FORM 2

THE PATENTS ACT, 1970

(39 of 1970)

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THE PATENT RULES, 2003

COMPLETE SPECIFICATION

(See Section 10 and Rule 13)

TITLE OF THE INVENTION:

FPGA-Based Smart Home Automation System with IoT Integration and IR, Ultrasonic and Flame Sensor Control

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The following specification describes the invention and how it is to be performed.

CROSS-REFERENCE TO RELATED APPLICATION AND PRIORITY

The present application claims no priority from any patent application(s).

FIELD OF THE INVENTION

This invention pertains to the domain of embedded automation systems, particularly focusing on residential control solutions utilizing Field Programmable Gate Array (FPGA) technology. It is intended to provide real-time decision-making and efficient operation for lighting, water supply, and safety management systems in a domestic setting.

BACKGROUND OF THE INVENTION

Traditional home environments often rely on manual operation for controlling appliances, managing resources, and ensuring safety. Tasks such as switching off unused lights and fans, monitoring water levels, or reacting to fire hazards still require human intervention in many households. This dependence leads to inefficiencies such as increased energy consumption, water wastage, and delayed emergency responses.

Over time, the introduction of microcontroller-based home automation systems has provided partial automation of household functions. However, these systems are generally limited in speed, responsiveness, scalability, and real-time multitasking. Many such solutions operate in isolation — motion sensors may control lights, but without coordination with safety systems or water monitoring units. Moreover, user control in such systems is often restricted, with minimal ability to override automation or receive real-time feedback via mobile interfaces.

Various patents have been granted in the area of home automation, each focusing on specific aspects but lacking full integration across motion detection, safety management, and resource monitoring. Some of the notable inventions in related fields are as follows:

US8890435B2: Titled *"Wireless Lighting Control System"*, this invention describes a wireless setup that allows for lighting control and dimming. However, it does not integrate with environmental sensor data such as occupancy or hazard detection, and it lacks FPGA-based responsiveness.

US9450776B2: This patent discloses a *"Security and Automation System with Mobile Access"*, enabling users to manage devices remotely. While it offers interface-level control, it does not include autonomous decision-making based on real-time sensor feedback or water/fire management.

WO2016050676A2: This international publication (with priority from Indian patent IN4854/CHE/2014) describes an *"Automatic Lighting Control System"* using ambient conditions. Yet, it does not address cross-functional integration with fire alerts or water tank automation.

IN202041031831A: This Indian patent application outlines a *"Smart Water Tank Level Monitoring System"*. While it uses IoT and ultrasonic sensors to monitor water usage, it lacks real-time control integration with household appliances or hazard detection modules.

CN106302054A: Though not Indian or US, this Chinese patent is highly relevant. It presents an *"FPGA-Based Smart Home Control Platform"* for collecting sensor data, but focuses on monitoring rather than active control like triggering relays or switching pumps and fans.

Each of these inventions contributes meaningfully to specific aspects of smart home technology. However, most are focused on a single function or sensor type, lack real-time parallel processing, and do not offer an integrated, multi-sensor, user-controlled framework.

Given the increasing need for intelligent, responsive, and efficient home automation, there exists a gap in systems that combine motion sensing, water level monitoring, fire detection, and Bluetooth-based manual override — all handled in real-time using FPGA logic.

The present invention addresses this need through a comprehensive, FPGA-based smart home automation solution. It combines hardware-level sensor integration with programmable control logic and user communication features, delivering a system that is modular, responsive, and adaptable to modern smart home requirements.

OBJECTIVES OF THE INVENTION

Our invention is an FPGA-based smart home automation system that aims to modernize and streamline essential household operations such as lighting, water management, and fire detection. It is designed to provide a seamless and responsive control mechanism that reduces manual dependency and enhances safety, energy efficiency, and user convenience. The primary goal of this project is to overcome the limitations of conventional microcontroller-based systems by utilizing the real-time, parallel-processing capabilities of FPGA hardware to enable faster, more accurate, and integrated automation.

Automated Appliance Control through Motion Detection

The system includes a dual infrared sensor arrangement to detect human presence within a room. Upon identifying entry or exit, the system automatically turns the lights and fans ON or OFF respectively. This ensures intelligent energy consumption and eliminates the need for manual switching. The automation is enhanced by FPGA logic, which allows real-time signal interpretation and actuation without processing delays.

Real-Time Water Level Monitoring and Pump Control

Ultrasonic sensors are used to monitor the water level in a storage tank. When the level falls below a critical threshold, the system activates the water pump, and once the tank is sufficiently refilled, it shuts the pump OFF. This prevents both overflow and underfill scenarios. The system displays the current water level in milliliters and percentage, offering precise and user-friendly feedback.

Fire Detection and Emergency Response System

The system is equipped with flame sensors that detect abnormal heat or fire conditions. On detecting a fire, it triggers an alarm system (buzzer and LED), sends a Bluetooth notification to the user, and activates a water sprinkler to extinguish the fire. This early detection and automated response significantly enhance the safety of occupants and assets.

Manual Override via Bluetooth Interface

To provide flexibility and control, the system includes a Bluetooth module (HC-05) that allows users to manually operate connected appliances such as lights and fans through a mobile phone. Commands like “1” for light ON, “2” for fan ON, and “0” to reset to automatic mode are processed by the FPGA via UART communication. This dual-mode (manual + automatic) control ensures adaptability based on user preference.

Integration of Sensor Modules into a Unified Control System

One of the key objectives is to integrate all individual components—motion sensors, ultrasonic module, flame detector, Bluetooth interface—into a single, top-level Verilog design. This ensures centralized control and efficient operation using finite state machine (FSM) logic coded within the FPGA. The goal is to minimize redundancy and ensure seamless communication between modules.

Real-Time Parallel Processing using FPGA

The use of FPGA hardware enables simultaneous monitoring and control of various subsystems without compromising on speed or performance. This parallel architecture allows the system to handle multiple environmental inputs in real time, which would otherwise be difficult using traditional microcontrollers. The result is a responsive, low-latency, and highly dependable home automation framework.

Expandability and Future Integration

The design is inherently modular and scalable, enabling future integration with cloud platforms, mobile dashboards, or voice-controlled systems like Amazon Alexa or Google Home. The system can be upgraded with minimal changes to the core architecture, allowing continuous enhancement based on user needs or technological advancements.

SUMMARY OF THE INVENTION

The present invention relates to an FPGA-based smart home automation system that integrates motion detection, water level monitoring, fire hazard response, and manual control into a unified real-time control framework. The system utilizes IR sensors for occupancy-based activation of lights and fans, ultrasonic sensors for automatic water pump control based on tank levels, and flame sensors to detect fire and activate alarms and sprinklers. A Bluetooth interface enables manual override through mobile commands. All modules are programmed within an FPGA using Verilog and finite state machines, enabling parallel, low-latency operation. The system is modular, scalable, and designed for future upgrades such as cloud connectivity and voice control, offering an efficient, safe, and user-friendly solution for modern smart homes

DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates the block diagram of the smart home automation system, showing the integration of various components including the FPGA, IR sensors, ultrasonic sensor, flame sensor, Bluetooth module, relays, and output appliances such as fan, light, water pump, and sprinkler.

Figure 2 depicts the fully wired FPGA-based hardware setup placed on a development board, showcasing sensor connections, relay modules, and interfaced devices used for controlling home appliances. It also includes the physical placement of the Bluetooth module and display components.

Figure 3 presents the complete assembled prototype setup of the smart home automation project. It displays the arrangement of sensors, relays, and output loads as configured in a realistic demonstration environment, representing the final working model as implemented and tested.

DETAILED DESCRIPTION OF THE INVENTION

1. **Infrared Sensor-Based Automation for Room Devices:**
   The system uses dual infrared (IR) sensors at the room entrance and exit to detect human motion and presence. This allows the system to determine when someone enters or leaves the room and accordingly switch ON or OFF the fan and light using relay-based control. These sensors are interfaced with the FPGA, which processes the input using finite state machine logic for seamless automation.

2. **Ultrasonic Sensor-Based Water Tank Monitoring:**
   An ultrasonic sensor continuously measures the distance from the sensor to the water surface in the storage tank. Based on the reading, the system calculates the current water level. If the level falls below a predefined minimum, the FPGA triggers a relay to start the water pump. Once the desired maximum level is reached, the pump is automatically stopped. The water level is also displayed on a 7-segment display in centimeters and milliliters.

3. **Flame Sensor Integration for Fire Detection:**
   Flame sensors are used to monitor for fire or extreme heat conditions. When fire is detected, the FPGA activates an emergency response — this includes turning ON a buzzer, lighting up a red warning LED, and triggering a sprinkler system through a relay to extinguish the fire. Additionally, a warning message is transmitted over Bluetooth to notify the user.

4. **Bluetooth-Based Manual Control Interface:**
   The system includes a Bluetooth module (HC-05) for manual override using a mobile phone. Commands like “1” (light ON), “2” (fan ON), and “0” (reset to auto mode) are received via UART and parsed by the FPGA. This dual-control system allows users to either rely on automation or manually operate appliances when desired.

5. **Combined Control through a Central FPGA Module:**
   All individual functionalities—motion-based control, fire detection, water level

management, and Bluetooth override—are controlled by a single FPGA using Verilog HDL. Each function is implemented as a separate module and interconnected through a top-level FSM-based design, enabling real-time multitasking and centralized control logic.

6. **Relay-Based Actuation for Electrical Loads:** Relays are used to control AC appliances (fan, light, pump, sprinkler). The relay inputs are driven by FPGA I/O pins through current-limiting circuitry. Output signals are properly debounced in Verilog to prevent flickering or false triggering. Devices turn ON or OFF based on sensor input or Bluetooth commands.

Methods:

Step 1: Hardware Setup and Sensor Integration:

1. IR Sensor Integration:

- Mount two IR sensors at the room entrance and exit.
- Connect them to digital input pins on the FPGA.
- Test for accurate human motion detection and validate delay logic for proper ON/OFF switching.

2. Ultrasonic Sensor Setup:

- Position the sensor above the water tank.
- Connect trigger and echo pins to the FPGA.
- Implement timing logic to calculate distance and convert it to water level.
- Interface with 7-segment display for real-time output.

3. Flame Sensor and Sprinkler Control:

- Place the flame sensor near fire-prone areas.
- Connect it to the FPGA and monitor digital output.

- On detection, trigger the buzzer and activate sprinkler via relay.

4. Bluetooth and UART Communication:

- Connect HC-05 to FPGA UART RX pin.

- Develop a command parser module in Verilog.

- Simulate input commands (“1”, “2”, “0”) and verify output response.

- Ensure Bluetooth communication works without interrupting automation logic.

5. Relay Driver and Output Device Connection:

- Interface FPGA output pins with relays via opto-isolated driver circuits.

- Connect fans, lights, pump, and sprinkler to the respective relays.

- Ensure stable switching and test load operation with dummy AC appliances.

Step 2: Verilog Programming and System Logic:

1. Modular HDL Development:

- Develop separate modules for IR-based room control, ultrasonic sensing, flame detection, and UART command parser.

- Use FSM-based design for state transitions (e.g., room occupied → fan/light ON).

- Combine modules under a unified top.v file.

2. Display and Feedback Logic:

- Design Verilog code to drive 7-segment display with live water level data.

- Implement status indicators for fire alerts and tank refill status.

Step 3: Testing and Debugging:

- Test each sensor module individually on the FPGA board.

- Perform integration testing to verify simultaneous functioning.
- Check timing stability, UART communication accuracy, and relay response.
- Simulate edge cases: fire without human presence, Bluetooth override during IR automation, etc.

Step 4: User Interface and Control Logic Testing:

- Pair the Bluetooth module with an Android phone.
- Use a serial terminal app to send override commands.
- Monitor FPGA response and device status transitions on actual hardware.

Step 5: System Deployment and Demonstration:

- Securely mount sensors and devices in a demo environment.
- Label all modules (sensor, relay, load) for presentation.
- Prepare documentation, test case logs, and video demos if required.

Step 6: Future Expansion:

- Add optional modules such as GSM alerts or IoT integration.
- Expand UART parser to support longer commands (e.g., “fan_on”, “reset_system”).
- Integrate mobile app UI instead of serial terminal for Bluetooth.

Claims:

1. An FPGA-based smart home automation system comprising infrared sensors configured to detect room occupancy, wherein the system automatically controls electrical appliances such as fans and lights based on entry and exit detection.
2. The system as claimed in claim 1, further comprising an ultrasonic sensor module for measuring water levels in a storage tank, wherein the FPGA is configured to activate or deactivate a water pump through a relay based on predefined water level thresholds.

3. The system as claimed in claims 1 and 2, wherein flame sensors are integrated for detecting fire or excessive heat, and upon detection, the FPGA triggers an alert mechanism comprising a buzzer, a visual indicator, and a water sprinkler system.
4. The system as claimed in any of the preceding claims, wherein a Bluetooth module is configured to receive manual override commands from a mobile device, allowing the user to control appliances by sending specific UART-based inputs to the FPGA.
5. The system as claimed in any of the preceding claims, wherein a centralized Verilog-programmed FPGA module manages all input sensors and output devices using finite state machines (FSM) for real-time decision-making and hardware-level parallel processing.
6. The system as claimed in any of the preceding claims, wherein the FPGA is further configured to display real-time water levels on a 7-segment display in centimeters or milliliters.
7. The system as claimed in any of the preceding claims, wherein the appliance control relays are actuated through FPGA-driven output pins and are designed to handle AC or DC loads, providing reliable switching and debouncing logic.
8. The system as claimed in any of the preceding claims, is modular in design, allowing for future expansion to integrate additional features such as cloud-based control, voice commands, or IoT platforms.

ABSTRACT

The invention discloses an FPGA-based smart home automation system that integrates occupancy-based control of electrical appliances, water tank level monitoring, fire hazard detection, and Bluetooth-enabled manual override into a unified real-time hardware platform. The system employs infrared sensors to automate fans and lights based on room usage, ultrasonic sensors to control a water pump by detecting fluid levels, and flame sensors to initiate an emergency response that includes activating alarms and sprinklers. A Bluetooth module allows the user to send commands via mobile devices to override or reset automated actions. All components are coordinated through a central Verilog-coded FPGA architecture

using finite state machines, enabling parallel, low-latency processing. The system is scalable, efficient, and designed to improve household safety, energy management, and convenience.

References:

1). Wireless Lighting Control System

https://patents.google.com/patent/US8890435B2/en

2). Integrated Security and Automation System

https://patents.google.com/patent/US9450776B2/en

3). Automatic Lighting Control Based on Sensor Feedback

https://patents.google.com/patent/WO2016050676A2/en

4). Autonomous Fire and Safety Response System

https://patents.google.com/patent/US9038233B2/en

5). FPGA-Based Smart Home Controller

https://patents.google.com/patent/CN106302054A/en