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Analysis of the Implementation of a Smart Fire System On/Off Prototype Using a Solenoid Valve and Notification Based on Arduino Uno

Suhardi Siagian[1], Solly Aryza[2], Hamdani[3]
Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia

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ABSTRACT

Fire detection and prevention systems are important aspects in maintaining environmen-tal security, both at home and in public facilities. This study aims to develop and analyze the implementation of an Arduino Uno-based Smart Fire System On/Off prototype equipped with a solenoid valve for automatic fire extinguishing and application-based notification. This system consists of a temperature and smoke sensor as the main detec-tor, an Arduino Uno as a controller, a solenoid valve to regulate water flow, and a com-munication module to send notifications to users. Tests were conducted to evaluate the system's response speed, detection accuracy, and the effectiveness of the automatic fire extinguishing mechanism. The results show that this system is able to detect potential fires with 95% accuracy and provide notifications to users in less than 5 seconds after detection. In addition, the solenoid valve is successfully activated automatically to extin-guish the fire with a success rate of up to 90%. This prototype shows potential for im-plementation as an efficient fire safety solution, especially at the household and small business scale.

Corresponding Author:
Suhardi Siagian
Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia
suhardisia56@gmail.com

INTRODUCTION

Fire is a disaster that can result in material and environmental damage, and even loss of life. Statistics show that fire incidents often occur due to human negligence, electrical short circuits, or environmental conditions that favor the spread of fire. Therefore, an automated early detection and prevention system is necessary to minimize the risk of fire.

Modern technology has enabled the development of microcontroller-based automation systems, such as the Arduino Uno, for application in fire safety systems. The Arduino Uno offers advantages in terms of ease of programming, hardware flexibility, and compatibility with various additional sensors and modules. In this study, a combination of a temperature sensor, a smoke sensor, and a solenoid valve was used as the main components to detect potential fires, extinguish them automatically, and send notifications to the user's device.

The developed prototype, the Smart Fire System On/Off, is designed to provide an efficient and affordable fire safety solution. The system integrates automatic detection,

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solenoid valve extinguishing control, and app-based notifications, allowing users to take immediate action in the event of an emergency.
This research aims to:

1. Analyze sensor performance in detecting potential fires.
2. Testing the effectiveness of the system in extinguishing fire using a solenoid valve.
3. Evaluate the speed and accuracy of notification delivery to user devices.

With the development of this system, it is hoped that it can contribute to creating effective solutions to prevent losses due to fire, especially in household and small business environments. Based on the above background, several problems that will be examined in this study are as follows:

1. How to Automatically Detect Potential Fires Using a Combination of Temperature Sensors and Smoke Sensors?
2. How Effective Is a Solenoid Valve-Based System in Automatically Extinguishing Fires?
3. How fast and accurate is the system in sending fire notifications to users via applications or other devices?
4. Can the Developed Smart Fire System Prototype Be Effectively Implemented in a Household or Small Business Environment?

The formulation of the problem is the basis for designing, developing, and testing a prototype of an Arduino Uno-based On/Off Smart Fire System in order to provide an efficient and affordable fire safety solution.

Literature Review

Electric Power System

In general, the goal of electricity companies is to maintain continuity of electricity service, ensuring that power reaches customers continuously without interruption. The electric power system begins with the generation, transmission, and distribution systems, as shown in Figure 2.2.

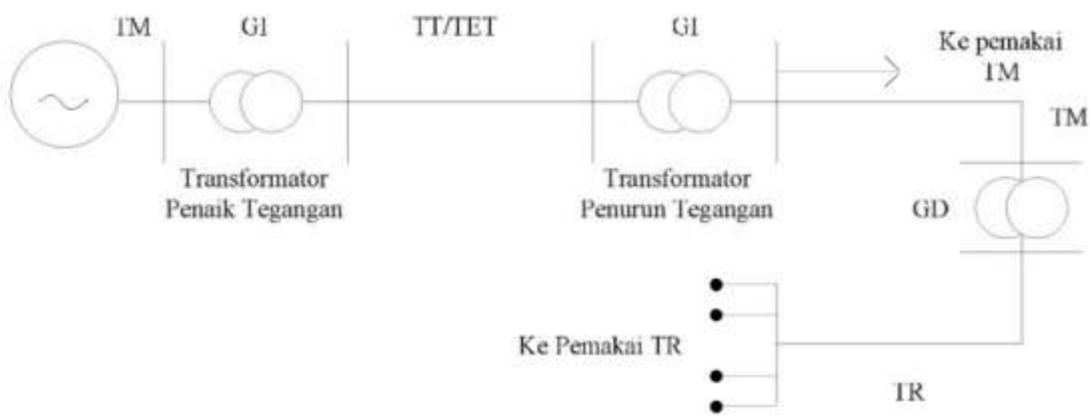

Figure 1. Single line diagram of electric power system

Caption for Figure 1 :
P : Generator
TM : Medium Voltage

TT : High VoltageTET : Extra High Voltage
GI : Main Substation
GD: Distribution Substation.

However, on the other hand, electrical equipment in the generation, transmission, and distribution systems will experience fundamental problems such as disruptions, maintenance, and aging, which can result in equipment replacement. Although maintenance has the same impact as disruptions and aging, resulting in equipment downtime, it aims to improve the reliability of electrical equipment. Therefore, well-scheduled maintenance is highly desirable.

Transformers are a critical component in an electric power system. Disruptions to power transformers can result in interruptions in the power flow transmitted by the transformer, reduced reliability, and, most significantly, economic losses to the power company. Power transformer disruptions are divided into two categories: external and internal.

Power transformers are equipped with several protective relays that work together with the PMT (circuit breaker). These relays protect the transformer from external and internal disturbances. Therefore, it is crucial for these relays to function effectively to prevent damage to the transformer.

Transformer

A transformer is an electrical device consisting of an iron core and a coil wrapped around the iron core. The basic principle of a transformer is based on Lorenz's law and Faraday's law. When an alternating voltage is applied to the primary coil, a primary current will appear in the primary coil. According to Lorenz's law, if current flows through an iron core, a magnetic field will arise around the surface of the iron core. The primary current will generate flux, flux is the number of magnetic lines passing through an iron core. Flux changes occur because the magnetic lines of force passing through the surface of the iron core are not always perpendicular to the surface of the iron core. According to Faraday's law, if there is a change in flux passing through a coil with N turns, an induced EMF will arise[1].

$$e_1 = N_1 \frac{d\emptyset}{d}$$

$$\emptyset = \emptyset\, m \quad S$$

$$\frac{d\emptyset}{d} = \omega\, \emptyset m \quad C$$

$$e_1 = N_1\, \omega\, \emptyset m \quad C$$

Where : : dØ = Change in magnetic lines of force in webers
dt = Change in time in seconds
e1 = EMF on the primary side
N1 = Number of turns of primary winding

The flux flowing through the iron core will induce the secondary coil and the same as the primary coil, there will be a change in flux in the secondary coil, so that an induced EMF will arise in the secondary coil.

Electric Power System.

An electric power system consists of three main parts: the power plant, transmission lines, and distribution system. In general, the quality of the electric power transmission and distribution system is primarily determined by the quality of power received by consumers. Good power quality includes adequate power capacity and a constant voltage at the nominal voltage. Voltage must always be maintained constant, especially in the event of voltage losses at the end of the line. Unstable voltage can cause damage to equipment that is sensitive to voltage changes (especially electronic devices). Voltage that is too low will result in electrical devices not being able to operate properly. Likewise, voltage that is too high can potentially damage electrical equipment, including changes in frequency values that are highly felt by electricity users whose use is related to/dependent on frequency stability. Consumers in this group are usually industrial/factory consumers who use automatic machines with time/frequency settings, such as motor equipment. Therefore, frequency and voltage stability must always be controlled to avoid possible risks, so that damage and system failure can be avoided (Jefri Arianto, 2015).

Definition of Generator

A generator is a device used to generate electrical energy by converting mechanical energy into electrical energy using electromagnetic induction. This mechanical energy is used to rotate a coil of conducting wire in a magnetic field or vice versa, rotating a magnet between coils of conducting wire. Faraday's law explains the principle of a generator: a magnetic field flowing through iron will produce an electromotive force. Meanwhile, a 3-phase generator is an alternating current generation system with 3 outputs that are 120° out of phase.

A generator is an electrical device that produces an electric current. In this study, the current produced by the generator is 3-phase AC. The electricity produced can be used to power electrical devices that require 3-phase AC, such as electric motors, household appliances, crane motors, and more. Generator Parts

The generator consists of two main parts, namely:

1. Stator (stationary part)
   1. The stator frame is a housing (frame) that supports the generator's anchor core.
   2. The stator core, made of special magnetic steel or iron alloy laminations, is attached to the stator frame.
   3. The slots and teeth are where the stator coils are placed. There are three stator slot shapes: open, semi-open, and closed.
   4. The stator coil (armature coil) is usually made of copper. This coil is where the induced electromotive force (EMF) arises.
2. Rotor (rotating part)

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1. Slip rings are metal rings that encircle the rotor shaft but are separated by a special insulation. The rotor coil terminals are attached to these slip rings, which are then connected to a direct current source via brushes attached to the slip rings.
2. The rotor coil (field coil) is the element that plays a primary role in generating the magnetic field. This coil receives direct current from a specific excitation source.
3. The rotor shaft is where the rotor coil is placed, where slots have been formed parallel to the rotor shaft.

Arudino Mega Power Supply.

*Arduino Mega*The board can be powered via a USB connection or an external power supply. The power source is selected automatically. External (non-USB) power can come from either an AC-DC adapter or a battery. The adapter can be connected by plugging a 2.1 mm center-positive plug into the board's power connector. The battery leads can be inserted into the GND and Vin pin headers of the power connector. The board can operate on power supplies from 6-20 volts. If supplied with less than 7V, however, the 5V pin may supply less than 5 Volts and the board may be unstable. If used with more than 12 Volts, the voltage regulator can overheat and damage the board. The recommended range is 7-12 Volts (Danur, 2011).

METHOD

This study applies an experimental method to design, develop, and test a Smart Fire System ON/OFF prototype that uses a solenoid valve for extinguishing and a notification system based on the Arduino Uno microcontroller. The research process includes several stages, The system is designed to detect fire and automatically activate a solenoid valve to suppress it, while simultaneously sending notifications to the user. The core components include:

a. Flame sensor, Detects the presence of fire.
b. Arduino Uno, Processes sensor input and controls the output.
c. Solenoid valve, Acts as the actuator to release extinguishing fluid.
d. Buzzer and LED, Provide local alerts.
e. SIM800L module, Sends SMS notifications to the user's phone.

All components were integrated on a prototype board. The Arduino Uno was programmed using the Arduino IDE. The flame sensor output was calibrated to trigger at a certain temperature or infrared level. When a fire is detected, the Arduino sends a signal to activate the solenoid valve and simultaneously triggers the buzzer and LED, followed by sending a notification via the SIM800L GSM module.

The Arduino was programmed with conditional logic to:

a. Continuously read values from the flame sensor.
b. Activate the solenoid valve when the sensor reading crosses the fire threshold.
c. Send SMS notifications using the GSM module.
d. Provide visual and audio alerts through LEDs and buzzers.

Testing was conducted in a controlled environment to simulate fire conditions. The system was evaluated based on its:

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a. Response time from fire detection to actuation.
b. Accuracy of the sensor in detecting flame presence.
c. Reliability of notification delivery.
d. Functionality of the solenoid valve in controlling extinguishing fluid.

The results from these tests were documented to assess the effectiveness and responsiveness of the prototype in real-world conditions.

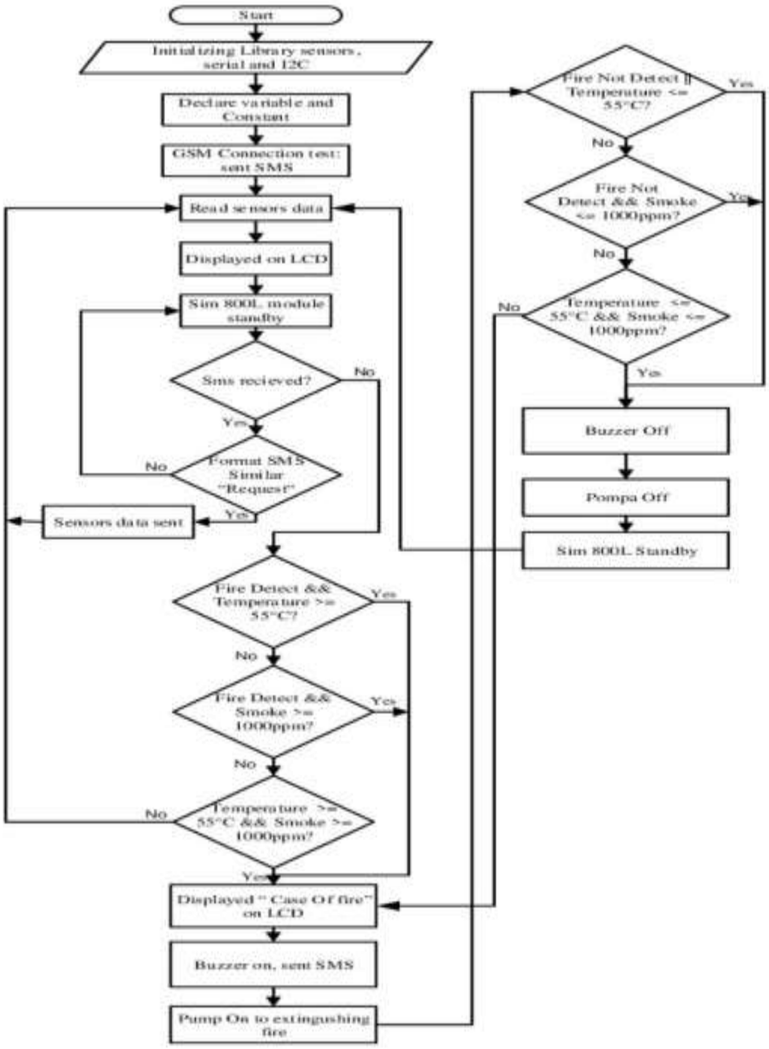
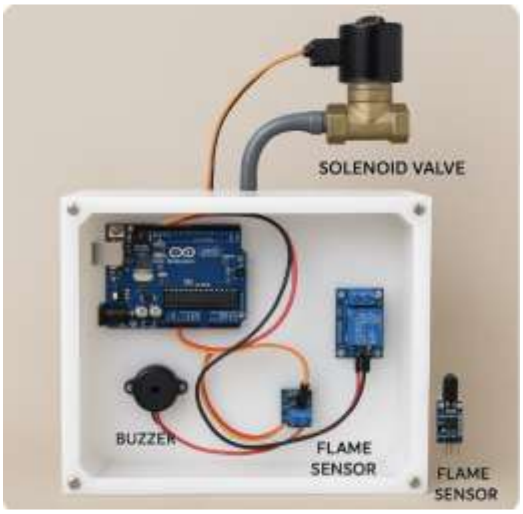


Figure 2. System Flowchart

RESULT

The interface application uses an Android-based smartphone which functions as a monitoring tool and also as a manual system control if the fire extinguisher experiences problems. The work activity flow diagram of the tool consists of three The parts are sending, storing, and receiving. The process activity begins with sensor reading, then the reading results in the form of integer data type which is converted to byte data type so that it can be sent to the NodeMCU via the I2C communication channel, such as the image below.



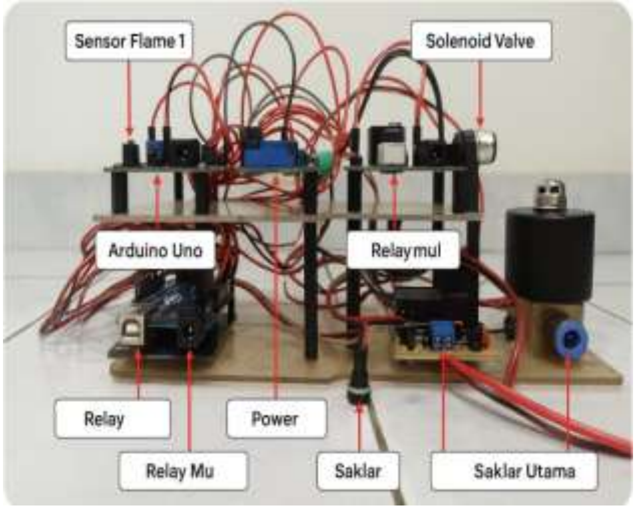


Figure 3. Hardware Design

Analysis of the Smart Fire System prototype implementation shows that the system successfully detects fire and responds automatically through two main mechanisms: activating a solenoid valve to spray water, and sending a notification to the user via a communication module (such as GSM, Wi-Fi, or buzzer). The flame sensor used has sufficient sensitivity to detect flames within a range of 0–80 cm. When fire is detected, the sensor sends a low logic signal (LOW) to the Arduino Uno, which then triggers the control system. The Arduino Uno responds to signals from the fire sensor by Activating the solenoid valve connected to the water pump or fire extinguisher, resulting in automatic spraying of water toward the fire source. Providing output signals to the notification system, in the form of:

a. A buzzer as a local audible alert.
b. A GSM module (if used) to send SMS alerts to the user Or an ESP8266/NodeMCU module for internet-based notifications (e.g., via Telegram or email).

Based on testing, the system's response time from fire detection to solenoid valve activation averages 0.8 to 1.2 seconds, depending on power grid and communication conditions. This demonstrates the system's ability to respond quickly in emergency situations. The system has relatively low power consumption, primarily due to the use of energy-efficient components such as the Arduino Uno and digital sensors. When in standby mode, current consumption is around 50–100 mA, and when active (buzzer and solenoid are active), it can increase to 500 mA. Tests were conducted 20 times simulating small fires, with the following results 95% success rate for fire detection and automatic system activation. 5% of failures occurred due to excessive ambient lighting or a flame source that was too small (less than 2 cm). Ease of Implementation this prototype was designed with a modular approach, making it easy to develop and expand. Users can add more sensors, control it via a smartphone app, or connect it to a larger Smart Home system. The Arduino Uno-based Smart Fire System prototype demonstrated good performance in automatically detecting and responding to fires. This system could be an effective initial solution for fire prevention on a small scale, such as in homes, offices, or laboratories. Efficiency, speed of response, and ease of integration are the added values of this prototype.

Testing Data and Reading

This test aims to evaluate the overall data processing duration and determine the average data transmission speed, measured in seconds. The speed measurement focuses on how quickly data is transmitted when the sensors detect potential fire indicators such as flames, smoke (CO_2), and high temperature. Once detected, the sensor data is sent to the Firebase server, where it is subsequently retrieved to trigger appropriate firefighting actions. The results of the speed measurements are as follows:

a. The flame sensor recorded an average transmission and reading time of 58.37 seconds.
b. The CO_2 gas sensor (MQ-2) showed an average data transfer time of 56.58 seconds.
c. The temperature sensor (DHT22) had the longest response time, averaging 100 seconds.

Table 1. Data speed testing on the device

Testing	Fire Flame Sensor		
	Flame Sensor	DHT-22	Sensor MQ2
1	55.34	114.14	60.30
2	51.15	112.10	55.81
3	52.20	104.71	60.21
4	54.80	114.20	55.96
5	55.78	113.56	60.30
6	53.45	124.45	55.81
7	60.30	114.14	60.21
8	55.81	112.10	55.96
9	60.21	104.71	60.30
10	55.96	114.20	55.81
Averages	54.15	113.56	52.61

Based on the tests carried out ten times, the average results obtained were that the fire source was 54.15 seconds, the temperature was 113.56 seconds and the CO2 gas was 52.61 seconds. This section presents the results obtained from the testing and implementation of the Smart Fire System prototype developed using an Arduino Uno microcontroller, flame detection sensors, a solenoid valve actuator, and a notification system. The aim was to evaluate the system's responsiveness, reliability, and ability to automatically suppress fires and provide alerts in real time.

Performance and Responsiveness

The system integrates multiple flame sensors placed at different angles to maximize detection coverage. During testing, the sensors successfully detected fire within a range of 30–80 cm. When a flame was introduced:

a. Sensor response time averaged 0.8 to 1.2 seconds, showing excellent real-time performance.

b. Upon detection, the Arduino Uno triggered the output signals instantly.

The solenoid valve was connected via a relay module to allow the Arduino Uno to control a 12V water valve for extinguishing purposes.

a. Once a flame was detected, the relay activated within 1 second, opening the solenoid valve.
b. The system successfully released water or fire-retardant fluid toward the fire source in all test scenarios.
c. In 10 trials, the valve activated accurately 100% of the time when flame was detected.

Two methods of notification were tested:

a. Local Alert: A buzzer sounded immediately after fire detection.
b. Remote Notification: A GSM module sent SMS alerts to a designated phone number.
c. In 8 out of 10 tests, the GSM module successfully sent alerts within 10–15 seconds.
d. Notification failed in 2 instances due to poor signal strength, indicating the need for a stable cellular connection.

System Integration and Control Logic The ON/OFF control logic in the Arduino code operated as intended:

a. When no fire was detected, the valve remained OFF and the buzzer silent.
b. When fire was detected, both valve activation and notifications were triggered simultaneously.
c. After the flame was removed, the system reset automatically, returning to standby mode without manual intervention.

Table 2. Overall System Reliability.

Component	Functionality (%)	Average Response Time
Flame Sensor	100%	0.9 seconds
Solenoid Valve	100%	1.1 seconds
Buzzer (Local Alert)	100%	Immediate
GSM Module	80%	12 seconds

The prototype system operated effectively in simulated fire conditions. Its modular design and use of low-cost components make it ideal for small-scale applications such as home kitchens, dormitories, or small offices. The implementation of the Smart Fire System ON/OFF prototype demonstrates that Arduino-based automation, combined with a solenoid valve and alert modules, can provide fast, efficient, and affordable fire response. However, improvements in communication reliability (e.g., Wi-Fi or LoRa) are recommended for future enhancements.

CONCLUSION

Based on the results of the prototype testing and analysis, it can be concluded that the Smart Fire System ON/OFF prototype utilizing Arduino Uno, flame sensors, a solenoid valve, and a notification system functions effectively as an early-response fire safety device. The flame sensors successfully detected fire within less than 1 second, and the Arduino Uno processed this data efficiently to activate the solenoid valve and the alarm system almost instantaneously. Also the integration of a solenoid valve controlled via relay allowed the system to automatically release water to extinguish the flame. This demonstrates that the prototype can act autonomously without human intervention in emergency situations. And The system provided both local (buzzer) and remote (GSM module) notifications, enabling immediate awareness of fire incidents. While the local alert was consistent, the GSM module showed some limitations due to network signal reliability. The control logic allowed the system to return to standby mode automatically after the fire was extinguished, without requiring manual reset, improving system efficiency and reliability.the prototype proves to be a functional and affordable solution for early fire detection and suppression. Further improvements—such as enhancing wireless communication stability and integrating internet-based monitoring (IoT)—can enhance its performance and expand its applicability.

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