitates cleaning, and protects workers' health. This system is suitable for powders and fine particles products, and it can be used in many industries, such as food and chemical industries.
- A new technique for the weighing system is proposed. A low-cost system based on Arduino board is realized to measure and control the weight of the product. This is a highly accurate system with a 0.1g margin of error.
- Totally Integrated Automation (TIA) solutions from Siemens are used to control the designed machine. TIA integrates innovative technologies which allow for optimizing production and processes. Additionally, the functionalities of TIA Portal, the software package provided by Siemens, make process automation more efficient and reduces development time and maintenance cost.
- A simulated process prototype of the weighing and bagging machine based on the SCADA system and PLC Siemens S-1200 is implemented to fill and seal bags containing a product. HMI interface is designed to monitor the system using Wincc SCADA system. HMI screen is used to control the system and acquire data from sensors. The PLC-based SCADA system allows visualizing the evolution of the machine in real-time and allows it to take the appropriate decision when any default is detected.
- An evaluation of the designed system is performed. In fact, the performances and limitations of this system are presented in order to improve the proposed conception.

This paper is structured as follows. Section 2 contains a description of the problem. Section 3 details the hardware components and software methodology used in the automated weighing and bagging machine. Section 4 is devoted to system modeling and programming. Section 5 is dedicated to the practical implementation of the system. In section 6, the HMI interface is designed, and a series of simulations are performed.

2. PROBLEM DESCRIPTION

ALMES Mateur is an animal feed company based in Tunisia, part of the SNA (Society of Animal Nutrition), which is one of the subsidiaries of Poulina Group Holding (PGH), the leading poultry group in the Maghreb.

Actually, ALMES uses mechanical scales to manually weigh CMV products. Manual weighing steps are described as follows (see Figure 1):

- A large amount of CMV is divided by the operator in bags with a random quantity.
- This quantity is weighed by a digital scale. Then, the operator gradually adds the CMV using a bowl until he reaches the requested weight, for example, 30 kg for each bag.
- After finishing adjusting the weight of the bags, the operator closes them manually.

Figure 1**.** Manual Weighing process

The use of a manual weighing
the system can lead to the following problems and risks:

- Measurement uncertainties and production quantification errors,
- Accumulation of bags in waiting weighing,
- Operator fatigue, waste of time and poor profitability,
- Risk of cross-contamination,
- Risk of damaging the product by natural factors such as humidity because the weighed bags are not closed,
- Risks to the operator during the weighing process, such as eye, skin and respiratory diseases.

To solve these problems and increase profitability, an automated weighing and bagging machine that reduces the tedious work associated with manual methods, optimizes manpower and time management and extends the storage period of bags is proposed for implementation.

3. MATERIALS AND METHODS

In this section, the hardware components and the software methodology used to realize the automated weighing and bagging machine are presented.

3.1 Hardware system

The components of the automated weighing and bagging machine include a conveyor, hopper, sewing machine, pneumatic cylinders, valve, sensors, weighing system, and programmable logic controller (PLC).

- **Conveyor**: it is a device designed to transport packed bags on straight paths. This system is driven by an asynchronous motor having a rotating speed of 1500 rpm. A mechanical reducer that connects the motor to the conveyor is required to reduce the output speed of the conveyor to 10-20m/min by increasing the torque to match the operating needs.
- **Hopper:** it contains the product to be weighed.
- **Sewing machine:** it is used to close the bags already filled. The sewing machine is activated using a sensor that detects the sac, and it is deactivated when the necessary time has elapsed.
- **Pneumatic Cylinders:** they are used to hold and tighten the empty bag by acting on two jaws.
- **Valve:** it is used to dose the CMV product into the bags.
- **Sensors:** in the proposed solution, several types of sensors are used in the weighing and bagging machine.
    - *Capacitive sensor* is used to detect the presence of the product in the hopper.
    - *Photoelectric sensors* are used to detect the presence of the bag under the hopper during the filling phase and before the sewing machine.
    - *Cylinder limit switches* are used to detect the positions of cylinders.

- **Weighing system:** in this work, a weighing system is realized to measure the weight of the product. The main components of the circuit are Arduino UNO, an HX711 amplifier, a force sensor, a relay and LCD display. The Force sensor is generally constructed using strain gauges connected in a suitable bridge. The amplifier is normally required to read the delivered signal. The weighing system allows to read the amplified data from the force sensor and to display these measurements in Kg on LCD display. If the desired weight is reached, it sends a signal to the PLC via a relay. This signal indicates that the bag is full. As a result, the valve is closed, and the conveyor transports the bag to the sewing machine. The circuit design of the weighing system is shown in Figure 2.

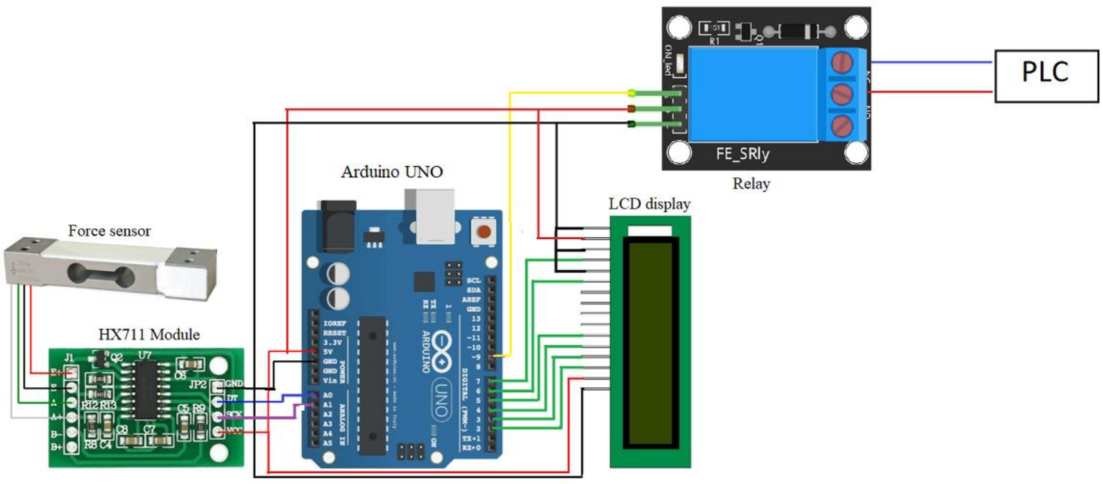


Figure 2. Weighing system circuit

The specifications of the chosen components sensors, and valves are summarized in Table 1.

Table 1. Components specifications

Components	Specifications
Photoelectric sensor	Model: Retro-reflective model with the Reflector is sold separately Power supply voltage:10 to 30V DC Sensing distance: 0.1 to 4m
Capacitive sensor	Model: M24 proximity sensor Distance range:15 mm Power supply voltage:12 to 24V DC
Cylinder sensor	Model: Limit Switch Actuator: roller or Lever Power supply voltage:24V DC kind of contact: No/Nc
Force sensor	Model: Digital Load Cell Weight Sensor Power supply voltage:5 -10V DC
Valve	Model: Electric Butterfly Valve Voltage:24 Volt DC Size: 100mm et 400mm

- **PLC SIMATIC S7-1200:** PLCs perform two main tasks to control automated processes (Mărgineanu 2005, Webb and Reis 2015). The first task is to monitor the status of the PLC inputs using sensors, buttons, process state variables, etc., while the second task is to process the input information and send the necessary command signals to the process actuators according to a specific program.

SIMATIC S7-1200, CPU 1215C (Salih *et al*., 2017, Barz *et al*., 2015), is selected to control the weighing packaging machine. The choice is justified by the fact that the SIMATIC S7-1200 PLC is equipped with different communication mechanisms for network connectivity: MPI, PROFIBUS, ETHERNET and expansion with 32 modules. Table 2 lists the specifications of the proposed PLC.

Table 2. Specification of S7-1200 PLC

Parameter	**Value**
Input Voltage	24V DC
Output Voltage	24V DC
Digital Inputs	14
Digital Outputs	10

3.2 Software system

Totally Integrated Automation (TIA) solution from Siemens is used to develop the control unit of the designed machine. TIA is the new Siemens environment, meaning fully integrated hardware, software and services are perfectly coordinated with each other. New technologies are gradually being incorporated and integrated into TIA, simplifying the automation process.

TIA portal is a software and tools package developed by Siemens for programming, development, and configuration of Siemens PLCs such as S7-1200, S7-1500, S7-300, and S7-400. The environment integrates basic software such as SIMATIC STEP 7, SIMATIC WinCC, SINAMICS Startdrive, SIMATIC Energy, etc...

SIMATIC Step7 is used to program SIMATIC controllers using the available programming languages: Ladder, FBD (Function Block Diagram), SCL (Structured Control Language), STL (Statements List), and S7 GRAPH. SIMATIC WinCC, on the other hand, is a control and data acquisition system used to develop HMI screens for supervisory systems. SIMATIC WinCC provides an innovative visualization system with a wide range of powerful functions for monitoring automation processes and offers complete functionality for all fields, highly complex visualization tasks and SCADA applications. In addition, it provides easy and secure access to process data and increases productivity when creating HMI projects.

In this work, the programming of the PLC S7-1200 is performed with TIA PORTAL software using the Ladder language. Furthermore, Arduino IDE software is used to develop the weight measurement and control program implemented on the Arduino board.

4. SYSTEM MODELING AND PROGRAMMING

In this section, we first detail the operation of the weighing and bagging machine. Second, provide a Grafcet model of the system. The third part of this section is devoted to programming the system using Ladder diagrams.

4.1 System operation

The operation of the automated weighing and bagging machine is divided into three main phases, which are described below:

Bag filling: when the photoelectric sensor detects the presence of the empty bag introduced by the operator under the hopper, two pneumatic cylinders move and act on the jaws to clamp the bag. Once the bag is well tightened, the valve opens to ensure the bag is filled.

Product weighing: When the product is dispensed into the bag, the Arduino board-based weighing system immediately measures the weight of the load until the set point (requested weight) is reached. The weighing card communicates with the PLC and transmits the information that causes the valve to close.

Bag closing: when the filling phase is finished, with avoiding the overflow of the product inside the bag, the cylinders ensure the opening of the jaws to release the filled bag. Afterwards, the bag falls onto the conveyor, which transports it to the sewing machine for closing. A photoelectric sensor indicates the presence of the filled bag before the sewing machine, which triggers the sewing process. When the required time has elapsed, the closing of the bag is completed.

4.2 Grafcet model

State Transition Graph (GRAFCET) can be considered the industry's primary automation design tool (Ponsa *et al*., 2010). According to the operation description of the system, the Grafcet model of the weighing and bagging machine is deduced. The model is shown in Figure 3.

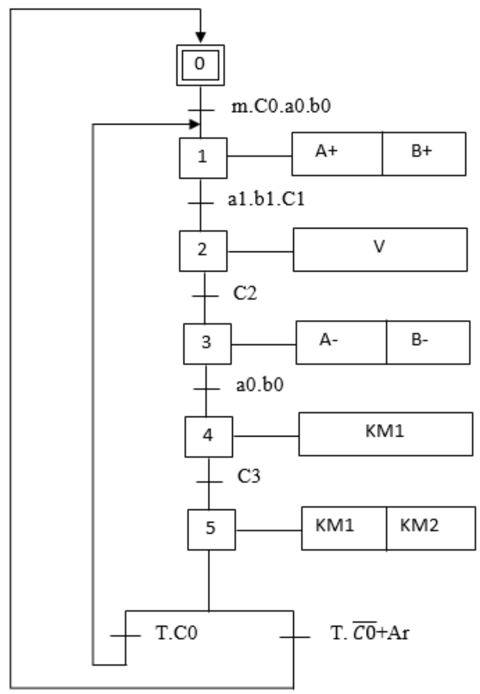


Figure 3. Grafcet model

with:

- m: start push button.
- C0: a photoelectric sensor which detects the presence of the bag under the hopper.
- C1: capacitive sensor that detects the level of powder in the hopper.
- C2: information provided by the weighing system to indicate whether the desired weight is reached or not.
- a0,b0, a1, b1: Cylinder Limit Switches
- C3: photoelectric sensor that detects the presence of the bag before the sewing machine.
- Ar: stop push button.
- T: timer that controls the closing time of the bag.
- KM1: conveyor motor contactor.
- KM2: motor contactor of the Sewing machine.
- V: valve.
- A+, B+: cylinders advancement.
- A-, B-: cylinders retraction.

4.3 Program design

In this work, the Ladder logic diagram (LD) is the programming language used to program the PLC S7-1200. It has evolved from electrical circuit diagrams and contains contact and relay symbols called coils (Antonsen, 2021). Ladder logic is the easiest and most efficient way to create logical expressions to automate the operations of PLC-controlled machines. Therefore, the Grafcet model is transposed into Ladder language to automate the proposed weighing and bagging machine.

To pass from Grafcet to Ladder language, the first step is to translate the Grafcet into logic equations. Let X_i be step i of a Grafcet, X_{i-1} the previous step and X_{i+1} the following step. T_{i-1} and T_i the receptivity associated with the transitions. The equation representing the step X_i is as follows:

$$X_i = X_{i-1}T_{i-1} + \overline{X_{i+1}}X_i \tag{1}$$

The equations, which describe the system operation are deduced from the Grafcet given in Figure 3. According to equation (1), step equations are described as (2).

$$X_0 = X_5.(Ar + T.\overline{C_0}) + \overline{X_1}.X_0 + \overline{X_2}.\overline{X_1}.\overline{X_0}.\overline{X_3}.\overline{X_4}.\overline{X_5} \quad (2a)$$
$$X_1 = X_0.m.C_0.a_0.b_0 + X_5.T.C_0 + \overline{X_2}.X_1 \quad (2b)$$
$$X_2 = X_1.a_1.b_1.C_1 + \overline{X_3}.X_2 \quad (2c)$$
$$X_3 = X_2.C_2 + \overline{X_4}.X_3 \quad (2d)$$
$$X_4 = X_3.a_0.b_0 + \overline{X_5}.X_4 \quad (2e)$$
$$X_5 = X_4.C_3 + \overline{X_1}.\overline{X_0}.X_5 \quad (2f)$$

Outputs equations are expressed as (3).

$$KM1 = X_4 + X_5 \quad (3a)$$
$$KM2 = X_5 \quad (3b)$$
$$V = X_2 \quad (3c)$$
$$A^+ = X_1 \quad (3d)$$
$$A^- = X_3 \quad (3e)$$
$$B^+ = X_1 \quad (3f)$$
$$B^- = X_3 \quad (3g)$$

Once the equations are determined, it is sufficient to represent each equation in a Ladder diagram, taking into account its symbol and its input/output elements. In the Ladder program, the state of steps (X0, X1, X2, X3,X4 and X5) are replaced by relay contacts (M0,M1,M2,M3,M4 and M5). The input, output and relay switch configurations are shown in Figure 4, and the associated Ladder network for each equation is given in Appendix A.

Name	Data type	Address
m	Bool	%I0.0
c0	Bool	%I0.1
c1	Bool	%I0.2
c2	Bool	%I0.3
c3	Bool	%I0.4
a0	Bool	%I0.5
b0	Bool	%I0.6
a1	Bool	%I1.0
b1	Bool	%I1.1
Ar	Bool	%I0.7
KM1	Bool	%Q0.0
V	Bool	%Q0.1
KM2	Bool	%Q0.2
A+	Bool	%Q0.3
B+	Bool	%Q0.4
A-	Bool	%Q0.5
B-	Bool	%Q0.6
M0	Bool	%M0.0
M1	Bool	%M0.1
M2	Bool	%M0.2
M3	Bool	%M0.3
M4	Bool	%M0.4
M5	Bool	%M0.5

Figure 4. Variables table

5. PRACTICAL REALIZATION

In this section, we indicate the electrical schematics representing the control and power circuits created by the WinRelais software. As shown in Figure 5, the control circuit represents the wiring of sensors, pre-actuators, and actuators to PLC addresses.

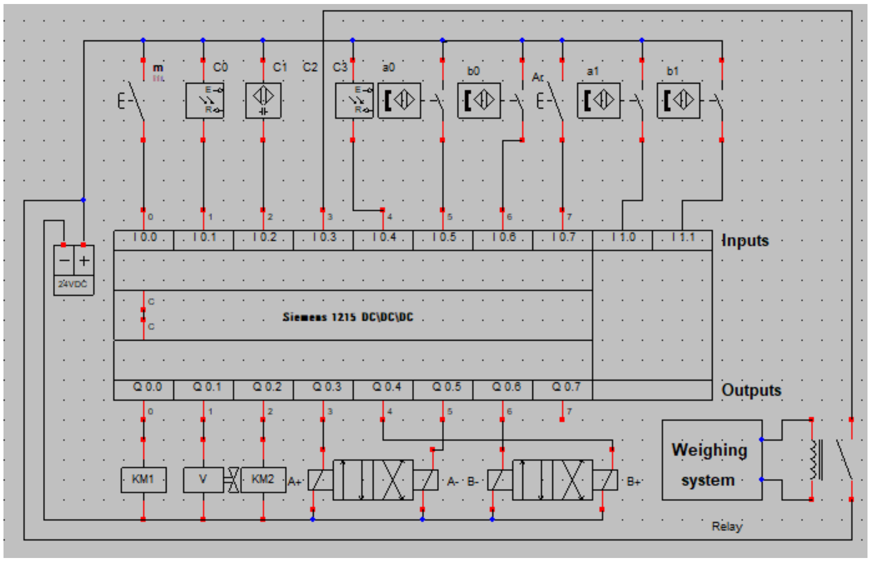


Figure 5. Control circuit

The power circuit of the conveyor motor or the sewing machine motor contains contactor (KM1 or KM2), thermal relay (RT) and fuse-disconnector (Q1), as given in Figure 6 below:

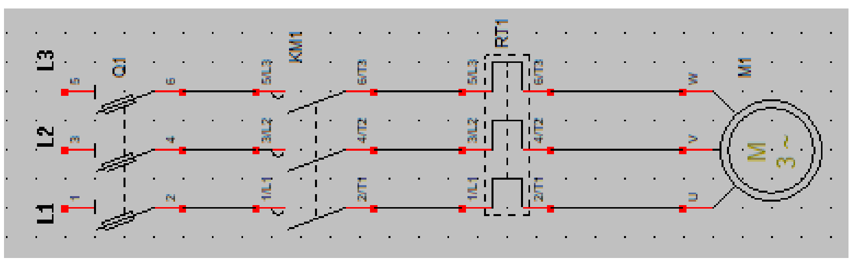


Figure 6. Power circuit of the three-phase motor

6. HMI DESIGN AND SIMULATION

6.1 HMI Design

The HMI, as defined by Thomas *et al.* (2004), refers to the interface required for the interaction between the machine and the operator/user of the SCADA system. The main functions of the HMI system are processing visualization, monitoring the inputs and outputs of the machines, and controlling and tracking of production time. HMIs are designed to be used in many areas to increase personals and materials safety. For example, in the automative industry, HMI is required to improve driver-system interaction and user comfort (Amditis *et al.*, 2010).

WINCC SCADA system is used to interface with Siemens S7-1200 PLC, collect information, perform the required control actions and display this data on the HMI screen. The HMI programmer shall schedule each indicator and button to a specific input or output address of PLC. The HMI and PLC must communicate with each other using protocols such as Modbus, Ethernet/IP and Profibus (Abdulwahid and Mohammed Wasel, 2020).

In order to design the monitoring system and HMI interface, we need to start programming the PLC. For this, we converted the Grafcet model into the Ladder Diagram language developed in SIMANTIC Step 7. Communication between the PLC Ladder logic program and the HMI is ensured through tags (Normanyo *et al.*, 2014, Dutta *et al.*, 2014).

In this work, the HMI interface is designed to control and monitor the weighing and bagging machine. It allows reading the values from the system inputs (sensors, push buttons..) and then controlling the actuators (valves, cylinders, sewing machine) according to the program already loaded in the PLC. Consequently, it is first necessary to create an Ethernet connection between the PLC CPU and the HMI in order to interact with PLC, as shown in Figure 7.

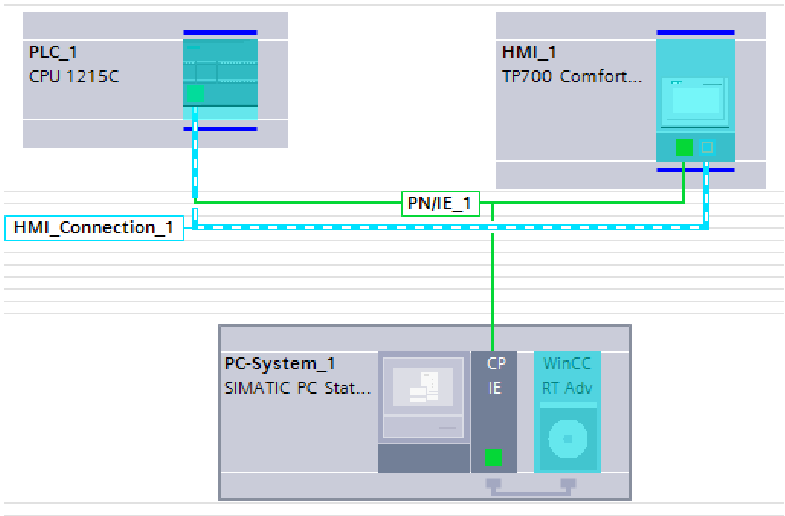


Figure 7. HMI and Ethernet connection

HMI screens can be created thanks to the wide range of objects and graphic elements provided by the SIMATIC WinCC library (SIEMENS, 2020). Predefined objects are used to represent installation components such as push buttons, valve, conveyor, sewing machines etc. After inserting the objects in the HMI view, they must be configured by following these steps:

- Assign each output object the corresponding variable (PLC address) used in the program representing the operation of the system, e.g., assign V to the valve, KM1 to the conveyor, KM2 to the sewing machine...
- Dynamicize the appearance of objects assigned to outputs (KM1, V, KM2,…) according to their states: active (1) or inactive (0) by modifying certain properties such as colors, flashing, visibility and movements.
- Add an event to the push buttons (m and Ar) by setting its bit 1 or 0 during runtime. Events determine what happens when a button is clicked, pressed, released etc.
- Use animation to show the position of the bag on a conveyor, which is an efficient indication of conveyor status.

The created HMI screen for graphical visualization is shown in Figure 8 below.

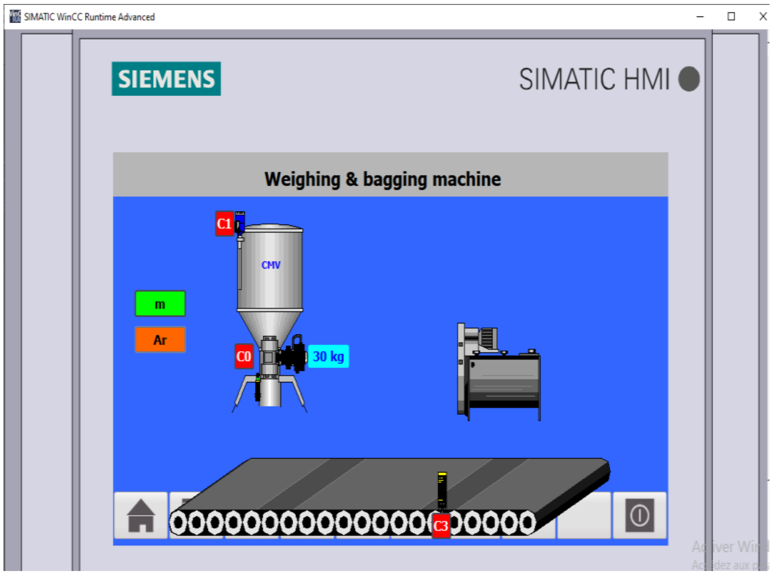
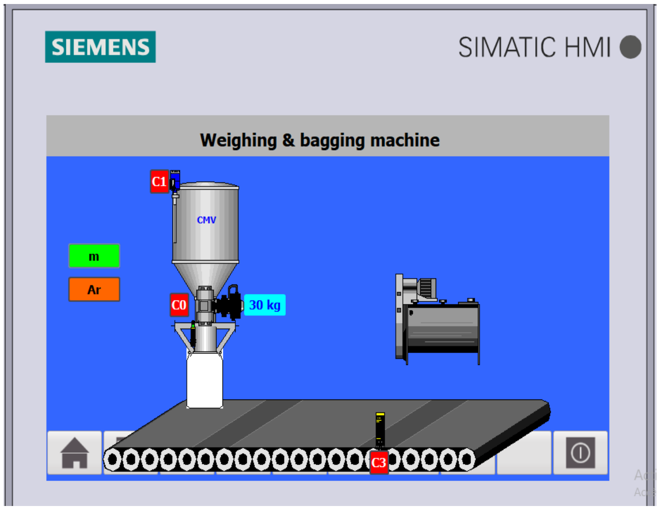


Figure 8. The main HMI screen

6.2 Simulation of HMI and PLC program

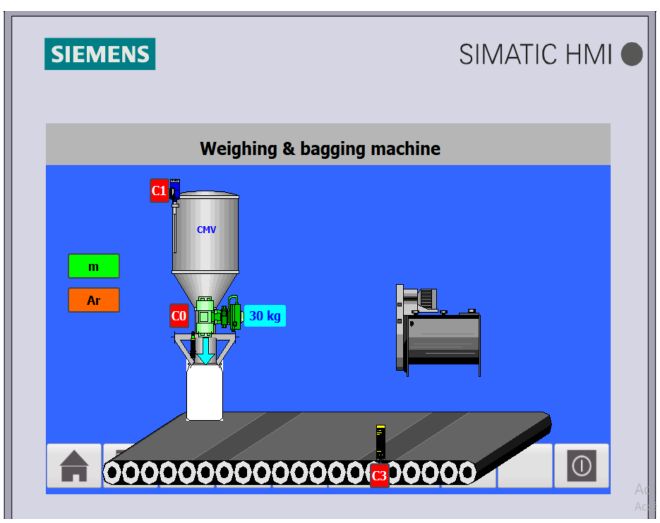
Simulation is used to test the reaction between the HMI program and the PLC program. Siemens' PLC simulator software (PLCSIM) is used for the simulation. The results are recorded in different situations and are presented in a variable table. When the start button "m" is pressed and the sensor "C0" detects the presence of an empty bag inserted by the operator, two cylinders move and act on the jaws to grip the bag (see Figure 9).



Name	Address	Display format	Monitor/Modify value
"m":P	%I0.0:P	Bool	TRUE
"c0":P	%I0.1:P	Bool	TRUE
"c1":P	%I0.2:P	Bool	FALSE
"c2":P	%I0.3:P	Bool	FALSE
"c3":P	%I0.4:P	Bool	FALSE
"a0":P	%I0.5:P	Bool	TRUE
"b0":P	%I0.6:P	Bool	TRUE
"a1":P	%I1.0:P	Bool	FALSE
"b1":P	%I1.1:P	Bool	FALSE
"Ar":P	%I0.7:P	Bool	FALSE
"KM1"	%Q0.0	Bool	FALSE
"KM2"	%Q0.2	Bool	FALSE
"A+"	%Q0.3	Bool	TRUE
"B+"	%Q0.4	Bool	TRUE
"A-"	%Q0.5	Bool	FALSE
"B-"	%Q0.6	Bool	FALSE
"V"	%Q0.1	Bool	FALSE

Figure 9. Tightening and hold of the bag

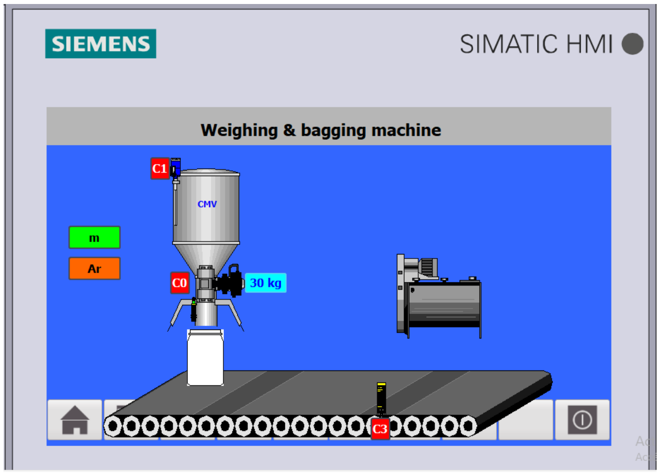
When the bag is well tensioned by the two cylinders, and there is a product in the hopper, indicated by the sensor 'C1', this generates the opening of the valve 'V' to fill the bag until reaching the desired weight. The valve will appear green (see Figure 10).



Name	Address	Display format	Monitor/Modify value
"m":P	%I0.0:P	Bool	FALSE
"c0":P	%I0.1:P	Bool	FALSE
"c1":P	%I0.2:P	Bool	TRUE
"c2":P	%I0.3:P	Bool	FALSE
"c3":P	%I0.4:P	Bool	FALSE
"a0":P	%I0.5:P	Bool	FALSE
"b0":P	%I0.6:P	Bool	FALSE
"a1":P	%I1.0:P	Bool	TRUE
"b1":P	%I1.1:P	Bool	TRUE
"Ar":P	%I0.7:P	Bool	FALSE
"KM1"	%Q0.0	Bool	FALSE
"KM2"	%Q0.2	Bool	FALSE
"A+"	%Q0.3	Bool	FALSE
"B+"	%Q0.4	Bool	FALSE
"A-"	%Q0.5	Bool	FALSE
"B-"	%Q0.6	Bool	FALSE
"V"	%Q0.1	Bool	TRUE

Figure 10. Bag filling

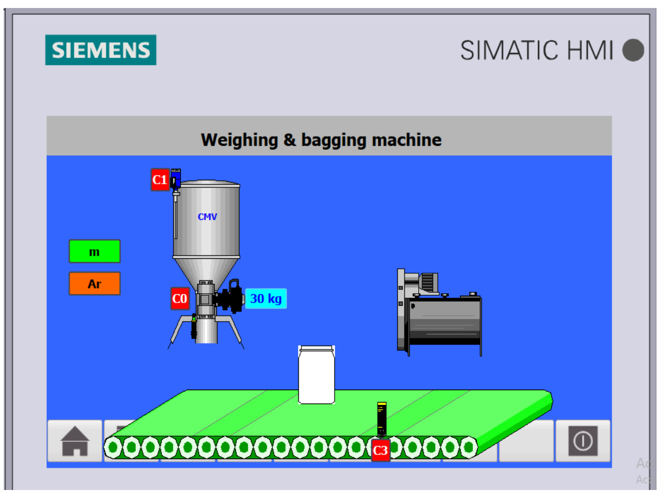
When the target weight is reached, the cylinders ensure the opening of the jaws to release the filled bag. Afterwards, the packaging bag will fall on the conveyor (see Figure 11).



	Name	Address	Display format	Monitor/Modify value
	"m":P	%I0.0:P	Bool	FALSE
	"c0":P	%I0.1:P	Bool	FALSE
	"c1":P	%I0.2:P	Bool	FALSE
	"c2":P	%I0.3:P	Bool	TRUE
	"c3":P	%I0.4:P	Bool	FALSE
	"a0":P	%I0.5:P	Bool	FALSE
	"b0":P	%I0.6:P	Bool	FALSE
	"a1":P	%I1.0:P	Bool	FALSE
	"b1":P	%I1.1:P	Bool	FALSE
	"Ar":P	%I0.7:P	Bool	FALSE
	"KM1"	%Q0.0	Bool	FALSE
	"KM2"	%Q0.2	Bool	FALSE
	"A+"	%Q0.3	Bool	FALSE
	"B+"	%Q0.4	Bool	FALSE
	"A-"	%Q0.5	Bool	TRUE
	"B-"	%Q0.6	Bool	TRUE
	"V"	%Q0.1	Bool	FALSE

Figure 11. Bag loosening

When the packaging bag is fallen on the conveyor, KM1 is activated, and the bag is moved by the conveyor to the sewing machine (see Figure 12).



	Name	Address	Display format	Monitor/Modify value
	"m":P	%I0.0:P	Bool	FALSE
	"c0":P	%I0.1:P	Bool	FALSE
	"c1":P	%I0.2:P	Bool	FALSE
	"c2":P	%I0.3:P	Bool	FALSE
	"c3":P	%I0.4:P	Bool	FALSE
	"a0":P	%I0.5:P	Bool	TRUE
	"b0":P	%I0.6:P	Bool	TRUE
	"a1":P	%I1.0:P	Bool	FALSE
	"b1":P	%I1.1:P	Bool	FALSE
	"Ar":P	%I0.7:P	Bool	FALSE
	"KM1"	%Q0.0	Bool	TRUE
	"KM2"	%Q0.2	Bool	FALSE
	"A+"	%Q0.3	Bool	FALSE
	"B+"	%Q0.4	Bool	FALSE
	"A-"	%Q0.5	Bool	FALSE
	"B-"	%Q0.6	Bool	FALSE
	"V"	%Q0.1	Bool	FALSE

Figure 12. Carrying the bag to the sewing machine

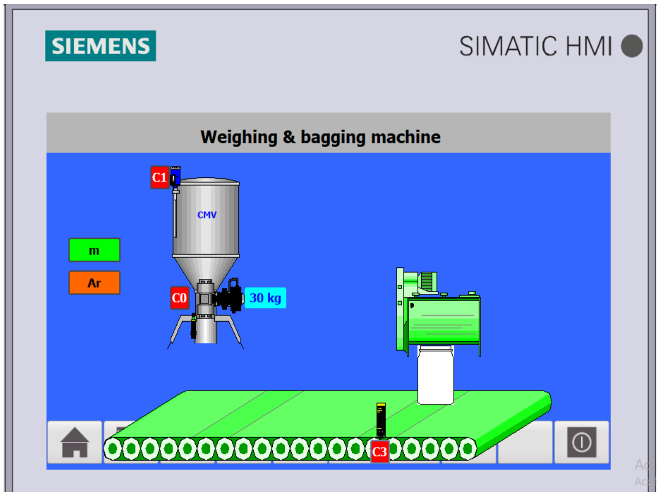
When the sensor "C3" detects the presence of a bag, the sewing machine (KM2) starts. Note that KM1 remains in state 1 to move the bag under the sewing machine and complete the closing process until the required time is elapsed (see Figure 13).

After this state, when there is an empty bag, the system will loop again, and the machine can be stopped by pressing the stop push button.

6.3 System evaluation

The proposed system is simple, easy to install and robust. Moreover, it reduces labor requirements and saves more time. Operators can bag 10 to 12 bags per hour in manual situations. According to the simulated tests carried out, the designed system can fill 200 bags per hour.

The convenient choice of the material enables the designed system to be more resistant to the harshest working environments and to be easy to clean and maintain. Depending on the selection of material, the bagging machine is suitable for finely divided products and powders with finer particles, such as flour, sugar, CMV, etc. Additionally, the low-cost weighing system based on Arduino board allows it to achieve +/- 0.1 g accuracy.



	Name	Address	Display format	Monitor/Modify value
	"m":P	%I0.0:P	Bool	FALSE
	"c0":P	%I0.1:P	Bool	FALSE
	"c1":P	%I0.2:P	Bool	FALSE
	"c2":P	%I0.3:P	Bool	FALSE
	"c3":P	%I0.4:P	Bool	TRUE
	"a0":P	%I0.5:P	Bool	FALSE
	"b0":P	%I0.6:P	Bool	FALSE
	"a1":P	%I1.0:P	Bool	FALSE
	"b1":P	%I1.1:P	Bool	FALSE
	"Ar":P	%I0.7:P	Bool	FALSE
	"KM1"	%Q0.0	Bool	TRUE
	"KM2"	%Q0.2	Bool	TRUE
	"A+"	%Q0.3	Bool	FALSE
	"B+"	%Q0.4	Bool	FALSE
	"A-"	%Q0.5	Bool	FALSE
	"B-"	%Q0.6	Bool	FALSE
	"V"	%Q0.1	Bool	FALSE

Figure 13. Bag closing

The PLC-baed SCADA system allows the control and monitoring of the designed weighing and bagging machine. In addition, it offers the opportunity to visualize its evolution in real time and take appropriate decisions in unusual events.

On the other hand, actually, the proposed system cannot be controlled and monitored remotely. However, this work can be extended to IoT applications using devices such as the Raspberry Pi board, which is essentially a ready-to-use IoT device. Raspberry PI can be utilized as a complement for PLC to make the leap to Industry 4.0.

Additionally, a web page can be developed to permit interaction with the system over the Internet and allow users to remotely monitor, control, and diagnose faults. In fact, users can view an interface designed with a SCADA system in a web application from anywhere with an internet connection. With the help of Raspberry Pi, IoT-based systems can send email and notification alerts when errors are detected.

Furthermore, Raspberry Pi can be used as a PLC thanks to OpenPLC retune, which makes it possible to run PLC programs, write programs in Ladder logic and other PLC languages, and create supervisory control applications (SCADA) for data collection and dashboards (Bernhardt, 2021).

7. CONCLUSION AND OUTLOOK

The fundamental objective of this research is to design an automated weighing and bagging machine that avoids all the risks and problems associated with manual weighing, such as reading uncertainty, low profitability and poor management of time and staff.

In this work, we introduce the hardware components of the proposed system and describe its operation, which leads us to program and automate the model. The S7-1200 PLC was chosen to control this machine. An HMI monitoring interface was developed using Win CC SCADA software to control and monitor the proposed machine. PLC-based SCADA systems make it possible to simulate programs and visualize system evolution in real-time.

In the future, we plan to use the IOT module to apply the designed SCADA system to Industry 4.0. As a result, users will be able to receive alerts, trends, alarms and notifications about system performance on their mobile screens.

ACKNOWLEDGMENTS

We gratefully acknowledge ALMES Staff for their support, notably M. Anouar Ben Mouhamed, Maintenance Manager, M. Chouaib Jmili, Technical Manager, and Mrs. Zohra Ferchichi, Human Resources Manager. We wish to express our humble gratitude to the SYSCOM ENIT members for their help and assistance.

REFERENCES

Abdulwahid, M. M. and Mohammed Wasel, N. B. (2020). Design and Implementation of Water Level Tank Model by using SCADA System. *Informatica: Journal of Applied Machines Electrical Electronics Computer Science*, 1(1): 63-96, https://doi.org/10.47812/ijamecs2010109.

Agarwal, T. and Fatima, Z. (2002). Master Station Architecture of a SCADA System. *IETE Journal of Education*, 43(3): 121-126, https://doi.org/10.1080/09747338.2002.11415771.

Aghenta, L. O. and Iqbal, M. T. (2020). Design and implementation of a low-cost, open source IoT-based SCADA system using ESP32 with OLED, ThingsBoard and MQTT protocol. *AIMS Electronics and Electrical Engineering*, 4(1): 57-86. DOI: https://doi.org/10.3934/ElectrEng.2020.1.57.

Amditis, A., Andreone, L., Pagle, K., Markkula, G., Deregibus, E., Rue, M.R., Bellotti, F., Engelsberg, A., Brouwer, R., Peters, B., and De Gloria, A. (2010). Towards the Automotive HMI of the Future: Overview of the AIDE-Integrated Project Result. *IEEE Transactions on Intelligent Transportation Systems*, 11(3): 567-578. DOI: https://doi.org/10.1109/ TITS.2010.2048751.

Antonsen, T. M. (2021). *PLC Controls with Ladder Diagram, Books on Demand*, Denmark.

Barz, C., Deaconu, S.I., Latinovic, T., and Berdie, A. D. (2015). PLCs used in smart home control. *International Conference on Applied Sciences (ICAS)*, https://doi.org/10.1088/1757-899X/106/1/012036.

Bejan, C. A., Iacob, M., and Andreescu, G. D. (2009) SCADA automation system laboratory, elements and applications. *7th IEEE International Symposium on Intelligent Systems and Informatics*. DOI: https://doi.org/10.1109/SISY.2009.5291169.
Bernhardt, J. (2021). *PLC Programming with the Raspberry Pi and the OpenPLC Project, Elector Books*.

Bin Mofidul, R., Sabbir, M. S. H., Podder, A. K., and Rahman, M. S. (2019). Design and Implementation of Remote Controlling and Monitoring System for Automatic PLC Based Packaging Industry. *1st International Conference on Advances in Science, Engineering and Robotics Technology*. DOI: https://doi.org/10.1109/ICASERT.2019.8934779.

Cai, B., Liu, Y., Liu, Z., Wang, F., Tian, X., and Zhang, Y. (2011). Development of an automatic subsea blowout preventer stack control system using PLC-based SCADA. *ISA Transactions*, 51(1): 198-207. DOI: https://doi.org/ 10.1016/j.isatra.2011.08.003.

Chakraborty, K., Choudhury, M. G., Das, S., and Paul, S. (2020). Development of PLC-SCADA based control strategy for water storage in a tank for a semi-automated plant. *Journal of Instrumentation*, JINST 15 T04007, https://doi.org/10.1088/1748-0221/15/04/T04007.

Dutta, S., Sarkar, A., Samanta, K., Das, R., and Ghosh, A. (2014). Supervision of Control Valve Characteristics Using PLC and Creation of HMI by SCADA, *IEEE First International Conference on Automation, Control, Energy and Systems (ACES*): DOI: https://doi.org/10.1109/ACES.2014.6808025.

Mărgineanu, I. (2005). Automate Programabile, *Ed. Albastră, Bucharest*, Romania.

Mich P. A. S. and Surarapu, P. K. (2017). PLC-HMI Based automatic screen printing system. *International Journal of Mechanical Engineering and Technology (IJMET*): 8(10): 101-107. Retrieved from: https://iaeme.com/Home/ article_id/IJMET_08_10_013.
Normanyo, E., Husinu, F., and Agyare, O. R. (2014). Developing a Human Machine Interface (HMI) for Industrial Automated Systems using Siemens SimaticWinCC Flexible Advanced Software. *Journal of Emerging Trends in Computing and Information Sciences,* 5(2): 134-144.

Ponsa, P., Vilanova, R., and Perez, A. (2010). SCADA Design in Automation Systems. *3rd IEEE International Conference on Human System Interaction*. DOI: https://doi.org/10.1109/HSI.2010.5514492.

Poosapati, V. R., Katneni, V., and Manda, V. K. (2018). Super SCADA systems: a prototype for next gen SCADA system. *IAETSD Journal for Advanced Research in Applied Sciences*, 5(3): 107-115. Retrieved from: http://iaetsdjaras.org/gallery/18-march-559.pdf.

Salih, H., Abdelwahab, H., and Abdallah. A. (2017). Automation Design for a Syrup Production Line Using Siemens PLC S7-1200 and TIA Portal Software. *IEEE International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE*): DOI: https://doi.org/10.1109/ICCCCEE.2017.7866702.

SIEMENS, AG. (2020). *SIMATIC HMI WinCC Unifed Getting Started*, *SIEMENS*, Germany.

Thomas, M. S., Kumar, P., and Chandna, V.K. (2004). Design, Development, and Commissioning of a Supervisory Control and Data Acquisition (SCADA) Laboratory for Research and Training. *IEEE Transactions on Power Systems*, 19(3): 1582 – 1588. DOI: https://doi.org/10.1109/TPWRS.2004.826770.

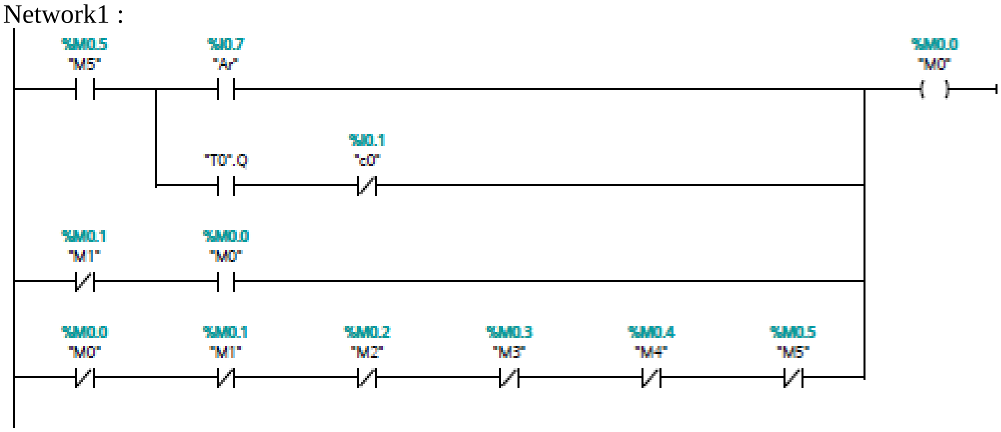
Tomar, B. and Kumar, N. (2020). PLC and SCADA based Industrial Automated System. *IEEE International Conference for Innovation in Technology*. DOI: https://doi.org/10.1109/INOCON50539.2020.9298190.

Webb, J. W. and Reis, R. A. (2015). *Programmable logic controllers*, Pearson India, 5th ed. edition.

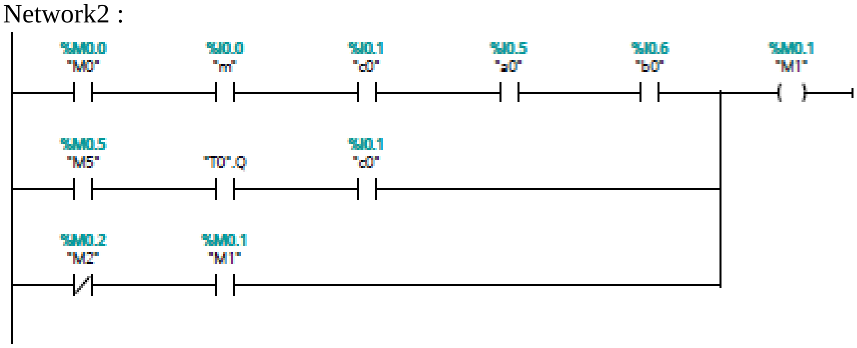
Younas, U., Durrani, S., and Mehmood, Y. (2015). Designing Human Machine Interface for Vehicle's EFI Engine using Siemen's PLC and SCADA System. *13th IEEE International Conference on Frontiers of Information Technology*. DOI: https://doi.org/10.1109/FIT.2015.44.

APPENDIX A – Ladder Program

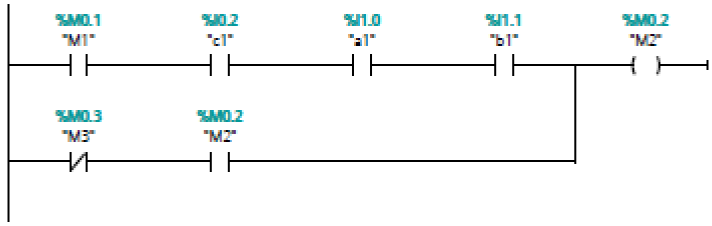
The Ladder logic program implemented in the PLC S-1200 is shown in the following networks:
Network1 :



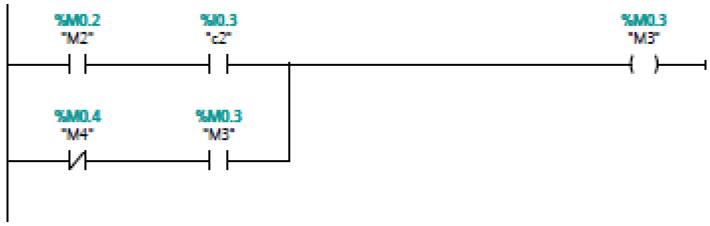
Network2 :



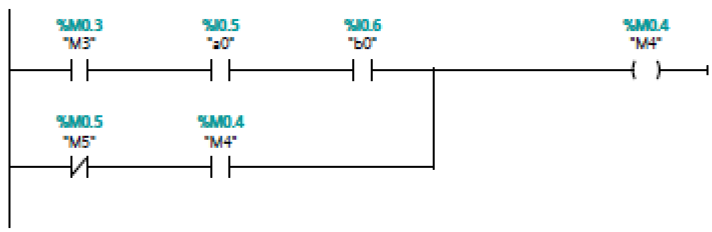
Network3 :



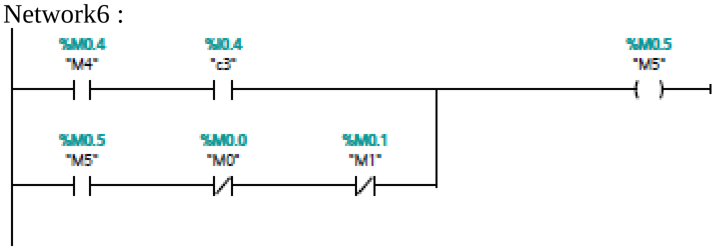
Network4 :



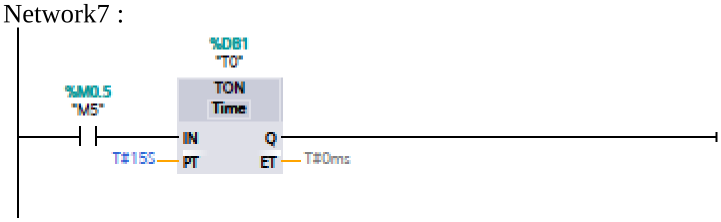
Network5 :



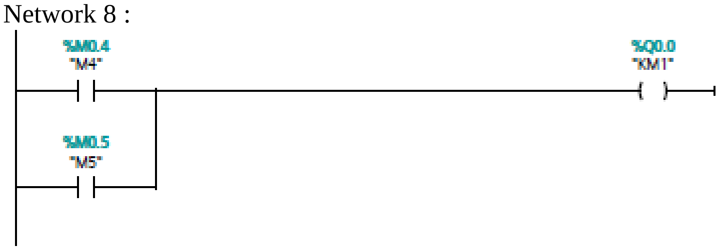
Network6 :



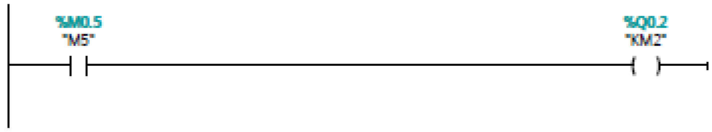
Network7 :



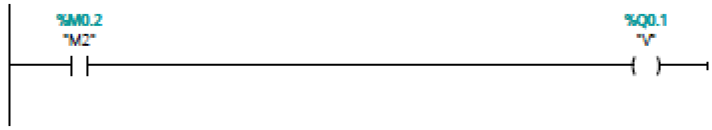
Network 8 :



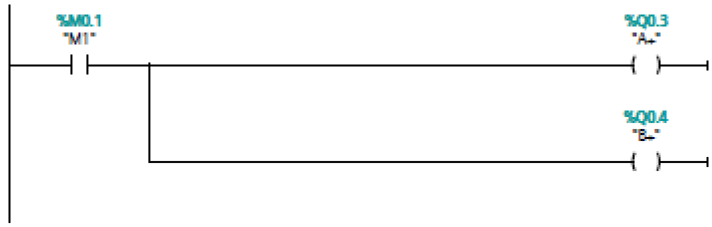
Network9 :



Network 10 :



Network 11 :



Network 12: