

Design and Implementation of a PLC- Based Disinfecting Doorway

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Abstract - Extensive scientific research has demonstrated that the maintenance of proper hygiene plays a crucial role in the prevention of diseases. In particular, the process of disinfection has become increasingly important in the context of highly transmissible and contagious illnesses. The task of disinfecting an individual's entire body and personal belongings can be labor-intensive and exhausting. To address this challenge, an automated disinfection model based on a Programmable Logic Controller (PLC) has been developed and implemented, enhancing the efficiency and ease of full-body disinfection compared to traditional manual methods. This model has been installed at the entrance of the Robotics and Automation Laboratory within the Mechatronics Engineering building at the Federal University of Agriculture, Abeokuta (FUNAAB). It operates by spraying a disinfectant solution, stored in a tank, through an array of misting nozzles directed at detected objects for a duration of five seconds. The system utilizes a Relay type PLC, programmed with GX Developer software, which activates upon receiving a signal from a mounted photoelectric sensor that detects an individual approaching the entrance. This triggers the diaphragm pump to dispense the disinfectant from a 5-liter storage tank through a hose to the overhead misting nozzle array for the predetermined time. This disinfection model minimizes the need for human involvement, streamlining the disinfection process while ensuring the appropriate quantity of disinfectant is applied.

Keywords: *Diseases; Disinfection; GX Developer; Photoelectric sensor; PLC.*

I. INTRODUCTION

Since the early 20th century, the implementation of comprehensive sanitation and public health principles has led to a remarkable increase in life expectancy, exceeding 30 years, while also enhancing the overall

quality of life [1]. However, there has been a notable rise in new risk factors associated with infectious diseases, even within developed countries. These risk factors are attributed to the emergence of novel pathogens, the proliferation of antibiotic-resistant microorganisms, demographic shifts, an increase in ambulatory and home care services, socioeconomic and environmental changes, technological advancements, global food distribution networks, and evolving human behaviors that reflect a diminished awareness of microbial threats. The global emergence of these challenges highlights the urgent necessity for a renewed commitment to a comprehensive approach to hygiene and public health [1].

Hygiene has been analyzed from multiple perspectives, including historical contexts and the behaviors exhibited by various species, including humans, to mitigate infection risks [2]. Recent developments have emphasized the critical importance of emphasizing "prevention through hygiene" as a core element of infection control strategies [3]. Furthermore, hygiene practices are increasingly integrated with electronic systems to enhance the precision and efficiency of automated detection and spraying technologies.

Automated systems have been utilized in production lines and machinery for an extensive period. The primary objective of integrating these systems is to accelerate processes, thereby improving overall efficiency. Such systems are capable of managing a variety of tasks that are either time-intensive or cumbersome. Essential components for their effective operation include a control system, mechanisms for data interpretation and distribution, and a human-machine interface. The application of

programmable logic facilitates data processing and the regulation of output devices [4].

The avian influenza outbreak in mid-June 2006 led to the death of approximately 890,000 birds due to mortality and culling efforts. With an average market price of around N700 per bird, the estimated total farm gate value of the lost birds reached approximately N617 million (equivalent to US\$4.8 million). These figures are based on official estimates and are believed to be conservative, as the actual impact on the poultry population in rural areas remains inadequately documented [5].

The outbreak of Ebola Virus Disease significantly affected ten countries across three continents, resulting in over 11,300 fatalities and more than 28,000 infections [6]. The first confirmed case of Ebola Virus Disease in Lagos on July 23, 2014, incited widespread fear among millions of Nigerians. On that same day, the Federal Ministry of Health, in collaboration with the Nigeria Centre for Disease Control (NCDC), declared a state of emergency in response to the Ebola outbreak in Nigeria.

The COVID-19 pandemic has had a profound global impact, influencing countless individuals across the globe. Researchers have prioritized efforts to mitigate the transmission of this ongoing pandemic. The primary mode of transmission of the virus occurs through direct contact between individuals, facilitated by respiratory droplets expelled from the mouth and nose, as well as through contact with contaminated surfaces [7].

Inadequate hygiene practices can exacerbate the infection rates during this crisis. Research indicates that the virus can persist on various surfaces for different lengths of time: it can remain viable in aerosols for up to three hours, on copper surfaces for up to four hours, on steel and plastic for as long as three days, and on cardboard for up to twenty-four hours [8]. This underscores the critical need for effective disinfection strategies to curb the swift transmission of the virus via surfaces and airborne particles.

Employing robust disinfection techniques for both surfaces and air can play a vital role in early containment and in preventing further spread. A 0.1% sodium hypochlorite solution has been demonstrated to neutralize the COVID-19 virus within one minute [9]. Furthermore, elevated temperatures and humidity levels have been found to diminish the transmission of the coronavirus [10]. The implementation of 'social distancing' measures has emerged as an effective tactic to decelerate the virus's spread; however, adhering to these measures in public settings can prove difficult.

Consequently, it is imperative to adopt necessary precautions in the fight against the virus. As the economy begins to stabilize, establishing a

disinfection protocol in public areas is crucial to interrupt the transmission chain, irrespective of individual hygiene practices.

An automated disinfection system is capable of conducting contactless disinfection of external surfaces. This method is essential to prevent the potential spread of infections that may occur due to contamination of the disinfecting vessel's surface. Automated disinfection serves as a strategic approach to facilitate and regulate the movement of individuals following the systematic lifting of lockdown measures. The automated disinfection gateway, developed by the Sree Chitra Tirunal Institute for Medical Sciences and Technology (MST) in Trivandrum, functions autonomously to eradicate viruses from the external surfaces of individuals.

In their design, [11] integrated two separate processes: the application of hydrogen peroxide fog for body disinfection and the utilization of ultraviolet (UV) light for sterilization. The choice of UV radiation wavelength is critically important, as an incorrect selection could endanger human health and bodily tissues. The PLC-based automated disinfection model features a chamber that automatically detects an approaching object using an infrared sensor and dispenses a disinfecting solution through a misting nozzle array. The entire system was integrated and tested to evaluate its effectiveness in real operational environments.

In this configuration, the tank was placed at ground level, while the pump was positioned above the tank, connected to the electrical components via a short length of wiring linked to the main power source. Furthermore, the model included two misting nozzles and a photoelectric sensor without a reflector. The testing process was conducted in phases. The disinfecting solution utilized is an alcohol-based disinfectant that has received approval from health organizations, including the World Health Organization (WHO). This method is effective in significantly reducing viral contamination on clothing, skin, and any other exposed body surfaces that require disinfection.

II. LITERATURE REVIEW

In [12] introduced a portable kiosk model named COVSACK, which seeks to diminish the dependence on personal protective equipment (PPE) among healthcare workers while concurrently lowering their infection risk through reduced patient interaction. Following the collection of a patient sample, both the patient and the kiosk's interior are subjected to a sanitization procedure that includes the application of disinfectant followed by a water rinse for cleaning purposes. However, the study does not specify whether this sanitization process is automated and

devoid of physical contact. [13] proposed a system aimed at maintaining social distancing measures within the context of smart city frameworks. Nonetheless, the research primarily presents a conceptual proposal and future directions without providing specific implementations, such as disinfection tunnels or other solutions, to protect the community from external pathogens.

In [14] recommended a two-chamber disinfection tunnel system designed to shield society from external contaminants. In the initial chamber, a disinfectant solution—comprising either a diluted formulation of approved chemicals or an Ayurvedic/herbal alternative—is sprayed on individuals. The subsequent chamber subjects the individual to hot air at a temperature of 70 °C, in conjunction with far-ultraviolet C rays (207–222 nm).

Additionally, [15] examined the operational autonomy of both chambers through the use of ultrasonic sensors for individual detection. However, the design of the second chamber does not accommodate individuals with health issues. The study also presents the COVID-19 WT screening centre, outlining its overall concept, advantages, and limitations. The WT centre improves patient access to screening services, ensures adequate protection for healthcare personnel, and reduces the need for personal protective equipment. Furthermore, it has the potential to increase the number of individuals tested by a factor of 9 to 10.

The study examines the challenges faced at testing facilities, particularly the potential for cross-infection during different phases of the screening process, including within the testing booths, alongside negative effects associated with the disinfection of these booths. Proposed solutions to mitigate these issues include the integration of mobile technology, the expansion of booth availability to reduce crowding, the minimization of booth dimensions to enhance airflow, and the utilization of a safe and effective environmental disinfectant. Nonetheless, the research does not take into account the possibility of implementing a contactless automated disinfection system.

III. METHODOLOGY

The components used in the development of this research project consist of a photoelectric sensor featuring a retro-reflective configuration, a diaphragm pump, a programmable logic controller, a storage tank, mist nozzles, and a power supply unit. A block diagram of all the segments is shown in Fig. 1.

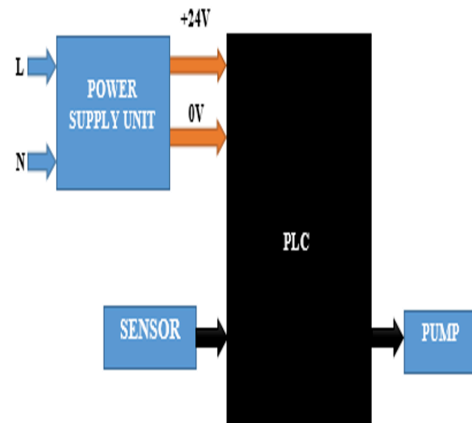


Fig. 1: Block Diagram of the PLC

A Photoelectric Sensors

In this research, a single photoelectric sensor is employed to detect the presence of an individual. This sensor is positioned at a height of one foot above the ground. A retroreflective configuration is implemented, wherein both the transmitter and receiver are housed together, utilizing a reflector to redirect the emitted light beam back to the receiver. The presence of a person is detected when the light beam is obstructed, preventing it from reaching the receiver. The reflector is strategically placed directly opposite the photoelectric sensor, thereby enhancing the sensing range of the device.

B Diaphragm Pump

Diaphragm pumps are extensively employed to create a high-pressure flow that is subsequently directed to nozzles, resulting in a fine mist spray within the disinfection system, as depicted in Fig. 2. These pumps are recognized for their capability to manage suction lifts with low pressure requirements. They are particularly adept at handling various materials, including abrasives, chemicals, concrete, effluents, gasoline, and diesel fuel, where leakage through packing is not permissible.



Fig. 2: Diaphragm pump

In addition, Diaphragm pumps are utilized across multiple sectors, such as hygiene, chemical processing, and industrial applications, and are regarded as one of the most prevalent types of

industrial pumps. Functioning on the principle of positive displacement, these pumps enable the transfer of liquids from one location to another. The design includes a chamber, diaphragm, and suction and discharge check valves, along with pistons linked to the diaphragm to propel hydraulic oil during the diaphragm's operation. Importantly, these pumps can function without liquid for a limited duration, and the pumping rate can be modified while in operation.

C Mist Spray Nozzles

In this project, three mist spray nozzles were employed to ensure that individuals receiving disinfection would not be excessively wet. These nozzles were strategically positioned above the entrance to the building, allowing for the effective application of the disinfecting solution to those entering. Each nozzle is connected to Tee-connectors, featuring an inlet and outlet port measuring 6 mm.

D Programmable Logic Controller (PLC)

The Programmable Logic Controller (PLC) is a specialized computing device designed for the automation of industrial processes, exhibiting reliable performance even under demanding industrial conditions. It can be customized to address the specific operational requirements of various processes through programming. A notable benefit of PLCs compared to traditional hard-wired control systems is their reprogrammability, allowing for adjustments as needed. They are capable of performing a variety of functions, such as timing, counting, comparing, calculating, and processing different analog signals [16]. The primary function of PLCs is to enable the electronic reconfiguration of hard-wired control panels, which would otherwise require the individual replacement of multiple relays. PLCs collect data from switches and sensors to efficiently manage and control a range of machines and devices. For this project, a JLING-20MR PLC was selected due to its portability, cost-effectiveness, and relay output ports, as illustrated in Fig. 3.

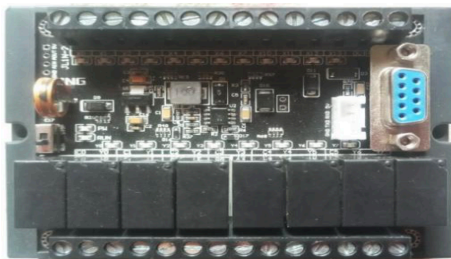


Figure 3: JLING JL1N-20MR PLC

In the execution of this project, a photoelectric sensor is connected to one of the input ports of the PLC

(specifically, X0), while the diaphragm pump is linked to the output port of the PLC (Y0). The PLC is responsible for the necessary switching and timing functions to automate the disinfecting doorway, as depicted in Fig. 4.

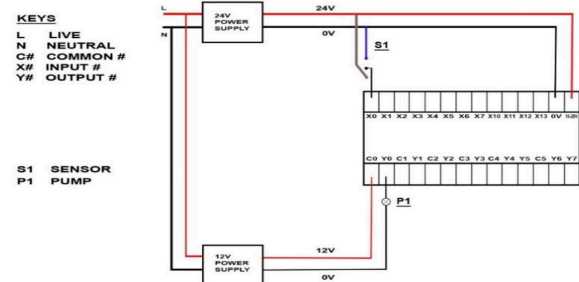


Figure 4: Connection of Electrical parts to the PLC

E Storage Tank

A clear and transparent plastic bucket with a lid is used to observe the level of disinfectant solution in it. It can store 5 litres of the disinfecting solution to be sprayed. The lid was bored to fit the hose that conveys the disinfectant from the storage tank to the pump inlet before the disinfectant is pumped out with higher pressure from the pump outlet around the misting nozzle array.

F Disinfectant

The disinfecting solution is an alcohol-based type. Materials required are Ethanol 96%, Hydrogen Peroxide 3%, Glycerin 98% and sterile distilled or boiled cold water. The quantity of the reagents for the formulation of 5 litres by W.H.O is shown in Table I

Table I: Reagents and amount for 5 L disinfectant preparation

S/N	REAGENT	AMOUNT
1	Ethanol 96%	3750ml
2	Hydrogen Peroxide 3%	200ml
3	Glycerin 98%	75ml
4	Sterile distilled or boiled cold water	Fill up the mixture to 5 Litre

G Flow rate mathematical calculations

Flow rate = Cross – sectional Area (A) X Average Velocity (V)
According to the equation of continuity for incompressible liquid,

$$Q_1 = Q_2 \quad (\text{eqn 1})$$

$$A_1 V_1 \quad (\text{eqn 2})$$

The pump flow rate (Q) is 5L/min

$$\text{Area} = \frac{\pi d^2}{4} \quad (\text{eqn 3})$$

$$\text{Taking } \pi = 3.14 \quad d_1 = 20\text{mm} = 0.02\text{m}$$

$$A_1 = \frac{3.14 \times 0.02^2}{4} = 1.256 \times 10^{-3} \text{m}^2$$

$$Q = Q_1 = A_1 V_1 \quad (\text{eqn 4})$$

$$Q = 5 \text{L/min} = 1.256 \times 10^{-3} V_1$$

$$\frac{0.005}{60} = 1.256 \times 10^{-3} V_1$$

$$V_1 = \frac{0.005}{60 \times 1.256 \times 10^{-3}} = 0.0663 \text{m/s} \quad (\text{at the pump})$$

$$d_2 = 6 \text{mm} = 0.006 \text{m}$$

$$A_2 = \frac{3.14 \times 0.006^2}{4} = 2.826 \times 10^{-5} \text{m}^2$$

$$Q = Q_2 = A_2 V_2 \quad (\text{eqn 5})$$

$$\frac{0.005}{60} = 2.826 \times 10^{-5} V_2$$

$$V_2 = \frac{0.005}{60 \times 2.826 \times 10^{-5}} = 2.949 \text{m/s} \quad (\text{at the nozzle})$$

The flow rate of spray from the nozzle

$$d_3 = 0.3 \text{mm} = 0.0003 \text{m}$$

$$A_3 = \frac{3.14 \times 0.0003^2}{4} = 7.065 \times 10^{-8} \text{m}^2$$

$$Q = Q_3 = A_3 V_3$$

$$\frac{0.005}{60} = 7.065 \times 10^{-8} V_3$$

$$V_3 = \frac{0.005}{60 \times 7.065 \times 10^{-8}} = 1180 \text{m/s}$$

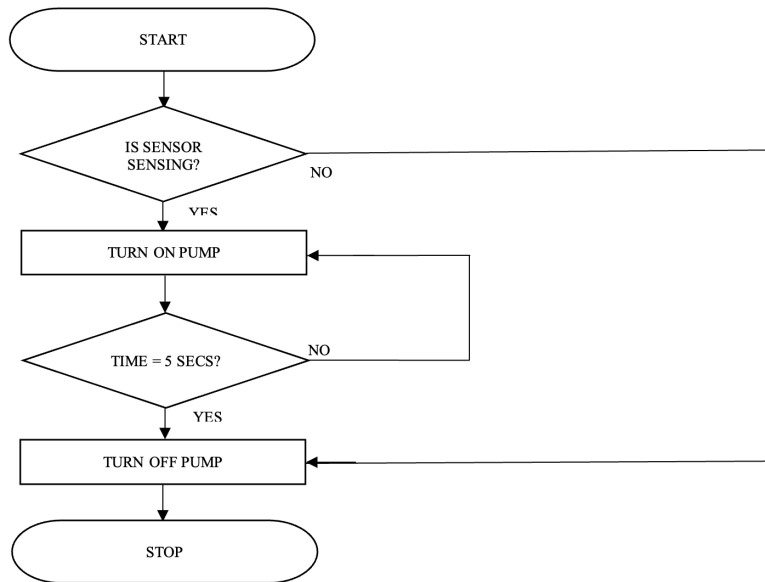


Fig. 5: Flow chart for developing the Ladder Logic program

The flow chart for developing the Ladder Logic diagram used in programming the PLC is shown in Figure 5, it was developed based on the operation of the system and the programmed time taken to disinfect.

H System Installation

The Photoelectric sensor was used together with the reflector which must be at the same line of sight to increase the range of the sensor. The Photoelectric sensor is encased in a plastic housing and mounted one foot above Ground level as shown in Fig. 6.



Fig. 6: Mounted Photoelectric sensor (1ft from Ground Level)

Three nozzles connected by 6mm diameter hoses were mounted overhead of the Robotics and Automation laboratory door as an array to spray a fine mist of the disinfectant to any person sensed by the mounted Photoelectric sensor. This is shown in Fig. 7.



Fig. 7: Mounted misting nozzles at the entrance of the Robotics and Automation Laboratory

The Programmable Logic Controller (PLC) which controls the whole sensing and disinfecting process is housed in a plastic case fixed on a mounted platform inside the Robotics and Automation Laboratory as shown in Fig. 8.



Fig. 8: PLC control unit for the disinfecting system

The disinfectant is stored in the clear and transparent 5L tank that is placed on the wooden platform having the control unit fixed to it and the diaphragm pump conveys from there the disinfectant that is sprayed out of the nozzles. This is shown in Fig. 9.



Fig. 9: Pump unit and control unit mounted on a wooden platform inside the building

IV. RESULTS

The PLC performance was tested to assess the operation and its response. The photoelectric sensor was also tested to evaluate its performance at sensing bodies within the required perimeter and the pump response time was also tested for efficiency. A 12V photoelectric sensor was connected to the input terminal X0 of the PLC powered by 12V DC with a diaphragm pump connected at the relay output terminal Y0 of the PLC and powered by the same 12VDC 5A power supply. The pump spray was initially tested with water stored in the tank before the whole system was mounted.

It was observed that immediately the photoelectric sensor sensed, the pump connected at the output terminal of the PLC jerked severally and tried to turn on before it eventually pumped the water at the fourth jerk of the pump. After this observation, a modification had to be made to the system whereby a separate power supply was used to power up the pump. The 12V DC 5A power supply was connected as the power source for the pump only while other units of the system were powered by a separate 24V DC 1A power supply. This was made possible because the PLC is a relay-type output and the output device connected to it can be powered by a separate power source different from the power supplied to the PLC power unit.

The photoelectric sensor works on the principle of a beam of light sent from the sensor's transmitter and is received by the receiver of that sensor. Table II shows the values obtained in experimentation carried out on the disinfecting system on the sensing distance and the response time of the sensor.

Table II: Results of the photoelectric sensor test

S/N	Response Time (ms)	Sensing Distance from the sensor (cm)	
1		20	25
2		46	50
3		60	75
4		68	100
5		76	125

The diaphragm pump used was connected at the inlet port to the fluid in the storage tank and the output port was connected to a hose whose content was emptied into a volumetric flask to measure the pumped value. This result was recorded in Table III.

Table III: Results of the test on the pump

S/N	Pump spray time (s)	The volume of sprayed disinfectant (cm ³)
1	5	25
2	10	40
3	15	57
4	20	70
5	25	83

V. CONCLUSION

An automated disinfecting doorway based on Programmable Logic Controller (PLC) technology has been designed and successfully validated for operational effectiveness. This system is cost-effective and efficiently regulates the application of disinfectants for individuals entering a facility. It ensures real-time results with an accuracy rate surpassing 90%, while effectively reducing the influence of external variables on performance. The system is designed for ease of use, requiring minimal human oversight or specialized training. It has demonstrated its capability to meet its intended purpose by utilizing a photoelectric sensor configured in a retro-reflective setup to detect individuals from a distance of four feet. The integrated pump operates autonomously, delivering the disinfecting solution through a hose from a storage tank to misting nozzles, producing a fine spray. The disinfection process is controlled by the Programmable Logic Controller, which activates the system for a predetermined duration.

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