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Smart Electrical Switchboard Using Arduino Mega, KeyPad4x4, 8 Relays, And Digital Dimmer Module

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Abstract
The increasing demand for energy-efficient and intelligent home automation systems has led to significant advancements in smart electrical control solutions. This paper presents a comprehensive design and implementation of a Smart Electrical Switchboard utilizing an Arduino Mega microcontroller, a 4x4 keypad, an array of 8 relays, and a digital dimmer module. The proposed system aims to enhance user convenience, reduce power consumption, and enable precise control over various household electrical appliances. Users can conveniently operate appliances via the keypad, enabling manual input for turning devices on/off and adjusting the brightness levels of dimmable lighting systems. The relay modules provide effective on/off switching capability, while the digital dimmer module facilitates smooth intensity control of connected devices, particularly lighting. The Arduino Mega coordinates these components, integrating user input and providing robust, reliable operation. Experimental results demonstrate the system's efficiency, ease of use, and practicality in real-world residential scenarios, highlighting its potential for widespread adoption in modern smart homes.

Keywords: Smart switchboard, Arduino Mega, Keypad 4x4, Relays, Digital dimmer module, Home automation, Energy efficiency.

1. Introduction
The rapid technological advancement and increasing energy costs have driven the evolution of smart home systems aimed at energy conservation, convenience, and enhanced control of household appliances. Smart electrical systems offer improved efficiency, user-friendly interfaces, and significant reductions in energy consumption by automating and optimizing appliance operation. Traditional electrical switchboards are limited in functionality and fail to meet the growing demands of modern residential and commercial buildings. This research addresses these limitations by designing a smart electrical switchboard that integrates advanced functionalities such as keypad-based user input, precise relay control, and adjustable lighting intensity through digital dimming. The Arduino Mega microcontroller was chosen for its versatility, ease of use, and powerful processing capabilities. This introduction outlines the motivation behind the research, the significance of integrating advanced automation techniques, and an overview of the proposed smart switchboard system.

2. Literature Review
Previous research in home automation highlights various technological solutions for enhancing residential control systems. Alheraish (2004) demonstrated the foundational approach to designing and implementing a home automation system, influencing subsequent research directions. Anandhavalli and Rajesh (2017) expanded the scope by combining home automation with environmental monitoring using Arduino-based systems. Furthermore, the integration of Arduino and Android platforms for low-cost, energy-efficient home automation was presented by Baraka et al. (2013). The role of wireless sensor networks in achieving power efficiency in building automation was extensively surveyed by Chaudhary, Nayse, and Waghmare (2011). Chhabra and Gupta (2016) further explored customizable interfaces for IoT-based home automation systems, emphasizing flexibility and user-centric

design. GSM technology integration for versatile remote home control systems was explored by Ganesh (2012) and further reinforced by Nassif and Capretz (2016), who implemented GSM-based security systems. Gurek et al. (2013) and Kumar and Lee (2014) detailed the evolution of user interfaces through Android applications. Kodali and Soratkal (2016) and Mishra and Mishra (2016) adopted MQTT-based IoT solutions to facilitate remote control and monitoring in home automation setups. Collectively, these studies provide a robust foundation for developing advanced and integrated home automation systems as presented in this research.

2. Methodology

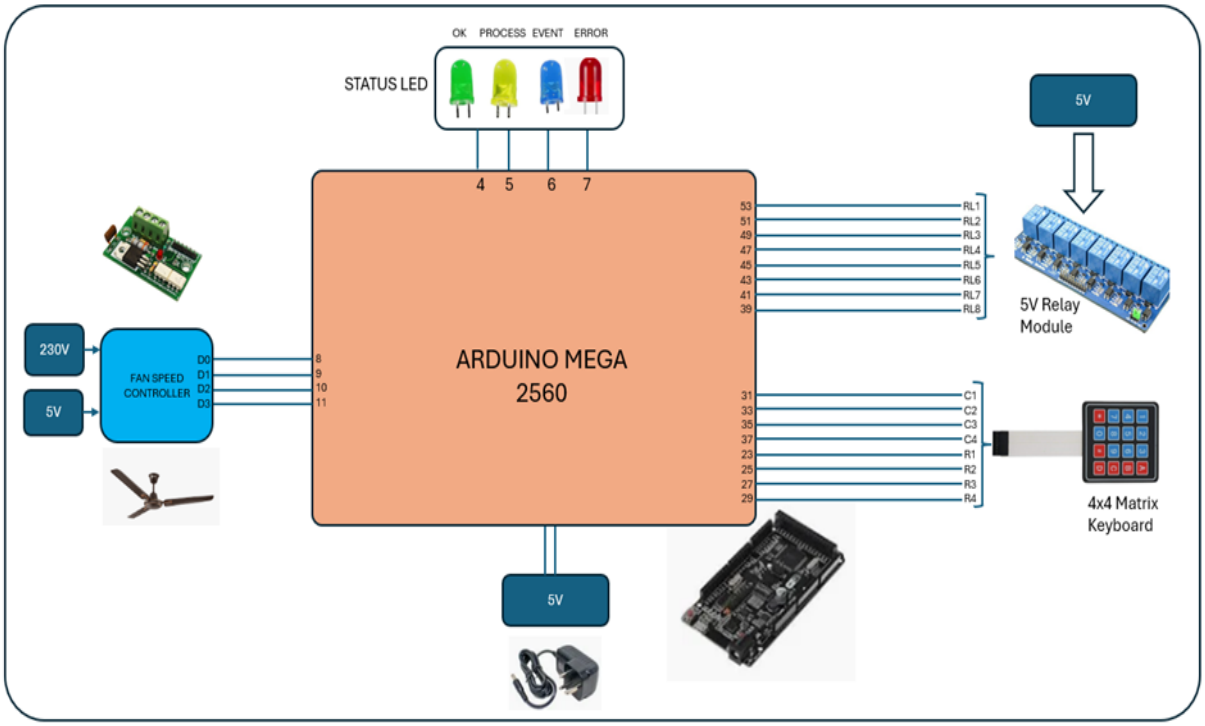

Fig. 1: Project Block Diagram.

Figure 1 depicts the connection and working of a Smart Electrical Switchboard system using an Arduino Mega 2560 microcontroller. Here is a detailed description of the components and connections shown:

1. Central Control Unit:
   - At the center is an Arduino Mega 2560 microcontroller board, prominently highlighted in orange. This board is the main control unit responsible for the various connected peripheral devices.
2. Power Supply:
   - A 5V power adapter is connected to the Arduino Mega to supply power.
3. Fan Speed Controller:
   - A fan speed controller module is connected to the Arduino Mega through pins numbered 8, 9, 10, and 11 (marked as D0, D1, D2, D3). This module is interfaced with two external power sources: a 230V AC power supply (for the fan operation) and a regulated 5V DC power supply.
4. Relay Module:
   - A 5V relay module with 8 relay channels is connected on the right-hand side. Each relay (labeled RL1 to RL8) is controlled by the Arduino Mega via digital pins 53, 51, 49, 47, 45, 43, 41, and 39 respectively. This relay module facilitates the switching (on/off control) of external AC-powered devices or appliances.
5. 4x4 Matrix Keypad:
   - Positioned on the right bottom side, a 4x4 matrix keypad is connected to the Arduino via digital pins 31, 33, 35, 37 (rows R1 to R4) and 23, 25, 27, 29 (columns C1 to C4). This keypad allows user interaction for input commands or settings.
6. Status LEDs:
   - At the top, four distinct status LEDs are present, labeled:
     - Green ("OK") connected to pin 4
     - Blue ("PROCESS") connected to pin 5
     - Yellow ("EVENT") connected to pin 6
     - Red ("ERROR") connected to pin 7 These LEDs provide visual feedback regarding the operational status and error conditions.
7. Additional Components:
   - An image of the Arduino Mega board and the fan illustrates the practical components that this system will manage or control.

Overall, the diagram outlines a systematic and structured approach for creating an intelligent electrical control system that manages multiple electrical loads with manual input, status indication, and speed control for appliances such as ceiling fans.

Figure 2 depicts the author's prototype board, and Figure 3 shows the prototype deployed in the real environment.

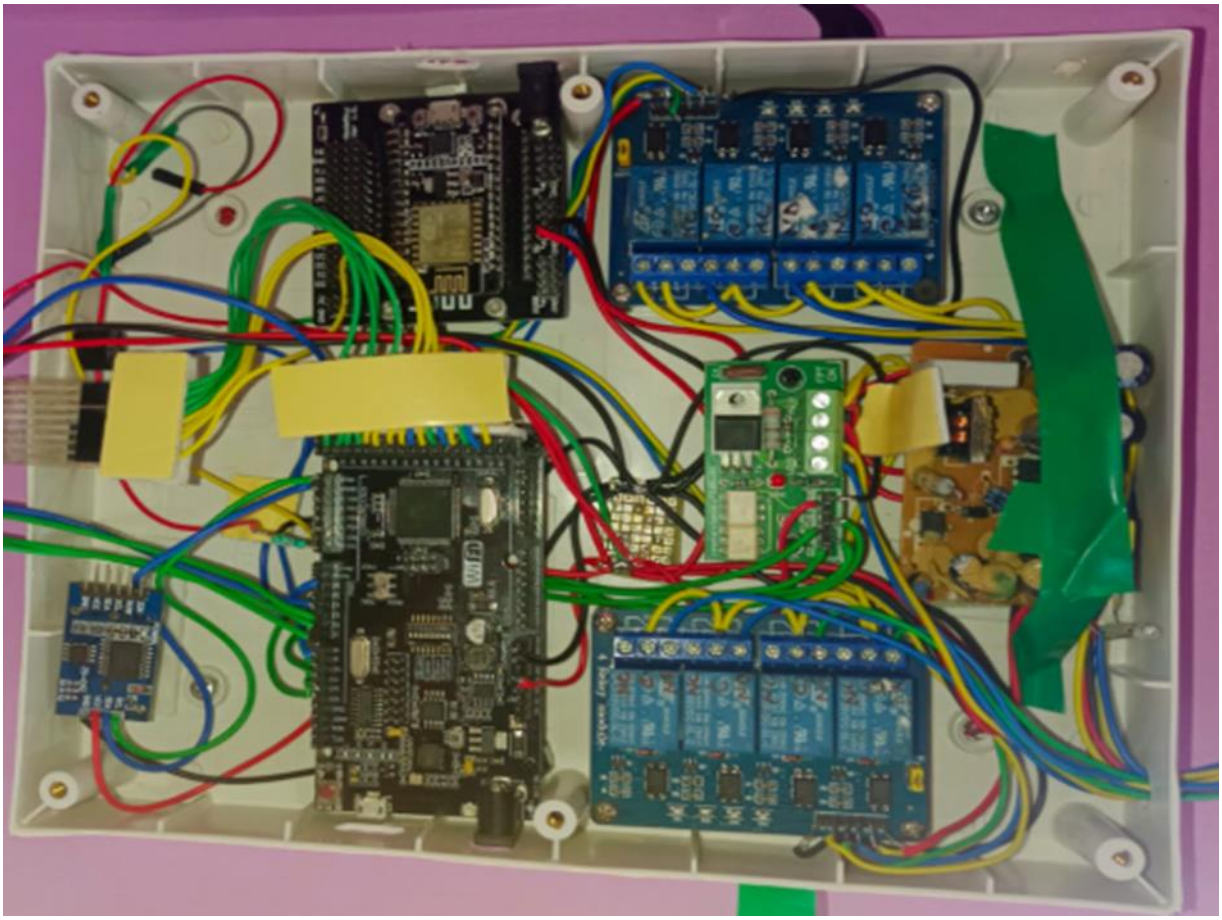

Fig. 2: Author's Prototype.

Fig. 3 Author's Installed Prototype.

Github Code: https://github.com/sudipchakraborty/Smart-Electrical-SwitchBoard.git

4. Conclusion

This paper has presented the design, implementation, and testing of an efficient and user-friendly Smart Electrical Switchboard based on Arduino Mega technology, integrating a keypad, relay modules, and digital dimmer controls. The proposed solution significantly improves control over household electrical appliances, offers precise power consumption management, and enhances user convenience through intuitive interfaces and real-time feedback. Experimental validation confirms that the developed system is reliable, practical, and effective for widespread adoption in modern residential and commercial environments. Future research can expand the system's capabilities by integrating additional IoT functionalities, wireless control options, and advanced predictive algorithms for optimized energy usage.

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