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Utilization of a Pressure Sensor as a Pressure Regulator in an Autoclave Machine for Medical Equipment Sterilization and IoT-Based Monitoring

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ABSTRACT

An autoclave is a sterilization device that operates using high-pressure steam to eliminate microorganisms. However, in conventional systems, pressure regulation is still performed manually, which can lead to inconsistencies in the sterilization process and reduced effectiveness. This study developed an automatic pressure control system based on a digital pressure sensor, controlled by an Arduino Uno microcontroller and equipped with an ESP8266 module for real-time monitoring via the Internet of Things (IoT). The system also utilizes a MAX6675 temperature sensor, a solenoid valve as a pressure actuator, and an LCD as a local interface. Testing was conducted at three pressure settings (10, 15, and 25 psi) for a duration of 15 minutes. The results showed that the system was able to maintain pressure with a fluctuation tolerance of ±0.3 psi and successfully transmitted temperature and pressure data to a cloud dashboard in real-time. This system is considered effective in improving the efficiency, accuracy, and safety of the sterilization process, and has the potential to be implemented in medical and laboratory facilities.

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1. INTRODUCTION

Sterilization is a fundamental procedure in the medical and laboratory fields aimed at ensuring that all equipment is free from pathogenic microorganisms [1]. One of the most effective sterilization methods is the use of an autoclave, a device that utilizes high-pressure steam to thoroughly eliminate bacteria, viruses, and spores. However, in practice, many conventional autoclaves still rely on manual pressure control, which poses a risk of mismatch between the required pressure and temperature [2][3].

Unstable pressure control not only affects the effectiveness of the sterilization process but also increases the risk of process failure and potential hazards to users [4]. Therefore, an automated system is needed to maintain pressure at an optimal point with precision and consistency. Along with advancements in industrial technology, the sterilization of medical equipment requires an efficient and accurate system to ensure both quality and user safety [5].

With the development of Internet of Things (IoT) technology, remote monitoring and control systems have become more easily applicable across various fields, including autoclave systems. By integrating pressure sensors, microcontrollers, and IoT connectivity, the sterilization process can be controlled and monitored automatically, accurately, and in real time [6][4][7].

This study proposes an automatic pressure control system based on Arduino Uno and a pressure sensor, equipped with an ESP8266 module to transmit data to a cloud platform [8]. The system is also equipped with a MAX6675 temperature sensor to ensure that sterilization parameters are met, as well as a solenoid valve to maintain pressure within safe limits [9]. A pressure sensor is a device used to detect or measure the pressure of a substance. Pressure itself is a physical quantity that describes the force applied over a specific area. Mathematically, pressure is expressed by the formula: $P = F / A$, where P is the pressure, F is the applied force, and A is the surface area over which the force is distributed. Pressure units are commonly used to evaluate the intensity of force within a fluid, whether liquid or gas [10].

Temperature data acquisition using a type-K thermocouple combined with the MAX6675 module for cold junction compensation is a feasible choice for researchers due to its affordability and wide availability in the market. The combination of the type-K thermocouple and MAX6675 is capable of providing accurate measurement results, provided that the sensor has been properly calibrated [11].

The main contribution of this research is the development of an intelligent sterilization system that not only maintains pressure automatically but also provides remote monitoring capabilities through an IoT-based dashboard. This system is expected to serve as an innovative solution to enhance the safety and efficiency of sterilization processes, particularly in environments that require strict supervision such as hospitals and laboratories [1][12][13].

This study aims to develop an automatic pressure control system for autoclave machines based on a digital pressure sensor and an Arduino Uno microcontroller, to implement real-time pressure and temperature monitoring through an Internet of Things (IoT) platform using the ESP8266 module, and to analyze the system's performance in maintaining pressure stability during the sterilization process at various predetermined pressure settings.

2. METHODOLOGY

2.1 Type of Research

This research falls into the category of applied experimental research, involving the development and testing of an automated pressure control system for an autoclave machine [14]. The main focus of this study is to design and implement a system based on a microcontroller and pressure sensor, integrated with Internet of Things (IoT) technology to monitor the sterilization process in real time.

2.2 Equipment and Materials

The hardware and software used in this research include:

Hardware:

- Arduino Uno
- ESP8266 WiFi Module
- Pressure Sensor
- MAX6675 Temperature Sensor
- Solenoid Valve
- LCD I2C 16x2
- Heater
- Relay
- Power Supply 12V
- Jumper Wires and Connectors

Software:

- Arduino IDE
- Arduino Cloud

2.3 System Design

Device design is the process of constructing a tool from electronic and mechanical components to support the intended system [15]. The system is designed to automatically regulate the pressure in the autoclave based on input from the pressure sensor. This section explains the software, which uses the Arduino IDE to program the microcontroller. The microcontroller periodically reads the pressure and controls the operation of the heater and solenoid valve[16]. In addition, the system transmits temperature and pressure data to the Arduino Cloud, allowing users to monitor the process remotely.

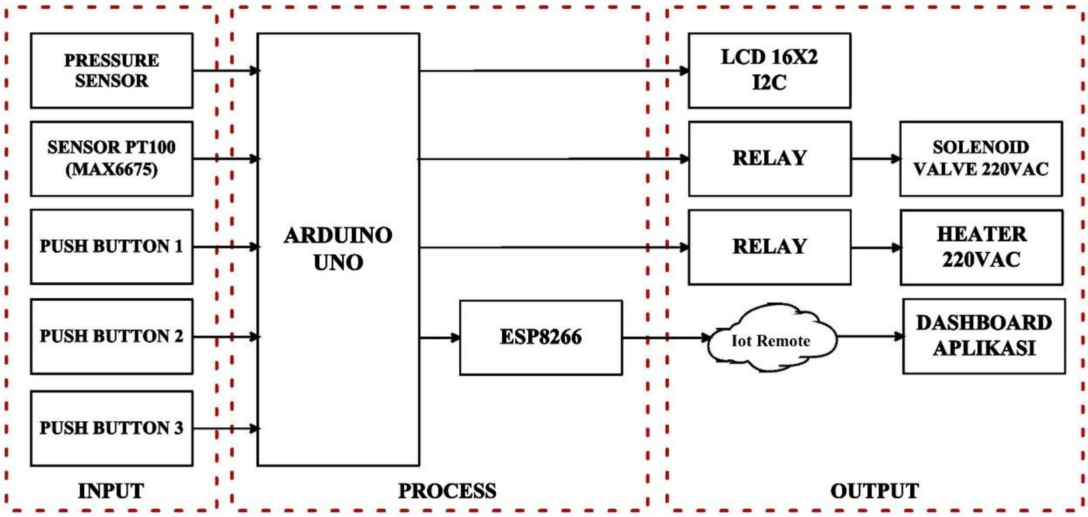

Figure 1. System Block Diagram

The main components are interconnected with the following configuration:

- The pressure sensor measures the pressure inside the autoclave chamber.
- The Arduino Uno serves as the main control unit.
- The heater activates when the pressure has not yet reached the setpoint.
- The solenoid valve opens after the process is complete to release pressure.
- The ESP8266 module transmits data to the cloud.

2.4 flowchart sistem

A flowchart is a graphical representation of the steps and sequence of procedures in a program [17]. The system flowchart illustrates the workflow of the system from initialization, pressure mode selection, sterilization process, to process completion.

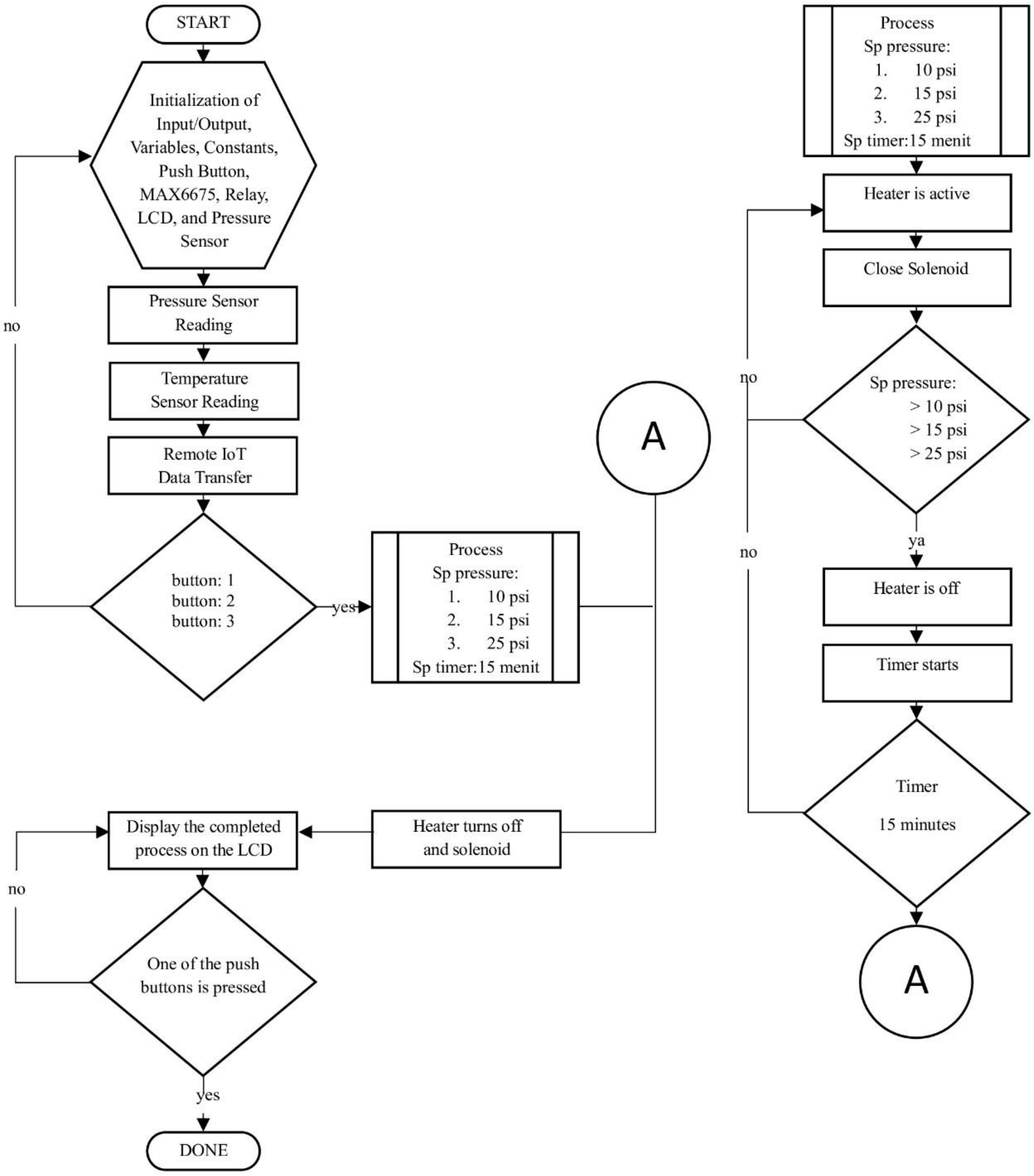

Figure 2. flowcart sistem

System Workflow:
1. Initialization of components (sensor, LCD, WiFi).
2. Reading the push button to select the pressure mode (10, 15, or 25 psi).
3. Heater is activated until the pressure reaches the setpoint.
4. Timer runs for 15 minutes once the target pressure is reached.
5. After the timer ends, the heater turns off and the solenoid valve opens.
6. The system displays the message "Process Complete" on the LCD.

2.5 Wiring Diagram

This diagram shows the connections between the Arduino Uno, pressure sensor, temperature sensor, solenoid valve, relay, heater, LCD, and ESP8266.

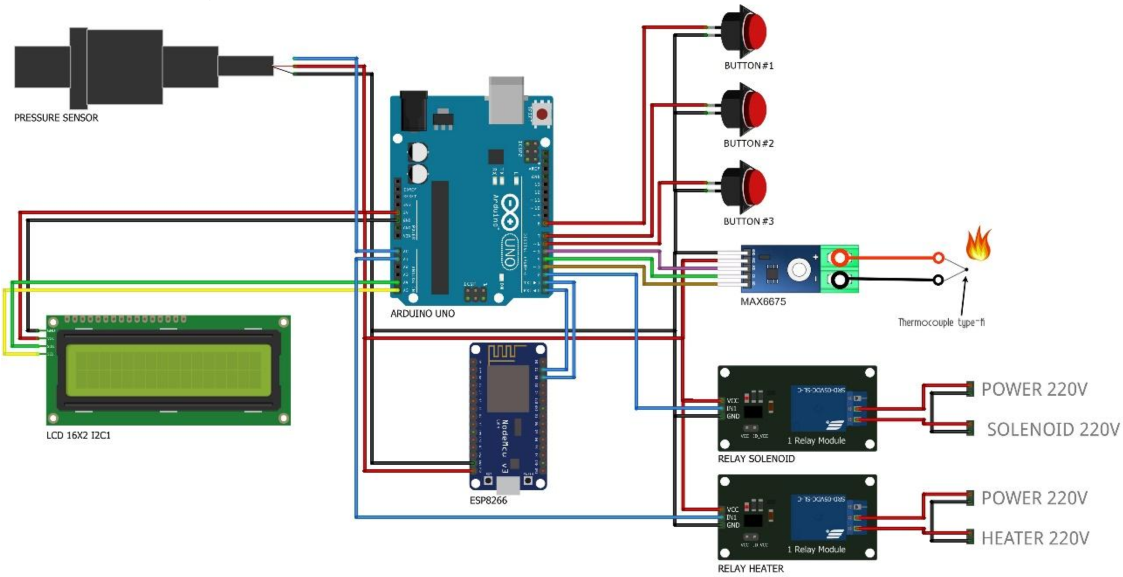

Figure 3. Wiring Diagram

This diagram is intended to facilitate the installation and integration process between components during system implementation on the autoclave hardware.

3. RESULTS AND DISCUSSION

In this section, the results of the system testing and the analysis of its performance are presented [18]. The testing was conducted to verify the accuracy of the pressure sensor in reading pressure, the capability of the control system to maintain the pressure at the defined setpoints, and the ability to monitor pressure and temperature data in real-time through the IoT platform [19].

. The testing was carried out under several different pressure scenarios—10 psi, 15 psi, and 25 psi—which represent standard pressures in the sterilization process of medical equipment. The results showed that the system was able to maintain pressure with a low fluctuation level, approximately ±0.3 psi, and responded automatically to pressure changes by activating or deactivating the actuators (heater and solenoid valve) as needed [20].

3.1 System Testing Results

The designed system consists of an Arduino Uno, a pressure sensor, a MAX6675 temperature sensor, an ESP8266 module, a relay, a heater, a solenoid valve, and an LCD display. The system was tested to evaluate the effectiveness of automatic pressure control as well as its cloud-based monitoring capability using Arduino Cloud.

Figure 4. Autoclave Machine

The system successfully operated in three sterilization modes based on pressure: 10 psi, 15 psi, and 25 psi, each with a duration of 15 minutes. The system periodically read the pressure and automatically controlled the heater and solenoid valve accordingly.

3.2 Pressure Sensor Calibration

Calibration was performed to convert the ADC values from the pressure sensor into pressure units (psi). The calibration results showed a linear relationship between the ADC values and the actual pressure, with the following data:

Table 1. Measurement Data ADC

no	Y(psi)	(X)ADC
1	0	160
2	15	550
3	25	780

From the data, a linear regression equation was obtained:

$$\text{pressure (psi)} = 0.0401 \cdot \text{ADC} - 6.60$$

his equation is used to convert ADC data into pressure values displayed on the LCD and the Arduino Cloud application.

3.3 System Performance in Maintaining Pressure

The system was tested to maintain pressure at the setpoint in a stable manner. The system logic is as follows:

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- The heater is activated when the pressure is below the setpoint.
- The heater is deactivated when the pressure is greater than or equal to the setpoint.
- The solenoid valve opens after the sterilization time is completed.

The testing results showed that the pressure could be maintained within the desired range with minimal fluctuations.

3.4 Pressure and Temperature Testing

Table 2. Pressure and Temperature Data Collection

No	Setpoint (psi)	Pressure on the LCD (psi)	Actual Pressure (psi)	Temperature (^{o}c)	Duration (minutes)
1	10	10.3-9.9	10	95-96	15
2	15	15.4-14.9	15	105-106	15
3	25	25.3-24.9	25	118-120	15

The results showed that the system was able to maintain pressure within a tolerance of ±0.3 psi, which is still within the safe range for effective sterilization.

3.5 IoT-Based Monitoring

The system successfully transmitted pressure and temperature data in real time to the Arduino Cloud dashboard using the ESP8266. Users can monitor the data directly via a smartphone or computer.

Table 3. IoT Dashboard Data Collection

No	Pressure (psi)	Pressure Gauge	Dhasboard Iot
1	10		
2	15		

3	25		

This feature is especially useful in hospital or laboratory environments that require fast and remote monitoring

3.6 Analysis and Discussion

The test results indicate that the system is reliable in automatically and precisely regulating the autoclave pressure, providing real-time cloud-based remote monitoring, and minimizing human intervention during the sterilization process. This system is designed to offer ease and efficiency in autoclave operation, especially in medical or laboratory environments that require consistent sterilization processes and remote control capabilities.

The accuracy of the system is highly influenced by the sensor calibration results, the stability of the power supply voltage, and the quality of the internet connection for IoT purposes. This innovation demonstrates great potential for application in modern sterilization devices, as it enhances the overall effectiveness, safety, and traceability of the process.

3.7 Advantages and Limitations of the System

Strengths:

- Fully automated pressure control system.
- Real-time monitoring based on IoT.
- Data display through LCD and cloud-based dashboard.
- Automatic pressure release after the sterilization process is completed.

Limitations:

- Dependent on a stable Wi-Fi connection.
- Does not yet include post-sterilization drying and cooling features.
- The pressure sensor requires a cooling period if used continuously.

4. CONCLUSION

Based on the testing and analysis that have been conducted, it can be concluded that the automatic pressure control system based on Arduino Uno, pressure sensor, and ESP8266 has been successfully developed and is capable of operating effectively according to the research objectives. The system is able to maintain autoclave pressure at three setpoints (10, 15, and 25 psi) stably, with a fluctuation tolerance of approximately ±0.3 psi, which remains within the acceptable range for the sterilization process. The integration with IoT platforms through the ESP8266 module and Arduino Cloud enables real-time remote monitoring of pressure and temperature, enhancing operational efficiency and safety. Furthermore, this system has the potential to be further developed with additional features such as drying control, cooling, historical data storage, and alarm notifications to ensure optimal sterilization quality.

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