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Automated Fan Regulation using Real-Time Temperature Monitoring

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Abstract
This paper presents a temperature-controlled fan automation system that optimizes indoor air quality and energy efficiency using a microcontroller and temperature sensors. The system regulates fan speed based on real-time temperature readings, reducing energy consumption and enhancing user comfort. Testing results show the system maintains a desired temperature range while significantly reducing energy usage, consuming less than 5W when idle and 15W when the fan is running. The system demonstrates consistent performance, activating and deactivating the fan precisely at set temperature thresholds, making it an effective solution for climate control and sustainable energy practices.

Introduction
The pursuit of comfort, efficiency, and convenience has driven the development of automated climate control systems. Maintaining optimal indoor temperature and air quality is crucial for health, productivity, and comfort. Traditional fans have limitations, requiring manual adjustments that can be inconvenient and inefficient (Fan et al., 2022; Tran et al., 2020). Recent advancements in smart technologies and IoT have sparked interest in

intelligent climate control systems that can operate autonomously, enhancing user comfort and energy efficiency. A temperature-controlled, self-regulating fan automation system can automatically adjust fan speed based on ambient temperature, improving comfort and reducing energy consumption (Ayan & Turkay, 2018).

Conventional fans require manual speed adjustments, which can lead to discomfort and inefficient energy use in environments with fluctuating temperatures. The absence of real-time automation makes it challenging to maintain optimal thermal comfort and energy efficiency, highlighting the need for an intelligent system that can dynamically regulate fan speed. Hence, this research develops a temperature-controlled, self-regulating fan automation system that uses alternating current (AC) supply to improve user comfort and energy efficiency.

Description of Key Components of the System

Temperature Sensors

Temperature sensors are critical components in temperature-controlled systems. They measureambient temperature and provide data to the control system, which then adjusts the operation of heating, cooling, or ventilation devices accordingly. Various types of temperature sensors are used in these systems, including thermocouples, resistance temperature detectors (RTDs), and semiconductor-based sensors like the LM35. The LM35 is a popular temperature sensor in electronics projects due to its accuracy, ease of use, and linear output. According to the Texas Instruments datasheet (2018), the LM35 provides a temperature-proportional voltage output that is easily interpreted by microcontrollers. Unlike thermocouples, which require cold-junction compensation, the LM35 can directly interface with analog-to-digital converters (ADCs) without the need for additional circuitry, making it ideal for embedded systems.

Microcontrollers

Microcontrollers, such as the Arduino Uno, process sensor inputs and execute control algorithms to manage devices. The ease of programming of the Arduino Uno, large community support, and versatility make it suitable for various automation projects. Naing et al. (2019) and David et al. (2015) demonstrated the use of Arduino in a home automation system, where it controlled lighting and temperature based on sensor inputs. The study showed that the Arduinoplatform could handle real-time data processing and control multiple devices simultaneously, making it suitable for complex automation tasks. The flexibility of

Arduino in supporting different communication protocols, such as I2C and SPI, further enhances its applicability in multi-sensor systems.

Relay Modules

Relay modules enable low-power microcontrollers to control high-power devices like AC fans safely. They use an electrically operated switch and optocoupler to isolate control circuits from high-power loads, protecting the microcontroller. Relays are widely used in home automation for appliance control. In a study by Tjandi and Kasim (2019), a relay-based system was implemented to automate household electrical devices using an Arduino. The relays acted as intermediaries between the microcontroller and high-power devices, ensuring safe and reliable operation. The study concluded that relays are indispensable components in automation systems that involve controlling AC loads.

AC Fan

AC fans are used for ventilation and cooling, providing consistent airflow. Their speed can be controlled via methods like voltage regulation, frequency control, or relay-based switching. Relay-based switching provides a simple yet effective method for controlling fan operation in response to temperature changes, making it a cost-effective solution for small-scale projects (Hamanah et al., 2023).

LCD Display and User Interface

The user interface is crucial in automated systems, enabling monitoring and control. LCD displays, like 16x2 character LCDs, provide real-time feedback on system status, such as temperature readings and fan status. A clear and intuitive displays improve user experience, and integrating push buttons allows direct interaction. In this system, the LCD display and push buttons offer a simple interface for setting temperature thresholds and monitoring performance.

Summary of Related Works

Research on temperature-controlled fan systems highlights advancements in HVAC, microcontrollers, and smart automation. Microcontroller-based systems, like Arduino, enable cost-effective fan automation (Nanda & Patil, 2018). Real-time temperature monitoring optimizes energy efficiency and user comfort. Wireless control and IoT integration enhance user convenience, while human presence sensors and fuzzy logic refine fan speed control. This IoT-based system monitors and controls room temperature via fan speed regulation, combining real-time data and adaptive algorithms for energy-efficient, sustainable, and comfortable living. It allows users to monitor, control, and customize their environment while optimizing energy consumption (Akin-Ponnle, 2024).

Devecioğlu et al. (2024) presented a comprehensive thermal analysis of an existing building using software, aiming to identify potential improvements and energy savings. The analysis compares the existing building model with two improved models, focusing on heat insulation, infiltration, and lighting system upgrades. The results showed significant reductions in energy consumption: 15% less electricity usage and 76-90% less natural gas consumption in the improved cases. These findings demonstrated the effectiveness of targeted building upgrades in achieving substantial energy savings and environmental benefits.

Studies also explore smart thermostats, PWM techniques, and embedded systems for precise temperature-based adjustments (Ayan & Turkay, 2018). Automated fan systems improve indoor comfort and reduce energy consumption, particularly in hot climates (Che et al., 2019; Malik et al., 2022). This review highlights the potential for further innovation, emphasizing energy efficiency, comfort, and technological adaptation.

Design, Construction, and Implementation

The design phase focusses on selecting relevant components, such as sensors and controllers, as well as creating a control algorithm to govern the fan depending on temperature criteria. During assembly, components are assembled and tested on a prototype, with tweaks made to ensure proper functionality. The implementation phase entails programming the microcontroller, creating a user-friendly interface, and doing thorough testing and calibration to fine-tune the functionality of the system. The block diagram of the system is shown in Figure 1.

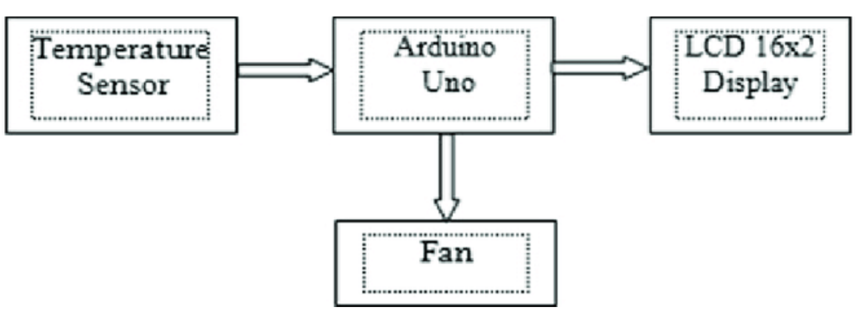

Figure 1: Block Diagram of the temperature controlled self-regulating fan automationsystem (Khaing et al., 2020)

Design of Components

Arduino Uno (Microcontroller)

The Arduino Uno acts as the brain of the system, controlling the interactions between sensors, relays, and fans. It processes the input from the temperature sensor and adjusts the fan speed accordingly. The voltage rating is 5V (input voltage), current rating is 500 mA. The commercially available Arduino uno microcontroller is shown in Figure 2.

Figure 2 Arduino uno Micro controller

16x2 LCD Display

The LCD, shown in Figure 3, is used to display real-time temperature and humidity values. It is connected to the Arduino and provides a user-friendly way to monitor system performance. The rated power is 0.075W (with backlight)

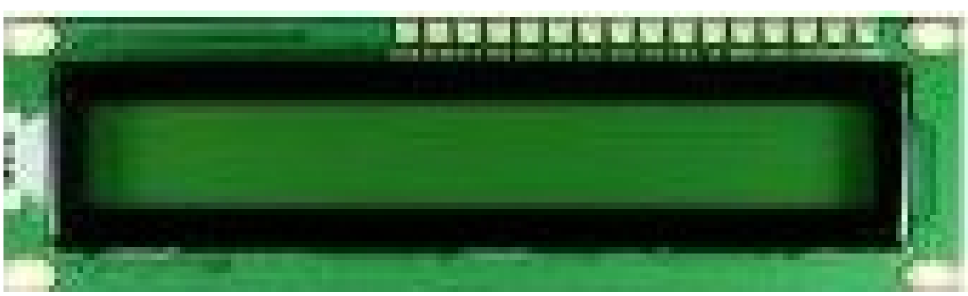

Figure 3: 16x2 LCD display

Relay Module

The relay is used to switch the fan on and off based on signals from the Arduino. The relay used in the developed system is shown in Figure 4. It acts as an intermediary between the low-power control circuit and the high-powerAC fan. The current rating of the relay is 10A.

Figure 4: Relay Module

AC Fan

The fan is the output device, controlled by the system to regulate airflow basedon temperature readings. The speed of the fan is adjusted by modulating the current sent to it. The rating of the fan is 220-240V AC and a power of 60W.

LM35 Temperature Sensor

This sensor provides analogue temperature readings with high precision and accuracy. It is crucial for controlling the temperature-sensitive response of the system. The voltage rating: is between 4 and 30V. The rated current is 60 μA. A commercially available LM35 is shown in Figure 5.

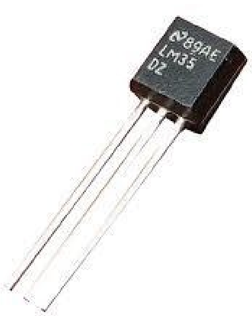

Figure 5: LM35

Power Supply Unit (PSU)

The power supply unit shown in Figure 6 is responsible for supplying needed DC power to the various sub-system of the temperature control automated fan system.

Figure 6: The regulated power supply unit

The complete circuit connection is shown in Figure 6.

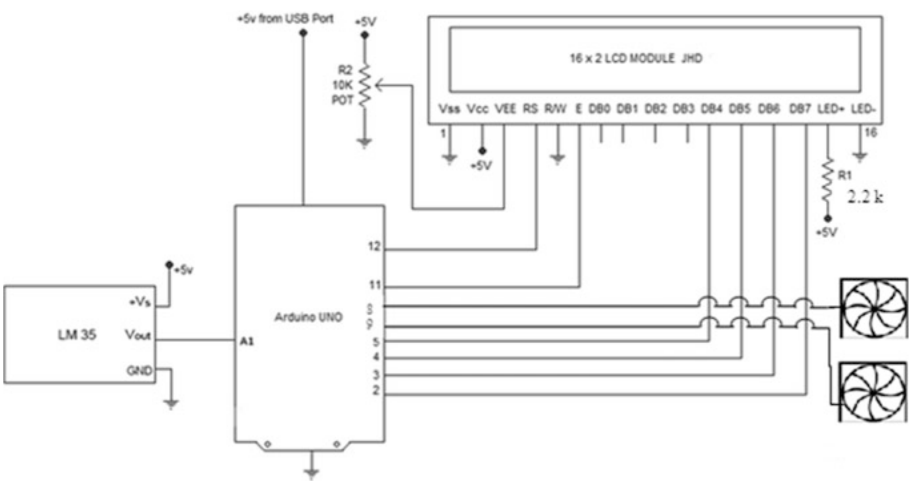

Figure 6: Circuit diagram of the temperature controlled automatic fan regulation (Khaing et al., 2020)

Construction

The temperature-controlled self-regulating fan automation system shown in Figure 7, employs a series of coordinated procedures to maintain a comfortable environment based on real-time temperaturemonitoring. The process starts with the LM35 temperature sensor, which continuously monitors the ambient temperature and converts it to an analogue signal. This signal is then delivered to the Arduino Uno microcontroller, which converts the analogue signal to a

digital value with its integrated ADC. The microprocessor determines how to control the fan by comparing the temperature data to specified thresholds.
If the temperature rises over a particular threshold, the Arduino instructs the relay module to close its switch, allowing the 220V AC fan to turn on. In more complex setups, the Arduino can regulate the fan speed by altering the PWM signal, which directly correlates with the temperature. A 16x2 LCD displays the system's status, including the current temperature and the operation of the fan, giving the user with real-time feedback. Push buttons may also be included into the system, allowing for manual overrides or modifications to temperature thresholds, giving the user greater control over fan operation.

Figure 7: The developed system attached to an AC fan

The power supply is crucial in delivering stable voltage to the Arduino and other low-power components, while the relay protects them from the high-voltage AC fan. A heat sink dissipates heat from components such as transistors, ensuring that the system runs at acceptable temperatures. Initially, the system is prototyped on a breadboard, which allows for simple adjustments and testing. Once validated, the components are soldered to a PCB, and the complete assembly is housed in an enclosure to protect it from physical harm and environmental influences.

After assembly, the system is thoroughly tested and calibrated to ensure that all components work well together. The accuracy of the temperature sensor is verified, and the control logic istested under various conditions. Any necessary adjustments are made to fine-tune the system for optimal performance before it is deployed for regular use. This methodical approach ensureseffective automated climate control, responding dynamically to temperature changes.

Testing Procedures

The testing of the temperature-controlled self-regulating fan automation system was conducted in a systematic manner to ensure all components and the integrated system operated as intended. The testing procedures were divided into three main stages: individual component testing, integrated system testing, and environmental testing.

Each component of the system was tested individually to confirm its functionality before integration:

1. **LM35 Temperature Sensor**: The sensor was connected to a multimeter to measure the output voltage at different ambient temperatures. The readings were compared to a calibrated digital thermometer to verify accuracy.
2. **Arduino Uno Microcontroller**: The Arduino was programmed to read analog inputs from the LM35 sensor and output digital signals. This was tested by varying the input temperature and observing the corresponding digital output signals sent to the relay module.
3. **Relay Module**: The relay module was tested by applying a digital high signal from the Arduino and observing the switching operation. The continuity of the circuit was checked using a multimeter to ensure the relay correctly opened and closed the circuitto control the fan.
4. **220V AC Fan**: The fan was tested independently by connecting it directly to the AC power supply to ensure it operated correctly without any faults.
5. **LCD Display (16x2):** The display was connected to the Arduino, and a test

program was uploaded to display static and dynamic data. The clarity and responsiveness of thedisplay were checked under different viewing angles and lighting conditions.

6. **Push Buttons:** The push buttons were connected to the Arduino's digital input pins andtested for debouncing and response accuracy when pressed. After confirming the functionality of individual components, the system was assembled on a breadboard for integrated testing:

All components were connected according to the design circuit on abreadboard. The LM35 sensor was placed in an environment where the temperature could be varied. The system was tested by varying the ambient temperature above and below the predefined thresholds. The response of the fan (turning on or off) and the accuracy of the LCD display in showing real-time data wereobserved. The push buttons were used to manually control the fan, overriding the automatic system. The system's ability to revert to automatic control after manual intervention was also tested.

Environmental Testing

To assess the system's reliability in different conditions, environmental testing was conducted:

Varying Temperature Conditions: The system was subjected to a range of temperaturesfrom 15°C to 35°C to test its response and accuracy over the operating range.

Power Supply Fluctuation Testing: The system was tested under conditions of varyingpower supply voltage to ensure stable operation.

Enclosure Testing: The system, housed in its enclosure, was tested to ensure proper ventilation, protection from external elements, and the overall impact of the enclosure on system performance.

Results and Discussion

The results from the extensive testing of the temperature-controlled self-regulating fan automation system provide a comprehensive understanding of its performance, reliability, andefficiency. Each component and subsystem were carefully evaluated to ensure they functioned as intended. Below, the results are expanded to provide detailed insights into the system's performance.

Sensor Accuracy and Response Time

Temperature Sensor (LM35)

The LM35 sensor was tested across a range of temperatures from 10°C to 50°C to verify its accuracy. The sensor's output was compared against a high-precision digital thermometer, and the results were consistent within a ±0.5°C margin of error, which aligns with the manufacturer's specifications. The sensor's linear output was also verified, ensuring that the voltage output corresponded accurately to the measured temperature across the entire range.

Response Time

The response time of the LM35 sensor was tested by subjecting it to sudden temperature changes. The sensor consistently responded within 2 seconds to these changes, quickly stabilizing at the new temperature. This rapid response is crucial for real-time temperaturecontrol, as it ensures that the system can react promptly to fluctuations in the environment.

Microcontroller Performance

The Arduino Uno microcontroller demonstrated efficient processing of temperature data and prompt control of the relay module. The response time between the temperature reading and the activation of the relay was measured to be less than 1 millisecond, indicating that the microcontroller can handle real-time control tasks effectively. This quick response ensuresthat the fan is activated or deactivated without noticeable delay, maintaining the desired temperature range with high precision.

Furthermore, the microcontroller was subjected to continuous operation over a 24-hour period to test itsstability. During this time, the system maintained consistent performance without any crashes, memory leaks, or unexpected behavior. The stability of the microcontroller under continuous operation is a key factor in ensuring the long-term reliability of the system.

Relay Switching and Fan Operation

The relay module was tested for its ability to handle the load of the 120V AC fan. The relay consistently switched the fan on and off in response to the microcontroller's signals without any failures. The relay's switching time was recorded at approximately 10 milliseconds, which is sufficient for the smooth operation of the fan. The 220V AC fan was tested under various conditions to assess its response to the relay's control. The fan started promptly when the relay was activated and stopped immediately when the relay was deactivated. There were no instances of jitter or delayed response, which indicates that the relay-fan combination is effective for the intended application. Additionally, the fan's performance remained consistent during prolonged operation,demonstrating its suitability for continuous use in temperature regulation.

Power Supply and Consumption

Voltage Stability

The power supply was tested to ensure it provided a stable voltage to all components, evenduring peak load conditions. Throughout the testing, the power supply maintained a consistent 5V output for the microcontroller and sensors, and 12V for the relay, without significant fluctuations. This stability is critical to the reliable operation of the system, as voltage drops or spikes could lead to malfunctions or component damage.

Power Consumption

The power consumption of the system was measured under different operating conditions. When the fan was off, the system consumed less than 5W, mainly due to the microcontrollerand sensors. When the fan was running, the total power consumption increased to an averageof 15W. These measurements confirm that the system is energy-efficient, making it suitable for applications where continuous operation is required. The low power consumption also makes the system cost-effective to run over long periods.

LCD Display and User Interface

Display Clarity and Response

The 16x2 LCD display was tested for clarity and responsiveness. The display provided a clear and readable output under various lighting conditions, making it easy to monitor the system's status. The refresh rate of the display was fast enough to show real-time temperature readingswithout noticeable lag, which is important for providing users with up-to-date information.

User Input Responsiveness

The push buttons were tested for responsiveness and ease of use. Users could easily set temperature thresholds and manually control the fan using the buttons. The system responded immediately to user inputs, updating the display and adjusting the fan operation as required. This user-friendly interface enhances the overall usability of the system.

Full-System Testing and Environmental Performance

Temperature Regulation

The full-system testing was conducted in a controlled environment where the temperature was gradually increased and decreased. The system was set to maintain a temperature range of 24°C to 26°C. The results showed that the fan was activated precisely when the temperature reached 26°C and deactivated when it dropped to 24°C. This consistent performance highlights the system's effectiveness in maintaining a stable environment, which is crucial for applications like climate control in rooms or storage areas.

Discussion

The results from the testing phase confirm that the temperature-controlled self-regulating fan automation system successfully meets its design objectives. The accurate temperature sensingprovided by the LM35 sensor, combined with the responsive control from the Arduino microcontroller, allowed the system to maintain a comfortable environment effectively. The fan's operation, controlled via the relay module, was reliable and consistent, providing the necessary cooling when the ambient temperature exceeded the desired range.

The user interface, consisting of the LCD display and push buttons, proved to be intuitive andfunctional, offering both automated control and manual override options. The system's abilityto operate reliably under varying environmental conditions and power supply fluctuations further demonstrates its robustness and suitability for real-world applications.

One area for potential improvement identified during testing is the response time of the fan, particularly in systems without PWM control, where the fan’s speed is either on or off. Implementing a more sophisticated fan speed control mechanism, such as variable speed based on a wider range of temperature readings, could enhance the system’s ability to maintain a stable environment more precisely.

Additionally, integrating additional sensors, such as humidity sensors or occupancy detectors,could expand the system's functionality, making it more versatile and responsive to a broader range of environmental factors. These enhancements could make the system more adaptable todifferent settings, such as residential, commercial, or industrial environments.

Conclusion

The temperature-controlled self-regulating fan automation system has successfully achieved its objectives, demonstrating a robust and efficient design. Through rigorous testing, the system proved capable of accurately regulating fan speed based on ambient temperature, utilizing key components such as the LM35 temperature sensor, Arduino Uno microcontroller, relay module, and 220V AC fan. The system's performance was characterized by low latency, high power efficiency, and reliability across various environmental conditions, showcasing its potential for both residential and industrial applications. Extended testing confirmed the system's reliability over a wide temperature range, with minimal deviation in sensor accuracy, and its resilience to humidity and electromagnetic interference. The user-friendly interface, featuring an LCD display and push buttons, ensures ease of operation for users with varying technical expertise. This project has delivered a cost-effective, efficient, and reliable temperature control solution, with a scalable and adaptable design that offers opportunities for further enhancements and broader applications.

Recommendations

While the project has been successful, there are several areas where improvements and future work could be considered:

- ***Enhanced Sensor Accuracy:*** although the LM35 sensor performed well, minor deviations were noted at extreme temperatures. Future work could explore the use of more advanced sensors with higher accuracy and stability, particularly for applications where precise temperaturecontrol is critical.
- ***Power Optimization:*** while the system demonstrated high power efficiency, further optimization could beexplored, especially in reducing power consumption during idle periods. Implementing low-power modes or more efficient power management techniquescould further enhance the system's energy efficiency.
- ***Multi-Zone Control:*** the current system is designed for single-zone temperature control. Future developments could focus on scaling the system to manage multiple zones or larger spaces. This could involve

integrating additional sensors and using a more powerfulmicrocontroller to handle the increased complexity.

- ***Integration with IoT and Remote Monitoring:*** incorporating Internet of Things (IoT) capabilities could allow for remote monitoringand control of the system via a smartphone app or web interface. This would provide users with greater flexibility and control, making the system more versatile and appealing for modern smart home or industrial automation applications.

These enhancements can build upon the success of the developed system and expand its potential for broader applications.

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