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Adaptive Ceiling Fan Automation System for Homes and Public Spaces

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Abstract: The Adaptive Ceiling Fan Automation System is a smart IoT solution designed to enhance energy efficiency by regulating fan speed based on environmental factors, such as temperature, humidity, and human presence. It utilizes the DHT11 sensor, ultrasonic sensors, and an ESP8266 microcontroller to dynamically control the fan, thereby minimizing energy consumption. The system is integrated with Firebase and a mobile application, allowing users to remotely monitor and manage fan operations. By optimizing energy usage and improving user convenience, this system is well-suited for residential, commercial, and public environments.

Key Words: IoT Automation; Smart Fan Control; Energy Optimization

1. Introduction

In modern households and public spaces, inefficient fan usage leads to energy wastage and higher electricity costs. Traditional ceiling fans require manual operation, making them inconvenient and unsustainable, especially when users forget to turn them off. To address this issue, the Adaptive Ceiling Fan Automation System offers an IoT-based smart solution that automates fan control based on temperature, humidity, and human presence. By leveraging DHT11 sensors, Ultrasonic sensors for motion detection, and an ESP8266 microcontroller, the system intelligently adjusts fan speed, optimizing energy consumption. Additionally, Firebase cloud integration and a mobile application provide users with remote monitoring and control. This system not only reduces manual effort and energy wastage but also promotes a sustainable and smarter living environment for homes, offices, and public spaces.

2. Material and Methods

The Adaptive Ceiling Fan Automation System is an IoT-based solution designed to regulate ceiling fan operations efficiently by considering real-time environmental factors. The system combines temperature and humidity sensors, a motion detection sensor, a microcontroller, and cloud-based data storage to enable automated and remote fan control. The methodology is categorized into three major phases: system design and hardware integration, software implementation, and system testing.

System Design and Hardware Integration:

The system automates fan operations by analyzing environmental data such as temperature, humidity, and human presence. The ESP8266 NodeMCU microcontroller was selected as the core component due to its built-in Wi-Fi capability, facilitating seamless data exchange with the Firebase cloud database and a mobile application for remote control and monitoring.

- **DHT11 Sensor:** Measures temperature and humidity in real-time and transmits the data to the ESP8266.
- **Ultrasonic Sensor:** Detects human presence and measures distance to ensure that the fan operates only when someone is in the room, reducing unnecessary energy consumption.

The architecture consists of the following key components:

- **NodeMCU ESP8266 Microcontroller:** Acts as the system's central controller, processing sensor data and enabling communication with the cloud.
- **L298N Motor Driver:** Controls the fan's speed dynamically based on temperature variations.
- **Relay Module:** Turns the fan ON or OFF based on sensor inputs or user commands from the mobile application.
- **Power Supply:** Provides stable voltage to the entire system to ensure smooth operation.

Interconnections:

- DHT11 and Ultrasonic sensors are connected to the GPIO pins of the ESP8266 to collect data.
- The relay module is linked to the ESP8266 to control the fan's ON/OFF state.
- The L298N motor driver adjusts the fan's speed based on temperature data.
- Firebase handles sensor data storage and processes user commands from the mobile app.

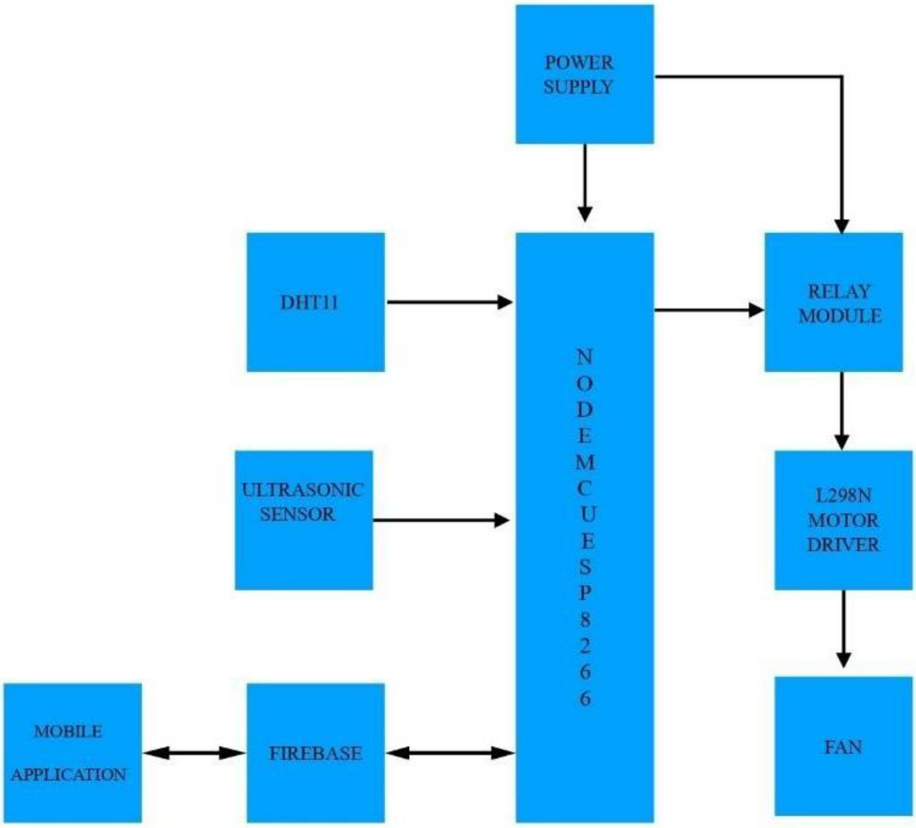

Figure no 1: *System Design and Architecture*

The mobile application enables users to monitor real-time temperature, humidity, and fan status remotely. The integration of cloud storage ensures data logging and remote access for improved control over fan automation.

Software Implementation:

The software was developed in two main parts: firmware for the ESP8266 microcontroller and a mobile application for remote control. The microcontroller was programmed using Embedded C in the Arduino IDE. Libraries for DHT11, Firebase and Wi-Fi were integrated into the firmware to facilitate sensor communication and cloud connectivity.

The microcontroller continuously reads temperature and humidity values from the DHT11 sensor and checks for motion detection from the Ultrasonic sensor. Based on predefined threshold values, the fan is automatically turned on or off, and its speed is adjusted accordingly. The logic for fan control is as follows:

- If temperature exceeds a set threshold and motion is detected, the fan turns ON and adjusts its speed based on the temperature range.
- If no motion is detected for a specified duration, the fan turns OFF to prevent unnecessary energy consumption.
- If the temperature drops below the threshold, the fan operates at a lower speed or turns OFF based on real-time conditions.

The system transmits sensor data and fan status to Firebase Realtime Database, enabling cloud-based monitoring. A mobile application was developed using MIT App Inventor, allowing users to remotely access real-time sensor readings, manually control the fan, and receive alerts.

Cloud Integration and Mobile Application Development:

The Firebase Realtime Database was used for storing and retrieving sensor values and user commands. The ESP8266 sends sensor data to Firebase at regular intervals, ensuring up-to-date information for the mobile application. When a user changes the fan status through the mobile app, the command is updated in Firebase, and the ESP8266 retrieves it to adjust the fan operation accordingly. The mobile application was developed with a simple interface, allowing users to:

- View real-time temperature, humidity, and fan status.
- Manually control the fan (ON/OFF, speed adjustment).
- Receive alerts if temperature exceeds a critical threshold.

To make this smart system easy to use, we built a mobile app using MIT App Inventor. It allows users to log in, select a room, and check live readings for temperature and humidity. When Mobile Mode is turned on, users can manually turn the fan on or off and adjust the speed to their liking. If Mobile Mode is off, the system runs completely on its own based on sensor data. This gives users the freedom to control the system when they want, or just let it run automatically when they don't. It's all about making everyday comfort easier and more energy-efficient.

System Testing and Evaluation

The system was tested under different environmental conditions to assess automation accuracy, real-time response, and energy efficiency. Various test scenarios were designed, including:

1. **Temperature-Based Fan Control:**
   - The system was tested in environments with varying temperatures to ensure that the fan speed adjusts correctly.
   - The temperature threshold was modified to observe its impact on automation accuracy.

2. **Motion-Based Fan Activation:**
   - Motion detection accuracy was tested by introducing and removing human presence from the room.
   - The system's ability to turn the fan off after a specific inactivity period was evaluated.

3. **Cloud and Mobile Application Performance:**
   - The mobile app was tested for real-time updates and remote-control response time.
   - Data synchronization between the ESP8266 and Firebase was analysed to ensure minimal latency.

4. **Energy Consumption Analysis:**
   - The system's energy efficiency was compared with traditional manually operated fans.
   - The reduction in power usage due to automated fan control was recorded and analysed.

Inclusion criteria:

1. Suitable for homes, offices, and public spaces with ceiling fans.
2. Requires a Wi-Fi-enabled environment for cloud-based control.
3. Works with smartphones for remote monitoring via a mobile app.
4. Uses temperature, humidity, and motion sensors for automated fan control.
5. Supports cloud-based data logging for historical analysis.

Exclusion criteria:

1. Not for outdoor spaces or extreme environments (e.g., high humidity, industrial areas).
2. Incompatible with manual, non-electric, or battery-powered fans.
3. Does not function without Wi-Fi or internet access.
4. Not integrated with other smart home devices (e.g., Alexa, Google Home).
5. Users without a smartphone cannot fully utilize remote control features.

3. Result

Login Page is the initial screen where users enter their registered credentials to log into the app. It ensures secure access by verifying the username and password before granting control of the fan system. Ensures that only registered users can interact with the fan control system, thereby enhancing privacy and system protection.

If the user is new, they can create an account through this screen by providing basic details like username and password. Once registered, they can proceed to log in and use the app's features as shown in Figure no. 3 Provides a seamless onboarding experience for first-time users.

***Figure no 2**: Login Page*

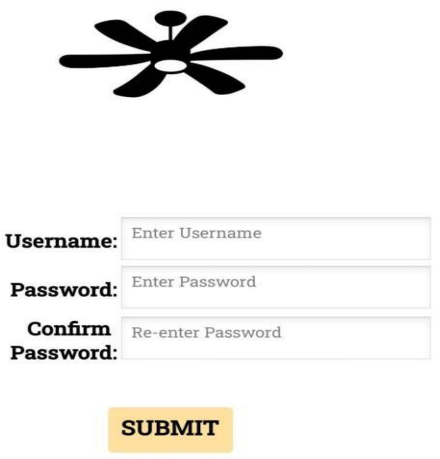

***Figure no 3:** Registration Page*

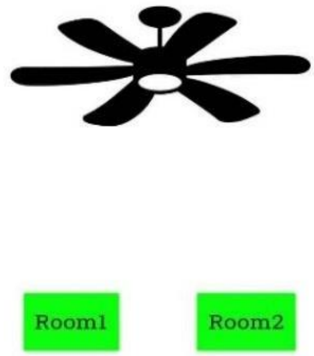

Figure no 4: *Room Selection Page*

After successful login, the user is directed to this screen to select a specific room where the fan needs to be controlled. This helps in identifying and managing multiple fan setups in different rooms.

Figure no 5*: Main Functionality Page*

From Fig no. 5 we can see that mobile mode option is given to enable manual control so that users can control fan speed and update fan status based on his/her requirements. This is the main functional screen where the user can turn on the mobile mode and control the fan. It allows manual or automated control of the fan depending on the input from sensors and user preferences.

The below output screen demonstrates the working of the Adaptive Ceiling Fan Automation System. Figure no. 6 shows the overall view of the prototype, which includes two ultrasonic sensors for motion detection, a DHT11 sensor for temperature monitoring, two miniature fans (Fan 1 and Fan 2), relay modules, a microcontroller, and a motor driver. All components are interconnected to form a smart automation system. Figure no. 7 highlights the real-time response of the system, where Fan 1 activates automatically as soon as motion is detected by the corresponding ultrasonic sensor. This indicates that the system is capable of detecting human presence and selectively turning on the fan located in that area, thereby demonstrating the project's goal of energy-efficient and intelligent fan control in smart environment

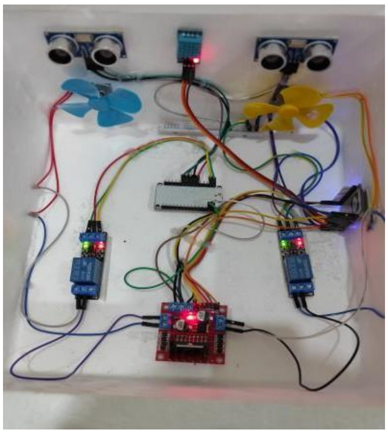

Figure no 6: *Overall View of Protype*

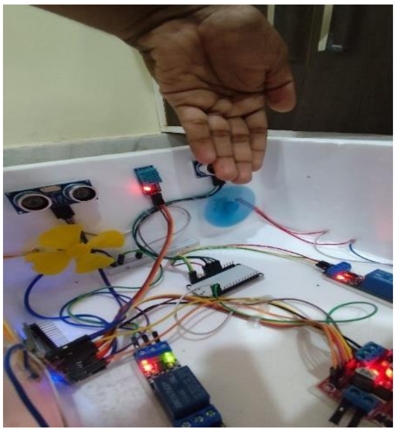

Figure no 7: *Fan1 Motion Detection*

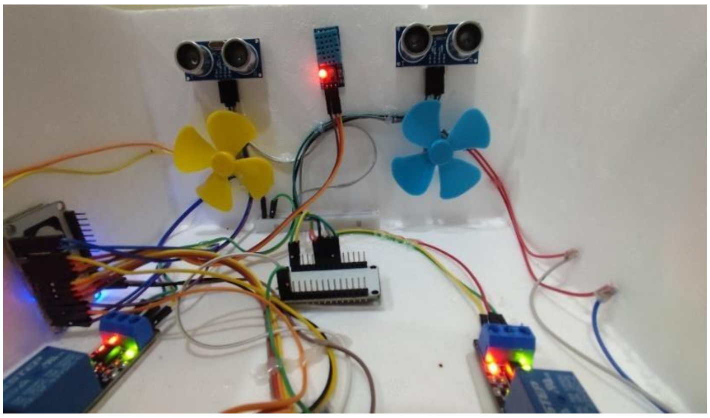

Figure no 8: *Fan1 and Fan2 are in off state*

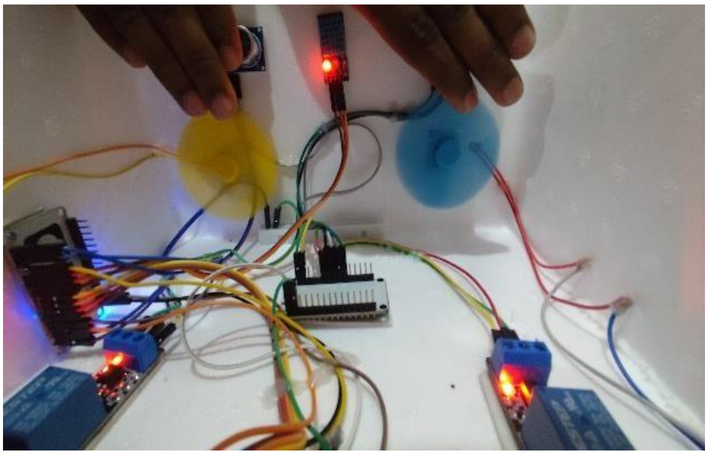

Figure no 9: *Fan1 and Fan2 are in on state*

The output screen shown above illustrates the dual fan control capability of the Adaptive Ceiling Fan Automation System. In Figure 7.1.7, both Fan 1 and Fan 2 are in the off state, indicating that no motion has been detected in the monitored areas. The system remains idle in the absence of human presence, ensuring minimal power consumption. In Figure 7.1.8, both fans are seen in the on state, activated as soon as motion is detected by their respective ultrasonic sensors. This demonstrates the system's ability to simultaneously detect motion in multiple zones and independently control the fans based on real-time human presence. The successful activation of both fans highlights the effectiveness of the prototype in providing intelligent, location-based fan operation, thereby supporting its goal of automation and energy efficiency.

4. Discussion

Improving energy efficiency and automating home appliances have become essential in modern smart home and public space management. Manual operation of traditional ceiling fans often leads to unnecessary energy consumption when users forget to turn them off. To solve this issue, the Adaptive Ceiling Fan Automation System leverages IoT-based automation and real-time environmental monitoring. The system uses a DHT11 sensor to monitor temperature and humidity and an ultrasonic sensor to detect human presence, ensuring that the fan operates only when needed. This automation helps reduce energy waste and lowers electricity bills.

The inclusion of ultrasonic sensors has improved the accuracy of motion detection. Unlike PIR sensors, which detect heat signatures and can produce false positives, ultrasonic sensors measure distance by transmitting sound waves. This results in more reliable presence detection, preventing unnecessary fan operation and promoting energy conservation. The system also dynamically adjusts fan speed based on temperature changes and turns off the fan when no occupants are present, ensuring efficient use of power.

Firebase cloud integration and a mobile application further enhance the system's functionality by enabling real- time data storage, remote monitoring, and control. Users can monitor room conditions, control fan speed, and switch the fan ON/OFF from any location using the mobile app. The system's adaptability allows it to be used effectively in homes, offices, hospitals, and public spaces where managing energy consumption is a priority.

Although the system delivers effective results, some challenges remain, such as potential Wi-Fi disruptions that may affect real-time synchronization. Introducing a battery backup could improve reliability during power outages. Future enhancements could include integrating machine learning algorithms to predict user behaviour for intelligent automation and enabling voice control with platforms such as Alexa and Google Home. Overall, the Adaptive Ceiling Fan Automation System offers an intelligent, energy-efficient, and scalable solution for optimizing fan operation and supporting sustainable living environments.

5. Conclusion

The Adaptive Ceiling Fan Automation System provides an efficient, smart, and sustainable solution for optimizing energy consumption in homes and public spaces. By leveraging IoT technology, including DHT11 temperature sensors, Ultrasonic sensors, and an ESP8266 microcontroller, the system intelligently adjusts fan speed based on real-time environmental conditions, reducing unnecessary power usage. Integration with Firebase cloud and a mobile application enables remote monitoring and control. This automation not only enhances user convenience but also significantly reduces electricity costs and promotes sustainability. With its scalable and adaptable design, the system represents a step toward energy-efficient smart living, making it a valuable addition to modern homes, offices, and public spaces.

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