© SEP 2026 | IRE Journals | Volume 10 Issue 3 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I3-1722809

Design, Development and Engineering Evaluation of An Automated Disinfectant Tunnel Developed At the National Space Research And Development Agency (NASRDA) During The Covid-19 Pandemic

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***Abstract*—The COVID-19 pandemic created an urgent need for innovative technological solutions capable of supporting hygiene, environmental control and infection-control activities in public and institutional environments. In response to this challenge, an automated disinfectant tunnel was designed and developed at the National Space Research and Development Agency (NASRDA), Nigeria. The system was conceived as a contactless, sensor-controlled liquid-dispensing structure through which an individual could pass while a disinfectant solution was automatically delivered through strategically positioned spray nozzles. This study presents the design, development and engineering evaluation of the prototype, with particular emphasis on its component architecture, sensing mechanism, control strategy, fluid-delivery arrangement and subsystem integration.**

The developed prototype comprised a 220 V electric pump, storage tank, spray nozzles, pipes, T-connectors, passive infrared (PIR) motion sensor, ultrasonic sensor, Arduino Uno microcontroller, relay, temperature indicator, breadboard and electrical wiring. The Arduino Uno served as the principal control unit, receiving signals from the sensing devices and processing them according to the programmed control logic. The PIR sensor provided motion detection, while the ultrasonic sensor provided distance-based presence detection. When the programmed detection condition was satisfied, the Arduino generated a control signal that activated the relay. The relay subsequently switched the electrical supply to the 220 V pump, causing liquid to be withdrawn from the storage tank and conveyed through the pipe network to the spray nozzles.

The engineering assessment demonstrates the integration of embedded control, sensing technology, electromechanical switching and fluid-delivery components in the rapid development of an indigenous technological response during an emergency situation. The prototype also demonstrates the potential of low-cost microcontroller-based systems for developing automated dispensing and environmental-control technologies. The principal contribution of this study is the systematic documentation of the NASRDA prototype, including its design architecture, component functions, operating principle, control strategy and engineering considerations. The study does not claim clinical efficacy or establish that human spraying prevents SARS-CoV-2 transmission; rather, it documents the engineering development and lessons arising from the prototype.

Keywords*—COVID-19; disinfectant tunnel; Arduino Uno; PIR sensor; ultrasonic sensor; automation; electric pump; spray nozzle; embedded control; NASRDA; fluid delivery.

I. INTRODUCTION

The emergence of Coronavirus Disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), resulted in a global public-health emergency and generated unprecedented demands for technological responses. Governments, industries, universities and research institutions were required to develop and deploy innovative approaches capable of supporting public-health interventions under rapidly changing conditions. The pandemic consequently demonstrated the importance of engineering innovation in responding to emergencies and in developing technologies that could reduce direct human intervention in routine hygiene and monitoring activities.

Engineering contributed to the COVID-19 response through the development of contactless monitoring systems, automated hand-sanitising devices, temperature-screening equipment, environmental-control systems, personal protective equipment and other technological solutions. Embedded systems and microcontrollers were particularly useful because they enabled relatively inexpensive sensors and actuators to be combined into automated systems capable of responding to predefined environmental conditions.

One technological concept that attracted considerable attention during the pandemic was the automated disinfectant tunnel. Such systems generally incorporated a structural passageway, liquid storage tank, pump, pipe network, spray nozzles and a control mechanism designed to initiate liquid dispensing when a person entered or approached the designated area. The automation reduced the need for an operator to manually activate the pumping system.

In Nigeria, the pandemic also encouraged indigenous engineering institutions to develop locally adaptable technologies. Among these efforts was the development of an automated disinfectant tunnel at the National Space Research and Development Agency (NASRDA). The prototype represented an attempt to combine readily available electronic and mechanical components into an automated system that could operate with minimal manual intervention.

The NASRDA prototype incorporated several engineering disciplines. The electronic subsystem consisted principally of an Arduino Uno microcontroller, PIR sensor, ultrasonic sensor, relay, breadboard and electrical wiring. The mechanical and fluid-delivery subsystem comprised a storage tank, electric pump, pipes, T-connectors and spray nozzles. A temperature indicator was also incorporated as part of the monitoring arrangement.

The Arduino Uno served as the central control element. It received signals from the sensors, processed the information according to programmed conditions and generated an output signal for the relay. Because the pump operated from a 220 V electrical supply, the relay provided an interface between the low-voltage control circuit and the higher-voltage pump circuit. This arrangement illustrates a basic but important principle of automation in which sensing, decision-making and actuation are separated into distinct stages.

The PIR sensor provided motion detection by responding to changes in infrared radiation within its detection field. The ultrasonic sensor provided distance-based information by transmitting ultrasonic waves and measuring the time required for reflected waves to return. The combination of the two sensing technologies provided complementary information that could be incorporated into the control logic.

The fluid-delivery subsystem was responsible for transporting and distributing the liquid. The electric pump generated the pressure and flow required to move the liquid from the storage tank through the pipe network. T-connectors divided the main flow into branches, while the spray nozzles converted the flowing liquid into spray at the designated dispensing points.

The importance of the prototype lies not only in its original COVID-19 application but also in the engineering knowledge demonstrated by its development. The project shows how an indigenous engineering team can integrate electronic sensing, programmable control, electrical switching and fluid handling into a functional prototype using relatively accessible components.

However, it is important to distinguish engineering functionality from clinical effectiveness. The present study therefore does not attempt to establish that spraying disinfectant onto people prevents COVID-19 transmission. Instead, it focuses on the design, construction, component functions, operating principle and engineering integration of the NASRDA prototype.

The study provides useful documentation of an indigenous technological response developed during an important period in Nigeria's technological history. It also identifies engineering improvements that could make future versions safer, more reliable and more appropriate for applications such as automated surface disinfection, controlled liquid dispensing and environmental monitoring.

II. AIM AND OBJECTIVES

2.1 Aim

The aim of this study is to document, analyse and evaluate the design and engineering integration of an automated disinfectant tunnel developed at NASRDA during the COVID-19 pandemic.

2.2 Objectives

The specific objectives are to:

1. identify the major mechanical, electrical, electronic and fluid-handling components used in the prototype;

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DOI: https://doi.org/10.64388/IREV10I3-1722809

2. describe the functions and operating principles of the selected components;
3. examine the sensing and control architecture of the system;
4. analyse the interaction between the PIR and ultrasonic sensors;
5. examine the Arduino Uno-based control mechanism;
6. analyse the relay-controlled activation of the electric pump;
7. examine the storage, transportation and distribution of the working liquid;
8. evaluate the integration of the major subsystems;
9. identify important engineering limitations of the prototype; and
10. propose improvements for future development of related automated liquid-dispensing systems.

III. SCOPE OF THE WORK

This study focuses on the engineering design and functional integration of the major components used in the NASRDA automated disinfectant tunnel.

The study covers the identification and classification of the components, their individual functions, the sensing architecture, microcontroller-based control, relay switching, pump operation, liquid storage, fluid transportation, flow distribution and spray dispensing.

Particular attention is given to the interaction between the electronic control system and the fluid-delivery system. The study also considers the engineering significance of integrating low-voltage electronic components with a 220 V pump system.

The study is primarily a design and engineering documentation exercise. It does not constitute a clinical trial, microbiological investigation or epidemiological study. Consequently, no claim is made regarding the ability of the prototype to prevent infection or interrupt transmission of SARS-CoV-2.

IV. LITERATURE REVIEW

4.1 Development of Autonomous Advanced Disinfection Tunnel

The study by the developers of the Techno Advanced Disinfection Tunnel (TADT) presented an autonomous tunnel designed during the COVID-19 pandemic for the treatment of external surfaces. The system incorporated a structural frame, disinfectant tank, pump, pipes, spray nozzles, electrical components, microcontroller and ultrasonic sensors. The ultrasonic sensors detected the presence of a person and automatically initiated the spraying process. The work demonstrates the feasibility of combining sensing, control and fluid-delivery components to develop an automated disinfection system. □
PubMed Central (PMC) +1

4.2 Smart Epidemic Tunnel Using Sensor Fusion

The study on the Smart Epidemic Tunnel investigated an IoT-based automated tunnel for COVID-19-related disinfection. The system used sensor-fusion technology, particularly an ultrasonic sensor, to detect a person's movement and activate an automatic sanitizer spray. The research is relevant to the present study because it demonstrates how human-presence detection can be integrated with an automatic spraying mechanism to reduce manual intervention. □
ScienceDirect

4.3 Disinfection Tunnels During the COVID-19 Pandemic

An analysis of disinfection tunnels reported that such systems became widely deployed around crowded locations during the COVID-19 pandemic. The tunnels generally consisted of steel or PVC structures, storage tanks, spray nozzles, pumps and sensors. Some designs employed infrared detectors to activate the spraying system when a person entered the tunnel. This provides useful engineering background for understanding the structural and control arrangements adopted in automated disinfectant tunnels. □
PubMed Central (PMC)

4.4 Solar-Powered Disinfection Tunnel

A 2021 study investigated a solar-powered disinfection tunnel mist-spray system intended for public and remote locations. The system integrated a solar-energy arrangement with a pump and spray-nozzle system. Solar energy was used to power the pump, which transferred disinfectant from a storage arrangement to the spraying nozzles. The study demonstrates the possibility of integrating renewable energy with automated disinfection technology, particularly where reliable grid electricity may be unavailable. □
ScienceDirect

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4.5 Automatic Disinfectant Spraying System Using Arduino
Gunawan and Desyani developed an automatic disinfectant spraying device using an Arduino Uno ATmega328P microcontroller and HC-SR04 ultrasonic sensor. The sensor detected an object and enabled the controller to activate the disinfectant spraying process. The system used a hose connected to a disinfectant container, demonstrating a relatively simple and low-cost approach to automated spraying. The study is particularly relevant to the present NASRDA tunnel because of its use of a microcontroller, sensor and fluid-delivery arrangement.
journal.mediapublikasi.id

4.6 Automatic and Smart Disinfectant Sprayer
Kusuma, Mutiarso and Megantoro investigated an automatic disinfectant sprayer based on the ATmega328 microcontroller. The system employed an ultrasonic sensor to identify the presence of an object and automatically activate the disinfectant pump. Their work demonstrates the application of microcontroller-based control in reducing manual operation and improving the automation of disinfectant spraying equipment.
Universitas Airlangga

4.7 Automatic Portable Disinfectant Device
Sujiwa and Raharjo developed an automatic portable disinfectant device using an ultrasonic sensor, MLX90614 temperature sensor and Arduino Uno R3. The ultrasonic sensor served as an object-detection mechanism, while the Arduino provided the control function. The study demonstrates the possibility of combining multiple sensors with a microcontroller to improve the functionality of COVID-19 prevention equipment.
jurnal.unipasby.ac.id

4.8 Automated Hand-Washing System
Bello, Ayeye, Bolaji and Omoyi developed a sustainable automated hand-washing system incorporating an Arduino Pro Mini and a water-recycling arrangement. The system was developed in response to the increased importance of hand hygiene during and after the COVID-19 pandemic. Its automation architecture demonstrates how sensors, electronic control and water-delivery components can be integrated to provide contactless hygiene facilities. This is relevant to the present study because the NASRDA disinfectant tunnel similarly depends on automated control of fluid delivery.
journal.engineering.fuoye.edu.ng +1

4.9 Arduino-Based COVID-19 Disinfection and Monitoring Tunnel
An Arduino-based COVID-19 disinfection and monitoring tunnel incorporated an Arduino Nano 33 IoT, ultrasonic sensor, PIR sensor, relay module, LEDs and buzzer. The system was designed to detect people entering the tunnel, activate the disinfection process and monitor tunnel occupancy. The use of a relay provides an important engineering principle for controlling higher-power devices such as pumps from a low-voltage microcontroller circuit. This concept is applicable to the design of automated disinfectant tunnels such as the one developed at NASRDA.
projecthub.arduino.cc5

V. MATERIALS AND METHODS

5.1 System Development Approach
The prototype was developed by integrating mechanical construction, fluid-delivery equipment, electronic sensors, a microcontroller and an electrical switching system.
For engineering analysis, the system was divided into four principal subsystems:
1. Detection subsystem
2. Control subsystem
3. Fluid-delivery subsystem
4. Power and switching subsystem

The detection subsystem consisted mainly of the PIR and ultrasonic sensors. The control subsystem was based on the Arduino Uno. The fluid-delivery subsystem comprised the storage tank, pump, pipes, T-connectors and spray nozzles. The power and switching subsystem included the electrical wiring and relay used to control the pump.
This subsystem-based approach makes it possible to examine the prototype systematically and to understand the contribution of each component to the overall operation.

5.2 Functional Architecture
The functional operation of the prototype can be represented as:

Person approaches/enters tunnel
↓
PIR motion detection / ultrasonic presence detection
↓

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Arduino Uno receives sensor signals
↓
Control logic processes detection condition
↓
Arduino activates relay
↓
Relay switches 220 V pump circuit
↓
Pump draws liquid from storage tank
↓
Liquid flows through main pipe
↓
T-connectors distribute liquid to branches
↓
Spray nozzles discharge liquid

Figure 1. Functional architecture of the NASRDA automated disinfectant tunnel

The architecture demonstrates the fundamental automation sequence:
Detection → Processing → Switching → Pumping → Distribution → Dispensing

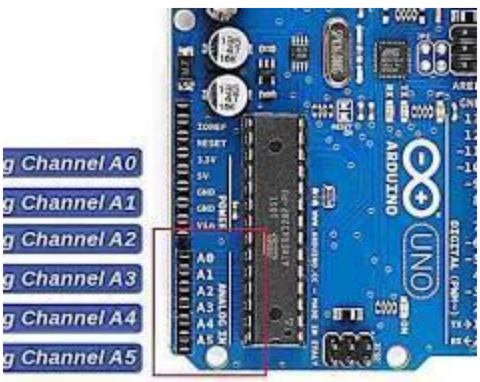
4.3 Component Selection
The prototype was based on components that were relatively accessible and capable of performing the required sensing, control, switching and fluid-handling functions.

The principal components included:

Subsystem	Component	Principal Function
Detection	PIR sensor	Motion detection
Detection	Ultrasonic sensor	Distance/presence detection
Control	Arduino Uno	Signal processing and control
Switching	Relay	Electrical switching
Fluid storage	Storage tank	Liquid storage
Fluid transport	220 V electric pump	Liquid movement
Fluid transport	Pipes	Liquid transportation
Distribution	T-connectors	Flow branching
Dispensing	Spray nozzles	Liquid atomisation/spraying
Monitoring	Temperature indicator	Temperature screening
Prototyping	Breadboard	Electronic interconnection
Electrical	Wires	Power and signal transmission

VI. DESCRIPTION AND FUNCTIONS OF THE MAJOR COMPONENTS

6.1 Arduino Uno Microcontroller



The Arduino Uno served as the central processing and control unit of the prototype. The controller received signals from the sensing devices and executed programmed instructions to determine when the pump should be activated.
The Arduino Uno R3 is based on the ATmega328P microcontroller and operates at a 5 V logic level. It provides digital and analogue input/output capabilities and operates with a 16 MHz clock. These characteristics make it suitable for relatively simple sensing and control applications.

Within the prototype, the Arduino performed several important functions. It received the output signal from the PIR sensor, processed the ultrasonic sensor information, determined whether the programmed activation condition had been met and generated an output signal to control the relay.

The programmable nature of the Arduino provides flexibility. Changes to activation distance, detection conditions or pump operating duration can potentially be implemented through software without reconstructing the entire system.

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DOI: https://doi.org/10.64388/IREV10I3-1722809

6.2 PIR Motion Sensor

The passive infrared (PIR) sensor was used to detect movement within its field of view. PIR sensors operate by detecting changes in infrared radiation associated with moving objects.
In the tunnel, the sensor provided a contactless method of detecting movement. When movement was detected, the sensor produced an electrical output that could be interpreted by the Arduino.
Its main advantages in the prototype included:

- contactless detection;
- relatively simple integration;
- low power consumption;
- automatic activation capability; and
- reduction of manual intervention.

However, a PIR sensor is primarily a motion detector rather than a precise distance-measuring device. Consequently, its output may depend on the movement, position and environmental conditions of the detected object.

6.3 Ultrasonic Sensor

The ultrasonic sensor provided distance-based detection. It generally operates by transmitting a high-frequency acoustic pulse and measuring the time taken for the reflected pulse to return.
The measured time can be converted into an estimated distance between the sensor and the detected object.
In the prototype, ultrasonic sensing provided complementary information to the PIR sensor. While the PIR sensor primarily responded to movement, the ultrasonic sensor could provide information concerning whether an object was within a predetermined distance.
This combination provided the possibility of establishing a more controlled activation zone.

6.4 Relay

The relay served as the electrical switching interface between the Arduino control circuit and the pump circuit.
The Arduino output cannot safely be used to directly operate a 220 V electric pump. The relay therefore allows a low-power control signal from the Arduino to command the switching of a separate electrical circuit capable of supplying the pump.
The control sequence can be simplified as:
Sensor → Arduino → Relay → Pump
The relay must be correctly rated for the voltage and current requirements of the pump, including its starting current. Appropriate electrical isolation and protective devices are also required when integrating mains voltage equipment.

6.5 220 V Electric Pump

The electric pump was the main fluid-transport device. When energized, it converted electrical energy into mechanical energy that caused the liquid to move from the storage tank through the distribution system.
Pump characteristics directly affect the performance of the dispensing system. Important parameters include:

- flow rate;
- operating pressure;
- electrical power;
- pump head;
- starting current; and
- operating duration.

The pump therefore represents a major determinant of the spray performance of the system.

6.6 Storage Tank

The storage tank served as the reservoir for the liquid used by the system.
Its functions included storing the working solution, providing a continuous supply to the pump and reducing the need for repeated manual filling.
The capacity of the tank should be selected according to the expected number of operating cycles and the flow rate of the pump. The tank should also be constructed from a material compatible with the intended liquid.

5.7 Pipes

The pipes provided the main pathways through which liquid travelled from the pump to the spray nozzles.
Pipe diameter, length, material, bends and fittings influence fluid resistance and pressure losses. Where multiple spray nozzles are connected to one pump, appropriate pipe sizing is particularly important because excessive pressure loss can result in uneven spray distribution.
The pipe network must therefore be designed to provide adequate flow to all dispensing points.

6.8 T-Connectors

T-connectors were used to divide the main flow path into branches.
A typical arrangement can be represented as:
Pump → Main pipe → T-connector → Branch pipe → Spray nozzle
Multiple T-connectors can therefore be used to create a distributed network serving several nozzles.
The number and arrangement of T-connectors can influence pressure distribution and should therefore be considered when designing the fluid network.

6.9 Spray Nozzles

Spray nozzles formed the terminal elements of the fluid-delivery system. They converted the flowing liquid into a spray pattern.

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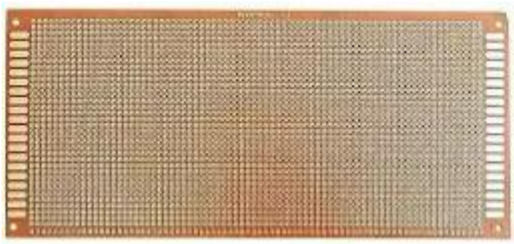
DOI: https://doi.org/10.64388/IREV10I3-1722809

Nozzle performance depends on several factors, including liquid pressure, nozzle geometry, flow rate, spray angle and droplet characteristics.
The arrangement and orientation of the nozzles determine the spatial distribution of the discharged liquid. Consequently, nozzle positioning is an important design consideration in any automated spraying system.
For future applications, the nozzle arrangement should be selected according to the intended target, particularly where the system is redirected toward surfaces rather than direct application to people.

6.10 Temperature Indicator

The temperature indicator was incorporated as a monitoring component. Temperature screening became common at entrances to public buildings and institutions during the COVID-19 pandemic.
The indicator could provide a visual or electronic indication of measured temperature depending on the specific device installed.
Temperature screening should, however, is regarded as a screening or monitoring procedure rather than a diagnostic method for COVID-19.

6.11 Breadboard



The breadboard provided a temporary prototyping platform for connecting the Arduino, sensors and other low-voltage electronic components.
Its principal advantage during development was that circuit connections could be changed rapidly without soldering. This made it useful during experimentation, troubleshooting and early-stage system development.
However, breadboards are generally unsuitable for permanent industrial installations, particularly where vibration, moisture or high-voltage equipment is present. A production version should therefore use a properly designed printed circuit board (PCB) or enclosed control panel.

6.12 Electrical Wiring
Electrical wiring provided the conductive pathways required for power and signal transmission.
The wiring can be broadly classified into:
- sensor signal connections;
- Arduino power connections;
- relay control connections; and
- pump power connections.

Because the prototype incorporated a 220 V electrical circuit, safe electrical design is essential. Proper insulation, earthing, circuit protection, fusing, enclosure and separation of low-voltage and mains wiring should be provided in any reproduction or upgraded design.

VII. SYSTEM OPERATING PRINCIPLE

The operating principle of the prototype was based on automatic detection followed by controlled activation of the fluid-delivery system.
When an individual approached or entered the designated detection area, the PIR sensor detected movement while the ultrasonic sensor provided distance-related information. The signals were transmitted to the Arduino Uno for processing.
The programmed control logic determined whether the detected condition satisfied the predefined activation requirement. When the condition was satisfied, the Arduino generated an output signal that activated the relay.
The relay then switched the electrical supply to the 220 V pump. The energized pump drew liquid from the storage tank and forced it through the pipe network.
The main pipe conveyed the liquid toward the T-connectors, which divided the flow into branches leading to the individual spray nozzles. The nozzles then discharged the liquid into the designated spray area.
The complete sequence can therefore be expressed as:
Detection → Decision → Switching → Pumping → Distribution → Dispensing

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DOI: https://doi.org/10.64388/IREV10I3-1722809

This arrangement represents a basic embedded automation system in which sensor inputs are converted into an automatic physical action.

VIII. ENGINEERING INTEGRATION OF THE SYSTEM

The principal engineering strength of the prototype was the integration of several independent technologies into a coordinated system.

Table 2. Integration of major subsystems

Subsystem	Components	Function
Detection	PIR and ultrasonic sensors	Detect movement and presence
Control	Arduino Uno	Process signals and execute control logic
Switching	Relay	Control pump circuit
Fluid storage	Storage tank	Store liquid
Fluid transport	Electric pump and pipes	Move liquid
Fluid distribution	T-connectors	Divide flow
Dispensing	Spray nozzles	Discharge liquid
Monitoring	Temperature indicator	Temperature screening
Prototyping	Breadboard	Temporary circuit development
Electrical	Wiring	Power and signal transmission

The prototype consequently combined elements of:

- embedded systems;
- electronics;
- electrical engineering;
- mechanical engineering;
- fluid mechanics;
- automation; and
- instrumentation.

This multidisciplinary integration was essential to achieving automatic operation.

IX. ENGINEERING EVALUATION

The engineering evaluation of the prototype focuses on functionality, subsystem integration, controllability, maintainability and opportunities for improvement.

9.1 Detection Performance

The use of both PIR and ultrasonic sensors provided two different forms of information. The PIR sensor detected movement, while the ultrasonic sensor provided distance-related information.

This arrangement has the potential to improve the definition of the activation zone. However, quantitative assessment would require experimental measurements of detection range, response time, false activation rate and missed detection rate.

Such measurements were not available in the documentation examined for this study and should therefore be included in future experimental evaluations.

9.2 Control Performance

The Arduino-based architecture provided programmable control of the system.

One important advantage of this arrangement was flexibility. The activation conditions and pump operating duration could potentially be modified through software.

The microcontroller also provided separation between the sensing and actuation stages. Sensors supplied information to the controller, while the controller issued commands to the relay.

This architecture is consistent with basic principles of automated control systems.

9.3 Pump and Fluid-Delivery Performance

The pump, pipe network, T-connectors and nozzles collectively determined the liquid-delivery performance.

Important parameters requiring measurement include:

- pump flow rate;
- pump pressure;
- nozzle flow rate;
- pipe diameter;
- pressure losses;
- spray angle;
- dispensing duration; and
- uniformity of spray distribution.

Without these measurements, it is not possible to provide a quantitative assessment of the hydraulic performance of the prototype.

Nevertheless, the functional arrangement demonstrates a conventional liquid-transfer and distribution architecture.

9.4 Electrical Safety

The incorporation of a 220 V pump alongside low-voltage electronic components represents an important engineering consideration.

The relay provides the necessary switching interface, but safe operation requires more than the presence of a relay. A complete design should include appropriate fusing, circuit breakers, earthing, insulation, enclosure and physical separation between mains and low-voltage circuits.

These measures become particularly important because the system is associated with liquid handling.

9.5 Maintainability

The use of commercially available components offers an advantage in maintenance because many components can potentially be replaced without redesigning the entire system.

However, maintenance requirements include:

- cleaning the tank;
- inspecting pipes;
- checking nozzle blockage;
- inspecting electrical connections;
- testing sensors;
- checking relay operation;
- inspecting pump performance; and
- replacing damaged components.

A modular construction would further improve maintainability.

X. DISCUSSION

The NASRDA automated disinfectant tunnel demonstrates the ability of an indigenous engineering team to combine accessible technologies into a functional automated prototype during an emergency period.

One of the most significant features of the design is its separation of sensing, processing and actuation. Rather than connecting a sensor directly to the pump, sensor information was first processed by the Arduino Uno. The microcontroller then controlled the relay, which switched the pump.

This arrangement creates a clear control hierarchy:

Input → Processing → Output

The approach also provides flexibility because the operating logic can be modified through software.

The use of PIR and ultrasonic sensors represents another important engineering feature. PIR sensing provides motion information, whereas ultrasonic sensing provides distance information. The two technologies are therefore complementary. Nevertheless, the extent to which their combination improves detection reliability must be established experimentally rather than assumed.

The fluid-delivery subsystem also demonstrates the importance of mechanical and fluid-engineering considerations in automated systems. Pump capacity alone does not determine spray performance. Pipe diameter, pipe length, fittings, T-connectors, nozzle geometry and pressure losses all contribute to the final distribution of liquid.

The prototype further demonstrates the importance of rapid prototyping during emergencies. The use of a breadboard allowed the electronic control circuit to be developed and modified quickly. Although this is suitable for prototyping, a permanent installation would require a more robust electrical assembly.

Another important lesson concerns the relationship between technological innovation and public-health application. During the COVID-19 pandemic, there was considerable interest in automated spraying systems. However, engineering development should always be distinguished from clinical validation. A machine may successfully detect a person and activate a pump without necessarily demonstrating that its operation reduces disease transmission.

The historical value of the NASRDA prototype therefore lies principally in its demonstration of rapid indigenous engineering innovation. The system shows how sensing, embedded control, electromechanical switching and fluid delivery can be integrated to address an emergency technological requirement.

XI. LIMITATIONS OF THE STUDY

The study has several limitations.

First, complete quantitative specifications for all components were not available. Parameters such as pump pressure, pump flow rate, tank capacity, nozzle discharge rate, nozzle spray angle and sensor response time should ideally be obtained from original prototype records.

Second, the study does not include laboratory microbiological testing. Consequently, it cannot establish the effectiveness of the discharged liquid against SARS-CoV-2 or other pathogens.

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DOI: https://doi.org/10.64388/IREV10I3-1722809

Third, the study does not constitute a clinical trial and does not establish that disinfectant spraying on humans prevents COVID-19 transmission.
Fourth, detailed measurements of spray uniformity and spatial coverage were not available. Such measurements would strengthen the engineering evaluation.
Fifth, the available prototype documentation may not contain detailed photographs of every individual component. Where possible, future publication should use photographs obtained directly from the original NASRDA prototype.

XII. RECOMMENDATIONS FOR FUTURE DEVELOPMENT

Future versions of the system should incorporate improvements in sensing, control, safety and fluid management.
12.1 Improved Temperature Monitoring
A non-contact infrared temperature sensor could be incorporated where temperature screening is required.
12.2 Liquid-Level Detection
A liquid-level sensor could be installed in the storage tank to prevent the pump from operating when insufficient liquid is available.
12.3 Emergency Stop
An easily accessible emergency-stop switch should be included to allow immediate shutdown.
12.4 Flow Monitoring
A flow sensor could be introduced to monitor liquid movement and detect pump or pipe faults.
11.5 Pressure Monitoring
A pressure sensor could provide information about the hydraulic condition of the distribution system.
12.6 Improved Electronic Assembly
The breadboard-based prototype should be replaced with a properly designed PCB or industrial control panel for permanent applications.
12.7 Electrical Protection
Future versions should incorporate appropriate fuses, circuit breakers, earthing, insulation, protective enclosures and electrical isolation.
12.8 Programmable Dispensing Duration
The Arduino software could allow the dispensing duration to be adjusted according to the intended application.
12.9 Data Logging
A data-logging system could record activation events, operating duration, liquid-level status and equipment faults.
12.10 Redirection Toward Safer Applications
Future development should consider applications involving automated surface or object disinfection and controlled liquid dispensing, rather than direct spraying of disinfectants onto people. This would allow the underlying automation technology to be retained while addressing important safety and public-health considerations.

XIII. CONCLUSION

This study documented and evaluated the engineering architecture of an automated disinfectant tunnel developed at the National Space Research and Development Agency (NASRDA) during the COVID-19 pandemic.
The prototype integrated a 220 V electric pump, storage tank, pipes, T-connectors, spray nozzles, PIR motion sensor, ultrasonic sensor, Arduino Uno microcontroller, relay, temperature indicator, breadboard and electrical wiring into a coordinated automated system.
The Arduino Uno served as the principal control unit, receiving information from the sensing devices and controlling pump activation through the relay. The PIR sensor provided motion detection, while the ultrasonic sensor provided distance-based presence detection. The relay provided the switching interface between the low-voltage control system and the 220 V pump. The pump, pipes, T-connectors and spray nozzles constituted the principal fluid-delivery pathway.
From an engineering perspective, the prototype demonstrates the integration of embedded electronics, sensing technology, electrical switching, fluid mechanics and automation. Its development also demonstrates the ability of indigenous engineering teams to respond rapidly to emerging technological challenges using relatively accessible components.
The study does not establish clinical efficacy or demonstrate that disinfectant spraying prevents SARS-CoV-2 transmission. Its principal contribution is the documentation and engineering analysis of the NASRDA prototype and the lessons that can be derived from its design.
The technological concepts demonstrated by the prototype remain relevant to modern automated systems. With improved sensing, electrical protection, hydraulic monitoring, industrial control architecture and application-specific design, similar technologies could be adapted for safer applications

involving automated surface treatment, controlled liquid dispensing, environmental monitoring and other contactless engineering systems.

XIV. ENGINEERING SIGNIFICANCE OF THE PROTOTYPE

The NASRDA prototype has significance in three major areas.

First, it demonstrates indigenous engineering innovation. The project was developed locally during a period when institutions were required to respond rapidly to an unprecedented challenge.

Second, it demonstrates interdisciplinary engineering integration. The prototype required knowledge of electronics, embedded programming, electrical switching, mechanical assembly, fluid transportation and spray distribution.

Third, it demonstrates the value of low-cost automation. Components such as Arduino Uno, PIR sensors, ultrasonic sensors and relays provide relatively accessible platforms for prototyping automated systems.

The underlying architecture can therefore be regarded as a foundation for further technological development beyond the original pandemic application.

XV. FINAL ENGINEERING ASSESSMENT

Overall, the NASRDA automated disinfectant tunnel represents a functional integration of sensing, microcontroller-based control, electrical switching and fluid dispensing.

Its principal engineering strengths include:

1. automatic operation;
2. contactless detection;
3. programmable control;
4. integration of two sensing technologies;
5. separation of low-voltage control from pump switching;
6. distributed fluid delivery;
7. use of accessible components; and
8. potential for adaptation to other automated dispensing applications.

Its principal areas requiring improvement include:

1. quantitative hydraulic evaluation;
2. improved electrical protection;
3. replacement of breadboard electronics with a permanent control assembly;
4. liquid-level monitoring;
5. flow and pressure monitoring;
6. improved sensor validation;
7. systematic testing of spray uniformity; and
8. safer application-specific use of the dispensing technology.

The prototype should therefore be regarded as an important example of rapid engineering prototyping during the COVID-19 pandemic and as a platform from which more advanced automated liquid-handling technologies can be developed.

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