JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Implementation of Smart Home Applications through FPGA

***Bhogadi Praneetha*[1], *R.Raghunadha Sastry*[2], *Dr. N. Sambasiva Rao*[3]**

1. *PG Scholar, Department of EEE, NRI Institute of Technology, Agiripalli, India.*
2. *Associate Professor, Department of EEE, NRI Institute of Technology, Agiripalli, India.*
3. *Professor and HOD, Department of EEE, NRI Institute of Technology, Agiripalli, India.*

Abstract: This paper presents the integration of a smart home application with an EDGE Spartan 6 device utilizing the Internet of Things (IoT) technology. The rapid evolution of IoT has facilitated the development of innovative solutions for various domains, including home automation. Smart homes leverage IoT devices to enhance convenience, security, and energy efficiency. The utilization of FPGA-based EDGE Spartan 6 offers significant advantages in terms of real-time processing, low power consumption, and reconfigurability. In this work, we discuss the architecture, implementation, and performance evaluation of the proposed smart home system. Experimental results demonstrate the effectiveness and reliability of the system in providing intelligent automation and seamless connectivity in residential environments.

Keywords: Smart home, EDGE Spartan 6, FPGA, Home automation, Internet of Things

I. INTRODUCTION

The concept of smart homes, enabled by the Internet of Things (IoT), has gained considerable attention in recent years due to its potential to revolutionize residential living. Smart homes utilize interconnected devices and sensors to automate and monitor various tasks, enhancing comfort, security, and energy efficiency. Traditional microcontroller-based solutions for smart home applications have limitations in terms of processing power, flexibility, and scalability. Field-Programmable Gate Arrays (FPGAs) offer a compelling alternative, providing high-performance, reconfigurability, and real-time processing capabilities. Among FPGA platforms, EDGE Spartan 6 stands out for its cost-effectiveness, low power consumption, and versatility. In this paper, we propose an innovative smart home application integrated with an EDGE Spartan 6 FPGA, leveraging the capabilities of IoT technology.

II. PROBLEM STATEMENT

The contemporary landscape of smart home automation presents a myriad of challenges in achieving seamless integration, robust functionality, and user-friendly interfaces. Existing solutions often encounter obstacles related to hardware-software compatibility, sensor data processing, and remote accessibility. Moreover, ensuring reliability, accuracy, and efficiency in environmental monitoring, safety alerts, and home automation remains a formidable task. As such, there is a pressing need for an innovative solution that addresses these challenges comprehensively, offering a unified platform that seamlessly integrates hardware design, software development, and system integration. This solution should harness advanced technologies such as the EDGE Spartan 6 FPGA and VHDL programming to deliver precise control, accurate measurements, and intuitive user interfaces. By bridging the gap between hardware and software, this solution aims to provide a reliable, efficient, and user-centric smart home automation system that fulfills the diverse needs of modern households while simplifying the complexities associated with setup, operation, and maintenance.

III. Background Work

Environmental monitoring and control systems have become increasingly vital in various fields, including industrial settings, agriculture, smart cities, and home automation. These systems aim to gather comprehensive data about the surrounding environment and take appropriate actions based on the collected information. Traditionally, environmental monitoring relied on manual observations or rudimentary sensor setups, limiting the scope and accuracy of data collection. However, advancements in sensor technology, embedded systems, and communication protocols have paved the way for more sophisticated and integrated solutions.

One significant aspect of modern environmental monitoring systems is the utilization of various sensors to capture diverse environmental parameters accurately. Light Dependent Resistors (LDRs) are commonly employed for measuring ambient light levels, providing insights into luminosity variations over time. These variations can be critical in applications such as outdoor lighting control, greenhouse management, and security systems. Temperature sensors, ranging from thermistors to digital temperature sensors, offer precise measurements essential for monitoring temperature fluctuations. In environments where temperature control is crucial, such as server rooms, industrial processes, and HVAC systems, these sensors play a pivotal role in ensuring optimal conditions.

Gas sensors, like the MQ135 mentioned in the project setup, are invaluable for detecting the presence of harmful gases such as methane, carbon monoxide, and volatile organic compounds (VOCs). Early detection of gas leaks is paramount in preventing accidents and environmental hazards, making gas sensors indispensable in industrial, residential, and environmental monitoring applications. Infrared (IR) sensors complement these measurements by capturing infrared radiation, which can be utilized for various purposes, including thermal imaging, motion detection, and proximity sensing. These sensors find applications in security systems, medical devices, and industrial automation.

The integration of Field-Programmable Gate Arrays (FPGAs) in environmental monitoring systems adds a layer of flexibility and computational power. FPGAs are reconfigurable hardware devices capable of implementing complex logic and processing tasks in real-time. They offer advantages such as parallel processing, low latency, and high throughput, making them well-suited for applications requiring fast response times and high data processing capabilities. Additionally, FPGAs can interface with various sensors, communication modules, and output devices, facilitating seamless integration and control of the entire system.

IV. SYSTEM ARCHITECTURE

The proposed smart home system architecture comprises three main components: IoT devices, EDGE Spartan 6 FPGA, and a central control unit (server or gateway). IoT devices, including sensors and actuators, collect data from the environment and interact with the Spartan 6 FPGA through wireless communication protocols such as Wi-Fi or Bluetooth. The FPGA serves as the processing unit, executing control algorithms, data processing tasks, and interfacing with external devices with the help of VLSI programming dumped into it by using Xilinx software. The central control unit facilitates communication between the smart home system and external networks, enabling remote monitoring and control via smart phones or web interfaces. The architecture consists of

1. Edge Spartan 6:

The Edge Spartan 6 FPGA is a versatile programmable device known for its high-performance capabilities in various applications. Built on Xilinx's Spartan-6 FPGA architecture. The Spartan-6 LX9 FPGA which is commonly used in development boards typically offers around 120 I/O pins. It can be powered by a power connector. It features rich development with SPI FLASH, Wi-Fi, Bluetooth, ADC, DAC, LCD, 7 segment Display, VGA, PS2, Stereo Jack, and buzzer, Push Button, Slide Switch, LED, Temperature Sensor and LDR. The Board also provides additional interfaces like CMOS Camera and TFT Display at the expansion connectors. The EDGE board provides USB JTAG interface for Programming and Debugging. It also provides a USB UART interface.

Fig.1: Edge Spartan 6 FPGA board

2. Temperature Sensor

The LM35DZ is a precision temperature sensor that can measure temperature in Celsius with a linear output voltage. Its operating range is -55 deg Celsius to 150 deg Celsius. The scale factor is 10mV/ deg Celsius. It has three pins: VCC (power supply), OUT (analog output), and GND (ground). The VCC pin is used to provide power to the sensor (typically 5V). DAEnetIP1, DAEnetIP2 and DAEnetIP3 and all kits and modules based on these controllers.

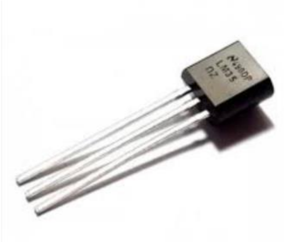


Fig.2: Temperature Sensor

3. Gas Sensor

An MQ-135 gas sensor is a simple-to-use sensor that can detect the presence of natural gas and other combustible gases. It can detect natural gas concentrations from 200–10,000 parts per million (ppm). The MQ-135 also has high sensitivity to methane, propane, and butane. It can also detect cooking fumes, cigarette smoke, and alcohol noise.

Fig.3: Gas Sensor

4. LDR Sensor

The Light Dependent Resistor Sensor used in this project to check the level of intensity of light. It consists of a semiconductor material whose resistance decreases as the intensity of light incident on it increases, and vice versa. When light falls on the sensor, photons excite electrons within the semiconductor material, causing a decrease in resistance and allowing current to flow more freely. Conversely, in low-light conditions, the resistance increases, restricting the flow of current. This change in resistance can be measured using an appropriate circuit, allowing the LDR sensor to detect variations in ambient light levels.

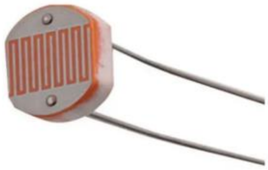


Fig.4: LDR Sensor

5. Buzzer

In this Research Work, a buzzer is utilized as a crucial component for alerting users about the presence of harmful gases beyond a preset threshold. Once the threshold is surpassed, the buzzer emits a continuous buzzing sound, providing a persistent auditory warning until the gas leakage is mitigated or resolved. This immediate and persistent alert system ensures timely response and action to prevent potential hazards or dangers posed by gas leaks.

Fig.5: Buzzer

6. ThingSpeak / ThingView Channel

Utilizing ThingSpeak channels in our project facilitates seamless data acquisition and analysis from FPGA-integrated temperature and LDR sensors. This centralized platform empowers efficient monitoring and evaluation of sensor readings, enhancing the project's reliability and scalability.

7. IR Sensor

Infrared (IR) sensors detect infrared radiation emitted by objects, providing valuable data beyond the visible spectrum. They are widely used in motion detection systems for security purposes and in proximity sensors for touchless interfaces. IR sensors also find applications in temperature measurement and thermal imaging, offering non-contact solutions for industrial, medical, and environmental monitoring. Their versatility and sensitivity make them essential components in diverse electronic devices and systems, enabling enhanced automation, security, and sensing capabilities.

Fig.6: IR Sensor

V. IMPLEMENTATION DETAILS

The implementation of the smart home application involves several stages, including hardware design, software development, and system integration. The EDGE Spartan 6 FPGA is programmed using Hardware Description Languages (HDL) such as Verilog or VHDL to implement the desired functionality, including sensor data acquisition, signal processing, and control logic. Additionally, software components are developed to interface with IoT devices, manage data communication, and provide user interfaces for remote access and control.The smart home applications work under the principle Finite State Machine. The Moore model promotes modularity which means it is a modular design approach, where each state corresponds to a specific behaviour or action of the system. This modularity makes it easier to add, remove, or modify functionality without affecting other parts of the system, which is beneficial in smart home applications with evolving requirements.

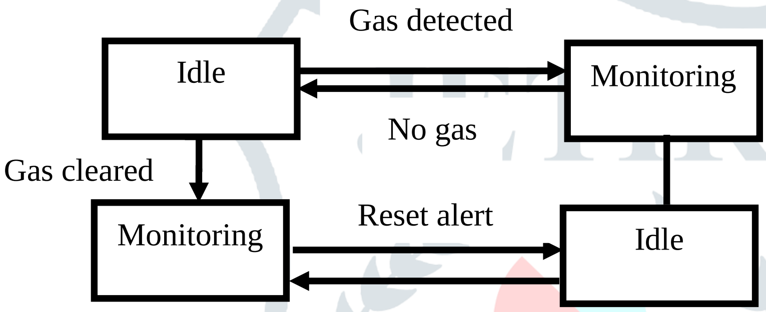


Fig.7: Flow Chart

In the state diagram [1] Idle: The system starts in the Idle state, where it continuously monitors for the presence of gas.[2] Monitoring: Upon detecting gas above a certain threshold, the system transitions to the Gas Alert state. In this state, alarms may be activated, notifications sent, or other precautionary measures taken.[3] Reset Alert: Once the gas levels drop below the threshold and the environment is deemed safe, the system transitions back to the Idle state. This transition occurs after the gas sensor indicates that the gas has cleared.

The transitions occur based on the gas sensor's readings, and appropriate actions are taken in response to these transitions, such as activating alarms or resetting alerts. The gas sensor's outputs (such as alarms or notifications) would be associated with the Gas Alert state in a Moore model, as the actions depend only on the current state.

The implementation of this project is done by writing the code in VHDL language. The respective pins are used to develop the output. The following are the pin assignments [1]clk: This signal is assigned to pin P84 on the FPGA. It likely represents the clock signal for your design, used for synchronization and timing purposes.[2] txd: This signal is assigned to pin P87 on the FPGA. It represents the transmitter data output from your VHDL design.[3] cs, din, do.[4] sc: These signals are assigned to pins P118, P119, P120, and P121 respectively. They are related to some communication interface, possibly SPI (Serial Peripheral Interface) or similar.[5] data(0) to data(7): These signals represent an 8-bit data bus. Each signal is assigned to a different pin on the FPGA, from P23 to P33.[6] lcd_e, lcd_rs: These signals are likely related to controlling an LCD display. lcd_e and lcd_rs may represent control signals for enabling the LCD and selecting command/data mode respectively. They are assigned to pins P35 and P34 respectively.[7] gsw, gas, ir, mot: These signals are assigned to pins P47, P85, P46, and P48 respectively. They likely represent various sensor inputs or control signals for external devices connected to the FPGA.

VI. Block Diagram

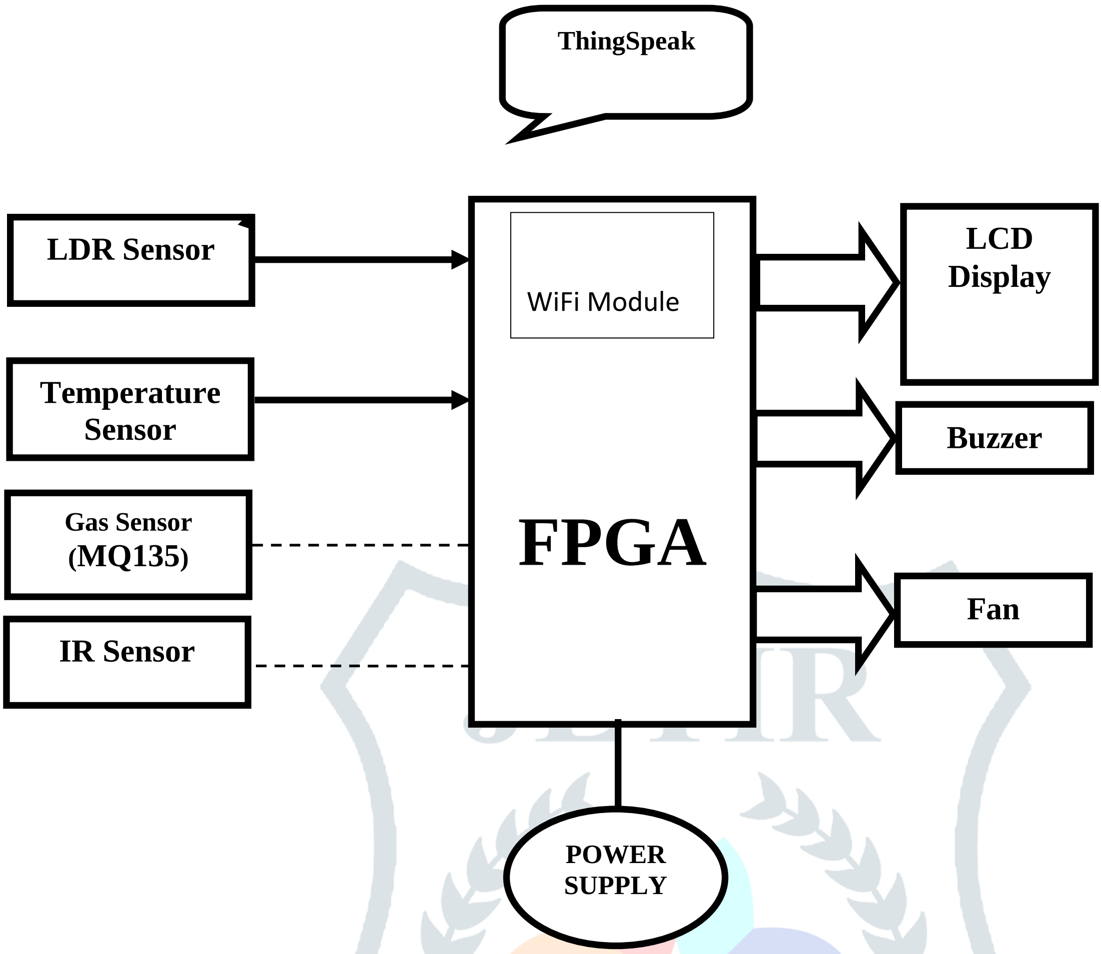


Fig.8: Block Diagram

In this Research work, the utilization of various sensors caters to the holistic collection of environmental data, offering a nuanced understanding of surrounding conditions. The LDR sensor provides insights into ambient light levels, aiding in the assessment of luminosity variations over time. Meanwhile, the temperature sensor offers precise measurements, crucial for monitoring and responding to fluctuations in temperature. The gas sensor, potentially the MQ135, plays a pivotal role in detecting methane presence, enabling proactive measures to be taken in the event of gas leaks or environmental hazards. Additionally, the IR sensor captures infrared radiation, providing valuable information for diverse applications such as thermal imaging or motion detection. Within the FPGA, the incorporation of a built-in Wifi module elevates the system's capabilities by enabling seamless connectivity to wireless networks. This connectivity not only facilitates efficient data transmission but also empowers remote monitoring, enhancing accessibility and flexibility in monitoring environmental conditions. Furthermore, the integration of a display, likely an LCD, serves as a vital interface for visualizing the collected data in a user-friendly manner, promoting effective analysis and decision-making. Alongside these components, the inclusion of a buzzer and a fan amplifies the system's functionality, allowing for the provision of timely alerts and the regulation of environmental conditions in response to predefined thresholds or user preferences. Through VHDL programming, the FPGA serves as the central orchestrator, seamlessly integrating sensor inputs, managing network connectivity, and orchestrating the control of output devices. This programming paradigm enables the implementation of sophisticated algorithms and logic, ensuring efficient data processing, real-time responsiveness, and adherence to predefined user requirements. Overall, the amalgamation of these components and technologies exemplifies a holistic approach to environmental monitoring and control, showcasing the versatility and potential of FPGA-based systems in addressing diverse application scenarios.

VII. METHODOLOGY

The work flow for this project involves several key steps to ensure the successful integration and operation of the EDGE Spartan 6 FPGA Board with the various sensors and communication modules. Here's an elaboration of the implementation process:

1. Hardware Setup: Begin by configuring the hardware setup, including connecting the EDGE Spartan 6 FPGA Board to power and ensuring all necessary components and sensors are properly connected to the board's GPIO pins or other interfaces.

2. Sensor Integration: Each sensor (IR Sensor, Gas Sensor, LDR Sensor, and Temperature Sensor) needs to be interfaced with the FPGA board. This involves connecting the sensor's output pins to the appropriate input pins on the FPGA, and ensuring compatibility with voltage levels and signal types.
3. Sensor Calibration: Calibrate the sensors to ensure accurate and reliable measurements. This may involve adjusting sensor thresholds, scaling sensor outputs, or compensating for sensor drift.

4. FPGA Programming: Develop the FPGA firmware or HDL (Hardware Description Language) code to interface with the sensors, process sensor data, and control the output devices (such as the buzzer, LCD, and motor control). This code will typically involve configuring GPIO pins, implementing sensor reading algorithms, and controlling output signals based on sensor inputs.

5. Wireless Communication Setup: Configure the Wi-Fi module on the FPGA board to establish a connection to a local Wi-Fi network or hotspot. This may involve setting up network parameters, authentication, and encryption settings.

6. Data Transmission to Thingspeak: Develop the firmware to format and transmit sensor data to the Thingspeak platform using the Wi-Fi module. This may involve implementing communication protocols such as HTTP or MQTT, and formatting data packets according to Thingspeak's API requirements.

7. User Interface Development: Develop a user interface for monitoring sensor data and system status. This may involve programming the 16x2 LCD display to show real-time sensor readings and status messages, and implementing user interaction features such as buttons or switches to control system behaviour.

8. Integration with Thingsview Mobile App: Configure the integration between the Thingspeak platform and the Thingsview mobile app to enable remote monitoring and control of the system. This may involve registering the system with Thingspeak, obtaining API keys, and configuring data feeds for visualization in the app.

9. Testing and Debugging: Thoroughly test the system to ensure all sensors are functioning correctly, data transmission to Thingspeak is reliable, and user interface features are intuitive and responsive. Debug any issues that arise during testing and refine the implementation as needed.

10. Deployment and Optimization: Once testing is complete, deploy the system in its intended environment and optimize performance as necessary. This may involve fine-tuning sensor calibration settings, optimizing FPGA code for resource utilization and power efficiency, and addressing any usability issues based on user feedback.

VIII. XILINX EXECUTION

1. In this project we need to write VHDL code consists of six entities: WIFI, ADC, LCD, gas sensor, ir motor, and pin assignments.

2. The WIFI entity is responsible for handling Wi-Fi communication. It defines states and processes for transmitting data over Wi-Fi. It also includes baud rate generation and data transmission logic.

3. ADC entity represents an Analog-to-Digital Converter (ADC). It handles SPI communication, reads analog values from sensors (temperature and LDR), and converts them into digital data. It also includes processes for converting the digital data into ASCII format.

4. LCD entity controls an LCD display. It generates signals for enabling, sending commands/data, and selecting channels. It also includes a constant array of command/data sequences to display information on the LCD.

5. A gas sensor entity handles a gas sensor input and drives an LED output based on the sensor's input. When the switch is off (logic '0'), the LED is turned on.

6. IR motor entity manages an infrared (IR) sensor input and drives a motor output accordingly. When the IR sensor detects an object (logic '0'), the motor is turned on.

7. Pin assignments (`NET` statements) are provided for connecting signals to physical pins on the hardware.

8. The overall process involves reading sensor data, transmitting it over Wi-Fi, displaying it on an LCD, and controlling outputs (LED and motor) based on sensor inputs.

9. Each entity consists of processes sensitive to the clock (`clk`), which indicates synchronous behaviour.

10. The code follows a modular structure, with each entity responsible for specific functionalities, enhancing readability and maintainability.

11. The provided pin assignments map signals to specific physical pins on the hardware, ensuring proper connectivity between the VHDL design and the target device.

12. The code seems to be designed for an embedded system application, likely implemented on an FPGA or similar hardware platform.

13. Detailed behavioral descriptions are provided for each entity, outlining their functionality and interaction with external signals and components.

14. The processes within each entity are triggered by specific events (e.g., rising edges of the clock signal or changes in input signals), indicating sequential execution of tasks.

15. The entities likely interface with other hardware components (sensors, Wi-Fi modules, LCD display, LEDs, motor) to enable a complete system solution for monitoring environmental parameters and controlling actuators based on sensor inputs.

IX. RESULTS AND DISCUSSION

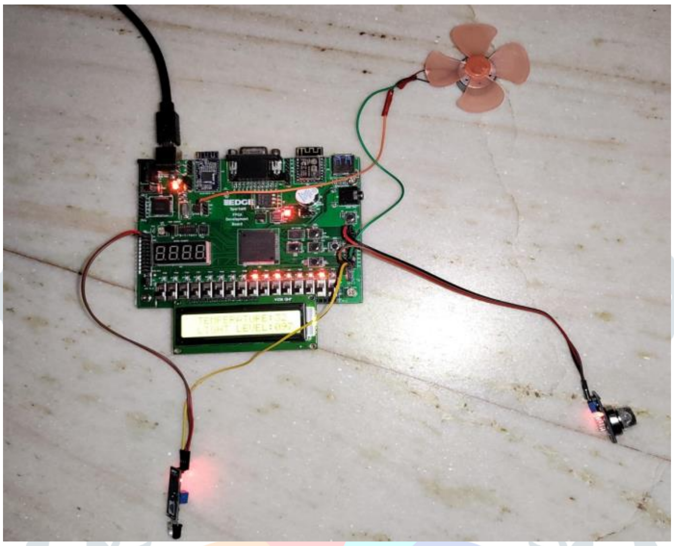


Fig.9: Hardware Model

In this scenario, the absence of detection near the IR sensor indicates that there is no movement, resulting in the fan remaining stationary. Such an application holds great potential for optimising energy usage in everyday situations, such as exhaust fans, by activating them intelligently only when a person is detected. By employing motion-sensing technology, unnecessary operation of fans can be avoided, leading to energy savings and enhanced efficiency. This approach not only contributes to cost reduction but also aligns with sustainability goals by minimising electricity consumption when ventilation is not required. Additionally, integrating motion detection with fan control adds a layer of convenience and automation to household appliances, making them more responsive to user presence and environmental conditions.

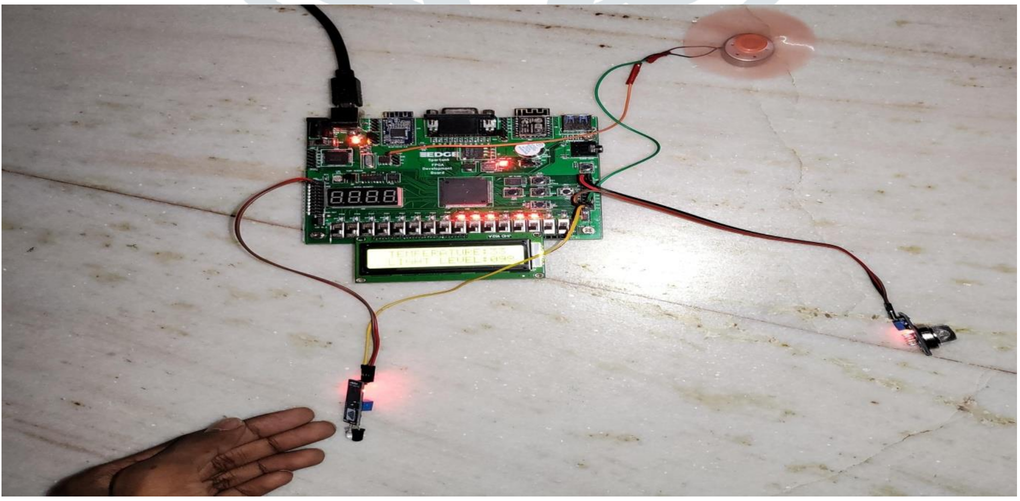


Fig.10: Working Model

In contrast to the previous scenario, the presence of a person detected by the IR sensor triggers the fan to turn on automatically in this figure. This automated response significantly enhances efficiency and convenience in everyday tasks compared to the previous setup. By activating the fan only when a person is detected, unnecessary energy consumption is minimized, leading to improved energy efficiency and cost savings. Moreover, this smart fan control system offers a more tailored and user-centric approach to ventilation, responding directly to the presence of individuals in the vicinity. Compared to traditional methods of fan operation, which rely on manual switches or timers, this automated system ensures optimal airflow based on real-time occupancy detection.

Additionally, the Gas Sensor (MQ135) plays a crucial role in detecting gas leaks, ensuring safety in various everyday scenarios. With its continuous monitoring capability, the sensor promptly triggers the buzzer upon detecting harmful gases, providing immediate alerts to users. This feature is invaluable in environments such as homes, offices, and industrial settings, where gas leaks pose significant risks to health and safety. By alerting occupants to potential hazards, the system enhances overall safety measures and minimizes the risk of accidents or adverse health effects. Furthermore, the real-time nature of the alerts enables timely intervention, mitigating potential damage and ensuring a safer living and working environment for individuals.

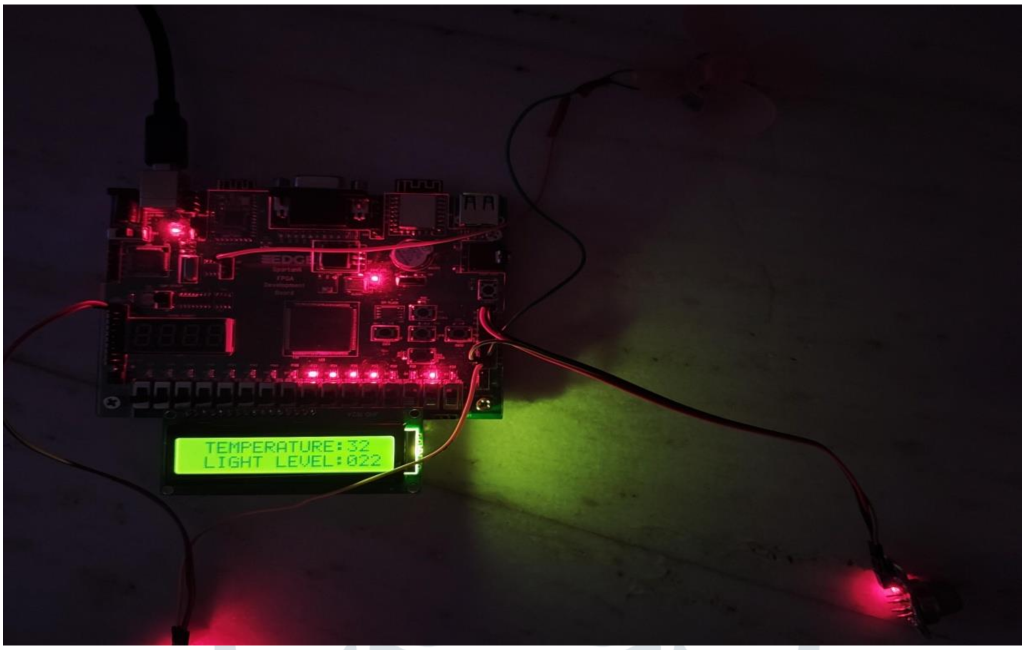
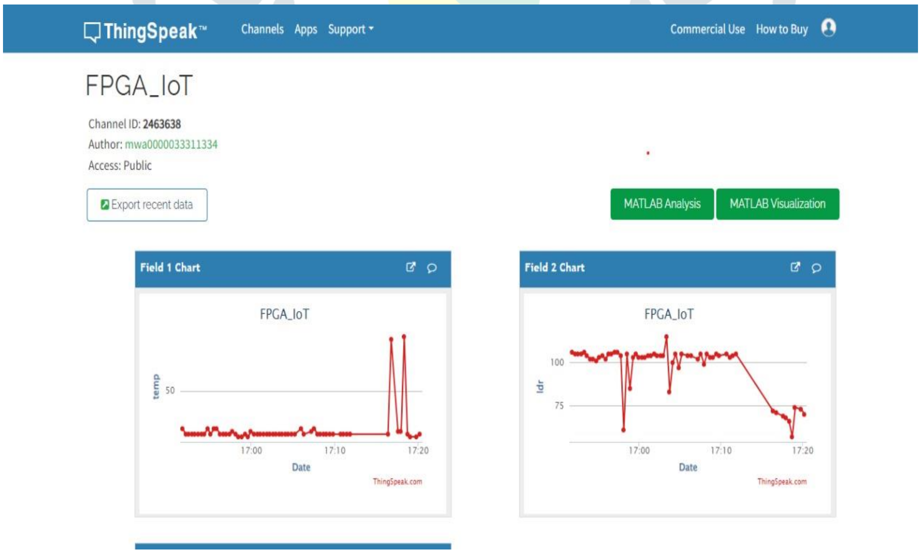


Fig.11: Results of Temperature on LCD Display

In this figure, the display provides real-time updates on both temperature and light intensity levels, courtesy of the LDR and temperature sensors. A noticeable difference from the previous image is the decrease in light intensity, indicating a darker environment. This change reflects the system's capability to adapt dynamically to varying light conditions, providing accurate feedback to users. The decreased light level is a direct response to the ambient lighting conditions, ensuring that the displayed information accurately reflects the current environmental status. This real-time monitoring offers valuable insights into environmental dynamics, enabling users to make informed decisions based on up-to-date data. Such responsiveness enhances the system's utility in diverse settings, where precise environmental monitoring is essential for optimizing comfort and energy efficiency.


FPGA_IoT

Channel ID: 2463638
Author: mwa0000033311334
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Fig.12: ThingSpeak Channel

In addition to monitoring temperature and light intensity levels, the system sends this recorded data directly from the sensors to the Wi-Fi module integrated into the FPGA board as shown in above fig. The Wi-Fi module facilitates seamless communication with the ThingSpeak cloud platform, where a dedicated channel is created for storing and retrieving real-time environmental data. This setup enables users to access and analyze weather conditions from any location, providing valuable insights into climatic changes and supporting various applications such as environmental monitoring and predictive analysis.

Fig. Results on graphical Representation

Moreover, users can conveniently retrieve and analyze the recorded data directly from their mobile devices by integrating the ThingView mobile app. By adding the channel created on ThingSpeak to the ThingView app, users gain quick access to real-time environmental data, allowing for on-the-go monitoring and analysis. This mobile integration enhances the system's accessibility and usability, empowering users to make informed decisions and respond promptly to changing environmental conditions.

X. LITERATURE REVIEW

The project introduces a smart system using an EDGE Spartan 6 FPGA Board to bring together different sensors, meeting today's demands for monitoring the environment, safety, and home automation. By combining sensors like the Gas Sensor (MQ135), LDR Sensor, and Temperature Sensor (LM35DZ), the system becomes a one-stop solution for detecting harmful gases, checking light levels, and monitoring temperature changes. This not only improves safety by quickly alerting users to gas leaks but also gives useful insights into environmental conditions on a 16x2 LCD screen. With a Wi-Fi modem, the system can wirelessly send sensor data to a Thingspeak channel regularly, ensuring accurate monitoring. Plus, with the Thingsview mobile app, users can conveniently keep an eye on live data and trends from afar, making informed choices. Compared to older systems, this project is more versatile, easier to use, and can be applied in various scenarios like cooling systems and security. With its focus on real-time data, wireless connections, and user-friendly design, it's a big step forward in using FPGA technology for modern needs, setting a new standard for smart sensor systems.

XI. PERFORMANCE EVALUATION

The performance of the project on the EDGE Spartan 6 FPGA Board can be evaluated across several key metrics. Firstly, the response time, or the speed at which the system reacts to events like gas leaks or motion detection, should ideally be measured in milliseconds for timely alerts. Energy usage must be optimized to ensure efficient operation, particularly for battery-powered applications. Resource utilization, which assesses the efficient use of FPGA resources like logic cells and memory blocks, is crucial for scalability and future enhancements. Throughput, or the system's data processing rate, should be high for real-time monitoring. Scalability evaluates the system's ability to handle increased workload or additional features without performance degradation, while reliability ensures consistent and predictable operation over time. Evaluating these metrics helps identify areas for optimization and improvement in the project's performance.

XII. CONCLUSION

In conclusion, this paper presents an innovative integration approach, seamlessly connecting a smart home application with an EDGE Spartan 6 FPGA using VLSI. The system offers superior performance, low power consumption, and exceptional flexibility. Future work will focus on refining the system architecture, enhancing security measures, and exploring advanced FPGA-based functionalities for smart home applications. The integration of the EDGE Spartan 6 FPGA with various sensors enables efficient environmental monitoring, safety enhancement, and home automation. Notably, the Gas Sensor's prompt alerts significantly improve safety in hazardous environments, while real-time data visualization from the LDR and Temperature Sensors contributes to a comfortable living environment, showcasing the system's robust analytical capabilities. The FPGA board's parallel processing capability, coupled with VHDL language, provides an efficient solution for handling repetitive functions. This combination of hardware innovation and smart technologies positions the EDGE Spartan 6 FPGA Board as a versatile platform driving advancements in safety, security, environmental monitoring, and home automation.

XIII. FUTURE SCOPE

In the future, this project could expand its capabilities by integrating advanced machine learning algorithms to predict maintenance needs based on historical sensor data patterns. Additionally, there is potential for incorporating a wider array of environmental sensors to provide more comprehensive monitoring, including parameters such as humidity and air quality. Enhancements to the user interface could involve the integration of graphical displays and touch-screen functionality for improved user interaction. Furthermore, integrating voice-activated commands through speech recognition technology could offer hands-free operation, further enhancing usability. Exploring energy harvesting techniques could also be beneficial to reduce dependence on external power sources, making the system more sustainable in the long term.

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