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Design of Control System for Concrete Machine based on PLC and HMI

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تصميم نظام التحكم لآلة الخرسانة على أساس PLC وHMI

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الملخص
تعتبر الخرسانة العمود الفقري للبناء والبنية التحتية. يتم استخدامها على نطاق واسع في المنشآت الصناعية والبنية التحتية المدنية ومحطات معالجة مياه الصرف الصحي وخطوط الانابيب ويتم استخدامه في العديد من المجالات الأخرى. الخرسانة هي عبارة عن خليط متجانس من الإسمنت والرمل والماء والركام الخشن. يتم خلط المكونات الأربعة بنسب مختلفة للحصول على فئات مختلفة من الخرسانة. خلاطات الخرسانة هي الأجهزة المسؤولة عن إنشاء هذه الخلطات. حيث تضمن تناسق الخليط وتضمن ايضا استيفاء المواصفات المطلوبة في عملية ثابتة وموثوقة. الهدف من هذه الورقة هو تصميم وتنفيذ خلاطة خرسانة آلية العمل، يمكنها إنتاج خلطات خرسانية مختلفة حسب الإعدادات المحددة من المستخدم. يستخدم المشروع المتحكم المنطقي القابل للبرمجة (PLC) وشاشة العرض والتشغيل (HMI) وحساسات كهربائية وصمامات ومفاتيح تحكم. الورقة تستخدم أيضا برمجيات ونُظُم تسمح للمستخدم برمجة وتعديل الاجهزة الخاصة بالمشروع وإمكانية التحكم بها. ويضمن استخدام هذه المعدات والأدوات أن يتمكن المستخدم من تشغيل آلي بالكامل للمعدة دون الحاجة للعمالة البشرية ويضمن أيضا الوصول الى درجة عالية من الدقة.
الكلمات المفتاحية: خلاطة الخرسانة، المتحكم المنطقي القابل للبرمجة، شاشة العرض والتشغيل، البرمجة.

Abstract
Concrete is the backbone of construction and infrastructures. It is widely used in industrial plants, civil infrastructures, wastewater treatment plants, and it is used among many other fields. Concrete is a homogeneous mixture of cement, sand, water and coarse aggregates. Concrete mixers are the machines responsible for mixing the four components in different proportions to obtain various classes of concrete. They ensure the consistency of the mixture and guarantee that the desired specifications are met in a steady and reliable process operation. The objective of the paper is to design and implement an automated concrete mixer that can produce different concrete types depending on the operator settings. The paper uses Programmable Logic Controller (PLC), Human Interface Machine (HMI), measuring sensors, actuators and control switches. The paper also uses software programs and logics that allow the user to program and control the hardware parts. The use of these equipment and tools ensures that the user can achieve a completely automated operation that is free of human labor and to reach a high degree of accuracy.
Keywords: Concrete mixer, PLC, HMI, Programming.

1- Introduction

Concrete is a fundamental construction material, crucial for the development of infrastructure and buildings. Over the years, the construction industry has witnessed significant advancements, and one notable area of innovation is the automation of concrete mixing processes. Automated concrete mixers represent a paradigm shift in how we approach the production of concrete, offering increased efficiency and precision. The conventional approaches to concrete mixing, predominantly reliant on manual labor, inherently introduce variations in mixing ratios and quality. These variations, however subtle, can have cascading effects on the structural integrity and longevity of constructions. The industry's persistent quest for consistently high-quality concrete structures necessitates a departure from these conventional practices. The recognition of this imperative challenge becomes the driving force behind the exploration of automated solutions, poised to redefine the concrete mixing paradigm. The primary aim of the paper is to explore and implement automated solutions for concrete mixing. By doing so, the following advantages can be carried out:

- Improve the efficiency of the concrete mixing process.
- Enhance the consistency and quality of the concrete produced.
- Evaluate the feasibility and benefits of automated concrete mixers in real-world construction scenarios.

This paper focuses on the development and implementation of automated systems to control concrete mixing processes. It will encompass the design, testing, and optimization. However, considerations will be made for adaptability to various scales of construction projects.

2- Significance of the Study

At the heart of this study lies its profound significance, with the potential to reshape concrete production methodologies and revolutionize the construction landscape. Automated concrete mixers emerge as a transformative force capable of streamlining construction processes, mitigating human errors, and substantially enhancing the overall quality and durability of concrete structures.

The paper aligns with the industry's dynamic needs, contributing to the ongoing modernization of construction practices and fostering sustainable innovation in the built environment.

3- PLC and HMI Combination

Nowadays, it is pretty impossible to imagine an automation system utilized to control and monitor some processes without PLC (Programmable Logic Controller) or some other microcontroller-based device [1].

If studying deeper into automation technology, as shown in Figure 1, PLCs are the basis for all other complex control systems specialized in different fields. The paper is dedicated to explaining PLCs, their operation, and all the benefits that have made them widely applicable and utilized in almost all modern industrial automation and control systems [2].

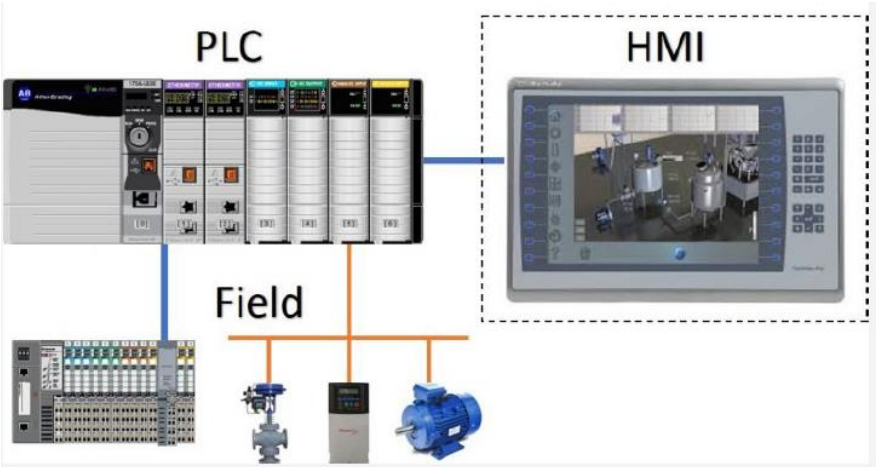

Figure 1: Typical PLC and HMI Control System.

4- PLC Architecture

All benefits provided by using PLC in process automation are directly driven by PLC's flexibility, modularity, and specific Central Processing Unit architecture (CPU) combined with a specific CPU's operating principle (see Figure 2). The modularity of PLC is expressed through different modules in charge of various significant tasks: Input/output (I/O) modules, communication modules, and the CPU mentioned above [1].

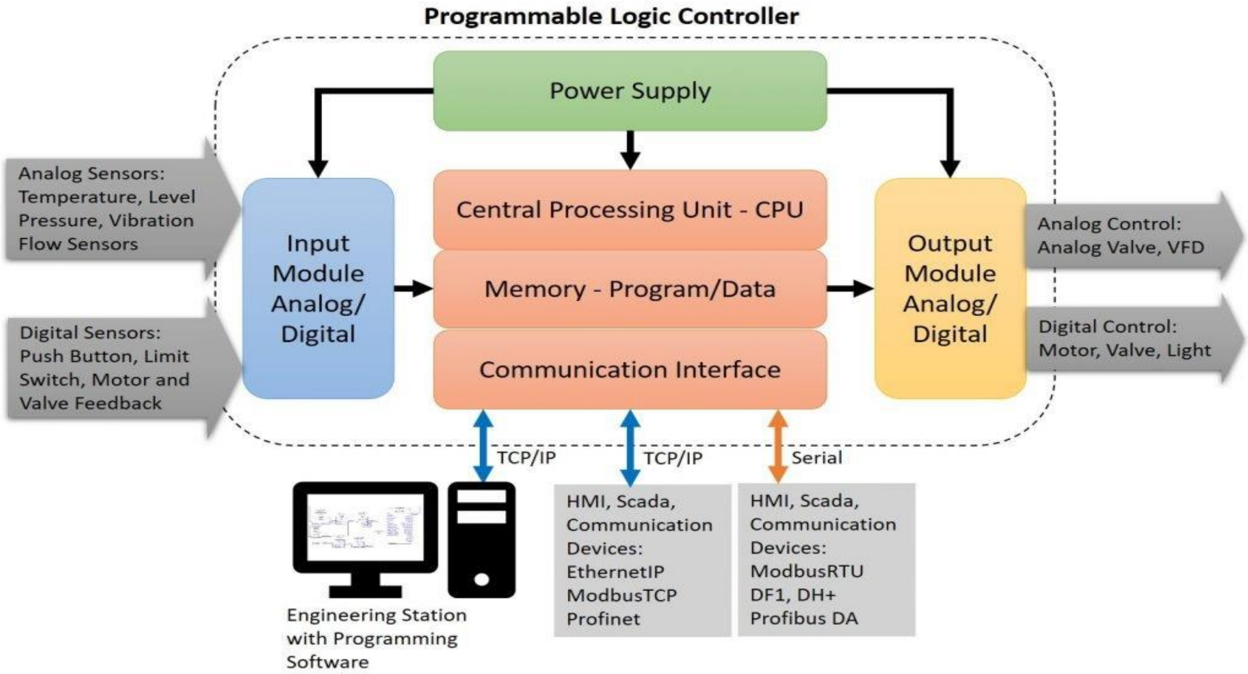

Figure 2: PLC Architecture Block Diagram.

5- PLC Scan Cycle

The main difference between PLC and some ordinary PC is in the CPU. CPU in PLC is designed to tackle specific tasks by cyclic repetition-defined command sequences in very short periods. Compared to the other microcontrollers, the PLC is characterized by a unique operating system running on a CPU. This operating system, specially designed to run cyclic commands in very short periods, is called Scan Cycle as shown in Figure 3 [1].

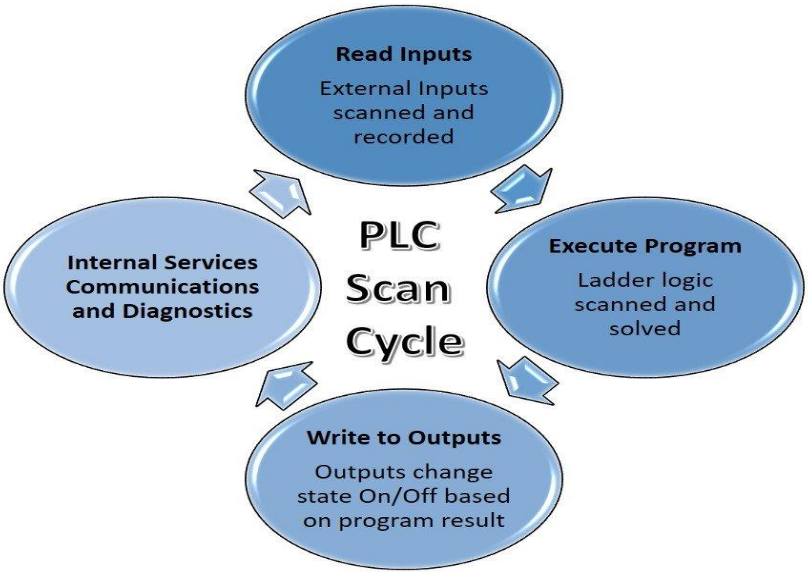

Figure 3: PLC Scan Cycle.

6- Definition of HMI

Human-Machine Interface (HMI) is a means of communication between humans and machines, allowing them to interact with each other. In industrial automation, HMI refers to the visual and interactive elements used to control and monitor machines and processes. HMI systems consist of hardware and software components, including touch screens, displays, input devices, and software applications [2].

7- Components of HMI

HMI systems consist of various components, including [2]:

- Touch screens and displays: These components provide the user interface for interacting with the machines and processes.
- Input devices: Input devices, such as keyboards, mice, and keypads, allow users to input commands and data into the system.
- Software applications: HMI software applications provide the programming and control functions necessary to operate the machines and processes.
- Sensors and actuators: These components provide the data and feedback necessary for the HMI system to monitor and control the machines and processes.

8- The Importance of HMI in Industrial Automation

The importance of HMI in industrial automation cannot be overstated. Some of the key benefits of HMI include [2]:

- Increased productivity: HMI systems make it easier for workers to operate and monitor machines, leading to increased productivity and efficiency.
- Improved safety: HMI systems can provide real-time data and feedback on machines and processes, allowing workers to identify and resolve safety issues quickly.
- Enhanced control: HMI systems provide precise control over machines and processes, allowing manufacturers to optimize production and reduce waste.
- Increased flexibility: HMI systems can be programmed to adapt to changes in the manufacturing process or to new products, allowing for greater flexibility in production.

9- Practical Implementation

The practical implementation depends on the hardware components and the software packages of PLC and HMI. The goal is to build an automated cement mixer using PLC and HMI. The mixer would be able to automatically create a batch of the desired concrete mix, set by the operator, and rely on the sensors' readings to get the necessary quantities from water, sand, gravel, and cement to establish the desired values and meet the required standards.

10- The Hardware Components

The hardware section will give a brief description of every component used and how they were used in the construction of the final work. For detailed information of the used components, refer to the datasheets in the appendices section. This section will also illustrate the wiring diagram and the principle of operation of the system. The followings components are used:

- **Siemens SIMATIC S7-200 PLC**

  The S7-200 series is a line of micro-programmable logic controllers that can control a variety of automation applications. Compact design, low cost and a powerful instruction set make the S7-200 a perfect solution for controlling small applications as illustrated in Figure 4. The wide variety of S7-200 models and the Windows-based programming tool give you the flexibility you need to solve your automation problems.

Figure 4: Siemens SIMATIC S7-200 PLC.

- **Delta DOP-107WV**

  It's a touch panel HMI platform that permits interaction between users and automation equipment. It provides various communication ports for fast communication and convenient control of a diverse range of machines, systems and facilities. The colored touch screen enables intuitive parameter entry and variety of ways to display variable data, including trend graphs and alarm elements. It's operable via USB port and serial COM port (see Figure 5).

Figure 5: Delta DOP-107WV.

- **Drok Adjustable Signal Generator**

  Figure 6 shows the signal generator used. It operates on 15-24V DC and it can generate a 4-20 mA current signal as well as 0-10V signal which are controlled by a rotary knob and it's displayed on a four-digit display. This signal is often used to simulate the readings coming from a sensor. It can also be used for devices adjustment, inverter control, PLC and panel debugging and to simulate the output of a transmitter.

Figure 6: Drok Adjustable Signal Generator**.**

- **Block Diagram of Control System for the Concrete Machine**

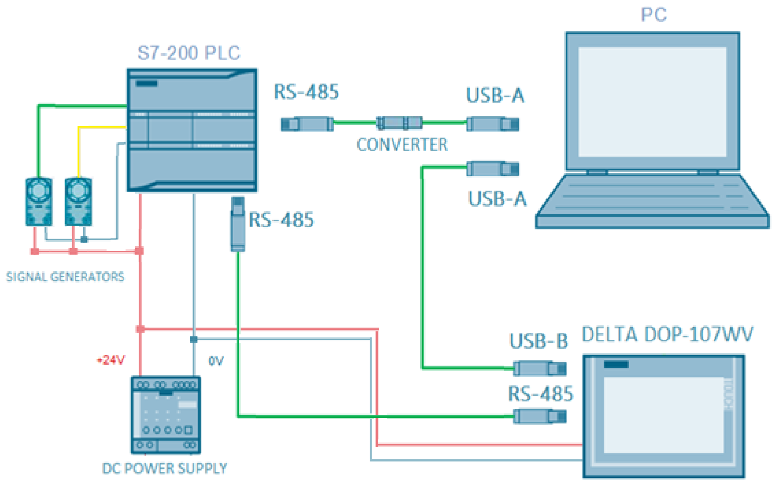

Figure 7: Block diagram of the control system.

Figure 7 illustrates a simplified block diagram of the hardware parts installation and connections of the project. The DC power supply converts 220 V_{AC} into regulated 24 V_{DC} that powers both the PLC and the DOP HMI screen. It's also used to power the two signal generators. The DELTA DOP-107WV is wired to the PC via USB-B to USB-A cable in a master / slave configuration. In such manner the PC acts as the (master) main controller and initiates commands to the DELTA screen (slave) and allow the user to change, edit and configure the software while the DELTA screen responds and executes commands accordingly and acts as a communication hub. The SIMATIC S7-200 PLC is connected to the DELTA DOP-107WV via RS-485 serial communication cable. It's also wired to the PC via the other RS-485 port using an adapter to convert from RS-485 into USB-A cable.

The two signal generators are connected to the PLC input module. They are set to give output voltage signal to mimic inputs coming from load cells.

11- The PLC Software Logics

In this paper, the PLC software logics is programed to control the machineries and create an error free execution sequence by utilizing conditional functions, interlock functions as well as counters and timers.

For the full software logics in Ladder Diagram and Function Blocks Diagram refer to Appendices E and F. Nevertheless, figure 8 demonstrates an algorithm that explains the PLC software logics in a less complex fashion. As the operator starts the program, then inserts the desired concrete mix, either C15 or C25. Afterwards he sets the production quantity. Consequently, the PLC makes internal calculations based on the previously chosen variables and give instruction to the ingredient inlet valves to open. These valves are Cement Valve 1, Sand Valve 1, Gravel Valve 1 and Water Valve1.While the aforementioned valves are open, the PLC keeps monitoring the quantity of their designated vessels by reading the data from load cells installed in every one of their vessels. Once any of the vessels is filled with the right amount of quantity it gets a signal from the PLC to close its inlet ingredient valve. After the four vessels are properly filled and the PLC sent signals to closet the four inlet ingredient valves then it sends signal to open the secondary valves to fill the main reservoir. These secondary valves are Cement Valve 2, Sand Valve 2, Gravel Valve 2 and Water Valve 2.The main reservoir also has a load cell that the PLC monitors its data and compare it to a calculated set point to ensure it is filled with the desired amount. After the main reservoir is properly filled and the set point is reached, the PLC then sends signal to closer the four secondary valves and start the mixing motor. The mixing motor will operate for a set amount of time calculated by the PLC. When the set time has passed, the mixer motor will stop and the PLC will send signal to open the concrete outlet valve for the mix to flow.

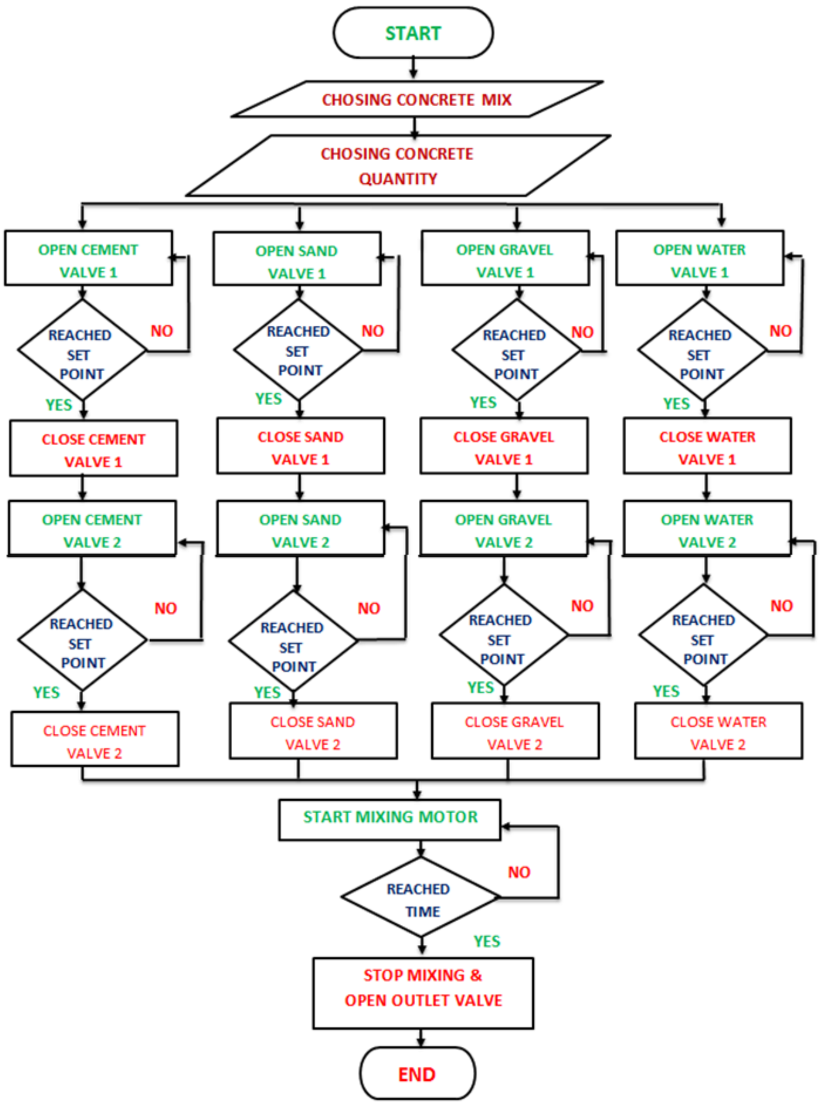

Figure 8: Algorithm of the PLC Software Logics.

12- DOP Soft

The HMI programming software used to design user interfaces that are compatible with Delta HMI hardware. Its ample features and responsive interface make it convenient and intuitive for users. DOP Soft is developed to run on windows-based computers and it's compatible with over twenty brands of programmable logic controllers.

The paper uses the DOP Soft for programing the HMI to be compatible with the PLC software logics, solenoid valves, and digital and analog I/O instruments.

13- The HMI Screen

Figure 9 illustrates the user's HMI screen designed by the DOP Soft which portrays the hardware parts that could only be simulated.

As seen there are four inlet valves. One for each of the ingredients such as cement, sand, gravel and, water. Consequently, there are four drums for each of the aforementioned ingredients with load cell for each of the drums. The four drums discharge their content to a main reservoir where the mixing motor and the outlet valve are installed. There's a fifth load sell installed to the main reservoir that measure the total weight of the mix.

The control panel consists of quantity, concrete types, and the basic operation pushbuttons which are ON, OFF and RESET as well as an indication lamp.

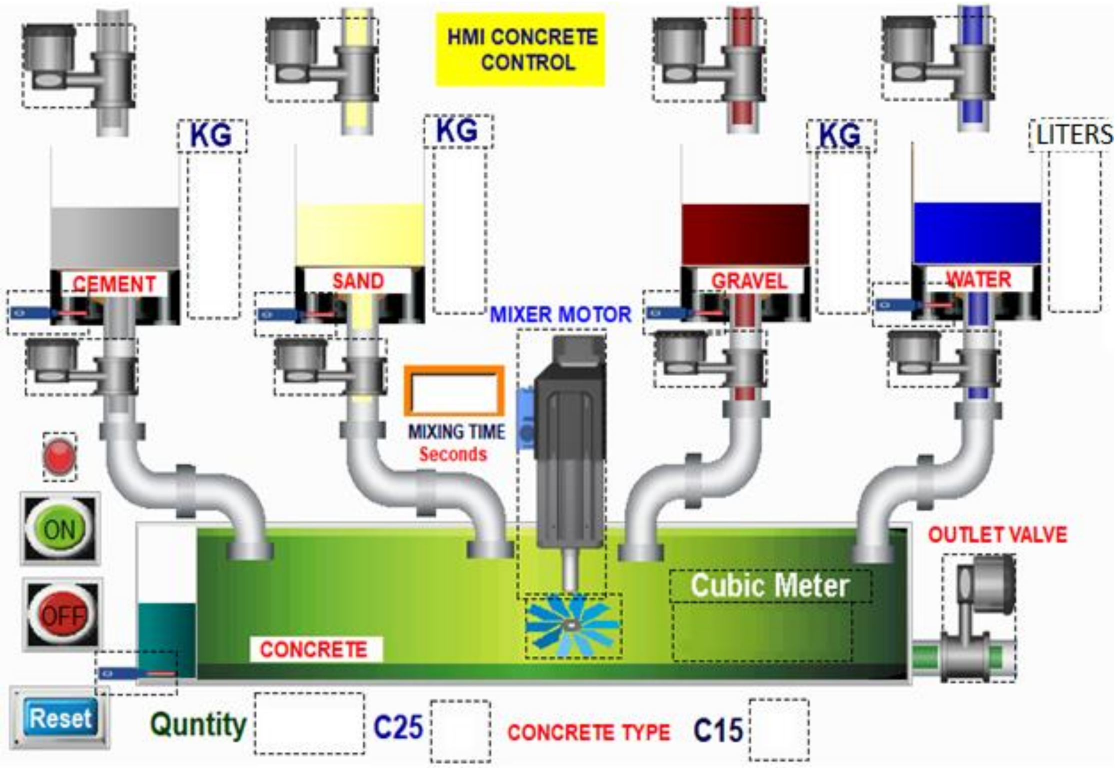

Figure 9: DOP Soft HMI Screen.

The operator can monitor the contents of the drums during operation in real time via a numerical field on the side of each one. The numerical indicator of the main reservoir is located on its bottom right. The mixing time is also indicated in a numerical box located in the center of the HMI screen. On the bottom of the screen there are three numerical fields, one is for the quantity of the mix and the remaining two are to determine the mix type.

14- Operation Process of the HMI Screen

Initially, operator clicks on the start button, (ON), on the Delta DOP-107WV screen. Afterwards, the operator choses the desired mix, either C25 or C15, and inserts the desired quantity in cubic meters via the delta screen by typing in the numerical field besides the designated mix symbols. The DOP Soft decodes this input signal and communicates with the SIMATIC S7-200 PLC to make the necessary calculations and determine the required quantities of the ingredients to achieve the desired quantity according to the chosen mix.

The PLC then sends output signals to the DOP screen to control the timing of the inlet valves to allow them to open for the right amount of time to fill the drums with required quantity. The inlet valves will open and close in concurrently. The drums will then empty their contents based on the readings determined by the load cells.

Once the main reservoir is filled accurately with the right amount of ingredients, the PLC will send the start signal to the mixer motor and start mixing the concrete for a calculated amount of time based on the type of mix and the quantity needed. After mixing for the time period set by the PLC is done, the outlet valve will open to allow the concrete flow.

The operator can stop the process at any given moment by pressing the shutdown button, (OFF), which will halt the operation of the process. The operator can also clear all the set values and calculations by simply pressing the (RESET) button.

15- Prototype of the Control System

Figure 10 demonstrates the practical implementation of the system which yielded The Automated Concrete Machine Using PLC and HMI Control System. The HMI screen Delta DOP-107WV is located on a panel in the middle of the bench while the PLC and both of the signal generators are positioned on surface of the bench. The wiring of the devices has undergone some neat management that lead to having the cables run below the table where the power supply is installed. One of the signal generators is used to simulate the quantity of the concrete in the main reservoir, and the second one is used for the load cell sensors for measuring the quantities of cement, sand, gravel and water.

Figure 10: The Automated Concrete Machine Using PLC and HMI Control System

16- Conclusion

Based on the integration between PLC and HMI, the concrete machines can be programmed to work autonomously with high efficiency. The operator can easily automatically operate the machine by choosing the concrete types and quaintly. Moreover, monitoring the measured values, mixing time, and indications.

The process starts by switching on the PC, the Delta DOPSoft of HMI's software, and the PLC that is communicated with the HMI touch screen in order to controlling the machine properly including automatic reading the input signals, analyzing, and executing the program.

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