HOME AUTOMATION CHIP ON FPGA

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Abstract:

In today's rapidly evolving world, the demand for home automation solutions spans across all strata of society, driven by the aspiration for dynamic and secure lifestyles. The prevailing paradigm for developing home automation systems often employs technologies such as Bluetooth, ZigBee, Wi-Fi, and the Internet of Things for communication and control. However, the inherent limitations of using such technologies are the limited range, availability of smartphones, and the internet or Wi-Fi connectivity. Such home automation systems use micro-controllers in conjunction with various sensors to monitor household appliances. The limitations of sensors physical robustness and micro-controller based architecture, characterized by restricted ports, fixed configurations, modest processing speeds, and lack of extensibility, pose challenges. To address these limitations, this paper introduces an innovative and cost-effective home automation system that uses a Field-Programmable Gate Array (FPGA) as a specific processor with limited peripherals. Here, the FPGA is used as part of rigorous experimentation before customizing an ASIC (application-specific integrated circuit) design. The specific processor for this application is synthesized on an Elbert V2 Spartan 3A FPGA and connected via an electrical cable to control five different locations or rooms; each location is equipped with five devices or switches. 8-bit data is transmitted via Short Message Service (SMS) to control the devices or switches in various locations or rooms. The entire design is tested with various test cases, and demonstrated for its feasibility, functionality, and practicality. This solution holds promise for broad accessibility, catering to users across various socioeconomic strata, including those without smartphones.

Keywords: Home automation, FPGA, SMS, ASIC, Elbert V2 Spartan 3A.

Introduction

Home automation plays a pivotal role in remotely managing household appliances and enhancing security, especially when homeowners are not physically present. This system offers an ideal solution to the daily challenges faced by homeowners, aiming to provide them with consistent access to automate their homes. This capability empowers users to tailor their home environment to suit their personal preferences. With the utilization of home automation systems, one can conveniently control various home appliances. For example, individuals have the capability to remotely switch off lights inadvertently left on in the kitchen or activate the air conditioner while on their way home.

Modern home automation systems incorporate various technologies, including Bluetooth, ZigBee integrated with Wi-Fi networks, the Internet, and Java-based 3D visual interfaces. Researchers and practitioners have shown significant interest in the concept of smart homes over the years. Recent advancements primarily focus on leveraging wireless communication to enable seamless interaction with devices. For example, a prior study [2] introduced the idea of using Bluetooth as a replacement for conventional cables in home automation, though it didn't delve into implementation details. Another system [3] was developed, centered around Bluetooth, consisting of a remote and a mobile host controller that communicate with different home appliances. A similar approach was suggested in [4], where a Bluetooth multihop mesh topology was employed to relay sensor node information to a mobile device or personal computer.

Another avenue of exploration involves ZigBee-based home automation systems, where integration with Wi-Fi networks is facilitated through gateways [5]. These gateways not only serve as an interface for the users but also provide accessibility to the system. This approach finds its application in [6] as well. In this case, an architecture was introduced that integrated a ZigBee home network into the Open Service Gateway Initiative (OSGi) framework-based home gateway.

Proposals leveraging the Internet for home automation have also surfaced. In one instance, a system [7] relied on an embedded controller interfaced via an RS232 port to a personal computer web server. This connection facilitated the control and monitoring of connected appliances and sensors, both locally and remotely. Another solution [8] combined the Global System for Mobile Communications (GSM), the Internet, and speech recognition for real-time monitoring and remote control of home appliances. While this approach enhances flexibility, the use of GSM technology increases costs.

In [9], the authors introduced a 3D visual interface to enhance the user experience and improve the graphic User Interface (GUI) of home automation systems. This design aimed to accelerate the adoption of such technologies while utilizing the Internet for external control and monitoring of the home environment.

Despite these advancements, existing systems have shortcomings due to microcontroller limitations such as fixed architecture, limited ports, low speed, and reduced durability. To overcome these challenges, this paper proposes a novel home automation system that offers an affordable solution with heightened security. This system leverages wireless communication, with a GSM module serving as a bridge for SMS-enabled commands. At its core, an FPGA controller drives the home automation system, interfacing with mobile devices through GSM networks to enable efficient monitoring and control. This system's versatility extends wherever cellular network coverage is available.

Home Automation System through FPGA

This new home automation system is a big step forward. It gets rid of the need for old sensors and solves the problems that come with using microcontrollers. With this system, each controller's output can control a whole room with up to five devices based on the input data. This means one can easily control their home appliances, like turning off the lights in the kitchen if they're still on or turning on the air conditioner on the way home. It's a perfect solution for the everyday problems that homeowners face. What's great is that it's really simple and cost-effective. The only thing you have to do is install one wire for each room from the main power supply. This makes the system affordable and reliable for everyone.

The system's architecture mainly comprises four key components: a GSM modem, a controller unit, an interfacing unit, and a serial port to connect them, as shown in Figure 1. The central controller connects to both the interfacing unit and the GSM modem via the modem's serial port. Programming for the controller is done using Xilinx ISE software, with control managed through interrupts in the form of messages sent by the GSM modem.

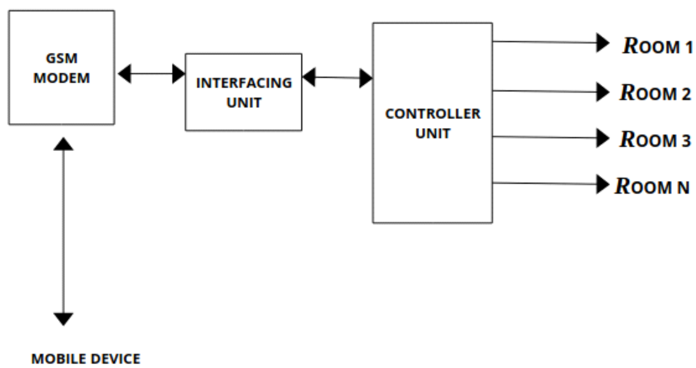

Figure 1. The Block diagram of home automation system

GSM modem features a SIM slot for a unique communication number and a serial port for external hardware communication. It employs AT commands to send and read SMS. Communication between the GSM modem and the controller occurs through the RS232 serial port.

The controller can manage multiple input and output ports linked to various devices and appliances. It's reprogrammable, allowing for the addition of new devices at any time. For this system, an Elbert V2 Spartan 3A FPGA board is used. Each FPGA port connects to a rooms or area's electrical panel via a wire carrying information bits to a serial-to-parallel port at the panel. Multiple output bits from this port control relays that, in turn, manage connected devices.

Because home appliances often use high AC/DC loads, relays serve as intermediaries between switches and ports. All control devices are connected to the controller board. The programmed controller establishes a connection with the GSM modem (input) and the interfacing unit (output) through the RS232 serial port of the GSM modem.Users can send an 8-bit input to the GSM modem, which then converts it to a serial format and sends it to the controller via RS232. The controller subsequently sends the 8-bit data through an output port to the interfacing unit using a specific algorithm. Devices corresponding to the enabled bits in the received data are activated. Each FPGA output port has the capacity to manage an entire room, controlling up to eight devices (with the potential for expansion). This is made possible by a serial-to-parallel converter positioned between the controller and the interfacing unit.It's worth noting that this home automation system has been thoroughly tested through practical simulation and synthesis to ensure its functionality and effectiveness

Working:

The FPGA's reprogrammable nature enables seamless integration with GSM networks using UART. Finite State Machines (FSMs), thoughtfully designed for both transmission and reception, govern the efficiency of communication within the system. Each room is treated as a separate FSM with its own set of states and transitions. Events, like incoming SMS messages in this case, trigger transitions between the states. By employing these Finite State Machines (FSMs), the system manages UART communication and interprets the received data. The received data is divided into two parts: the first three bits represent room selection, while the subsequent five bits denote device selection. Upon the reception of data, the controller operates the selected devices through a relay-based system. This innovative architecture allows each FPGA output port to control an entire room, accommodating up to five devices.

The Transmit (TX) FSM, as shown in figure 2, regulates the transmission process. Initiating from a wait for Data state, the FSM progresses to sent state upon data availability. It sends data bit by bit, encapsulating it with a start and stop bits. Following completion, the FSM cycles back to the wait for Data state, facilitating subsequent data frame transmissions. Acknowledgment signals are then dispatched, and the FSM resets registers, signaling Data to Send module.

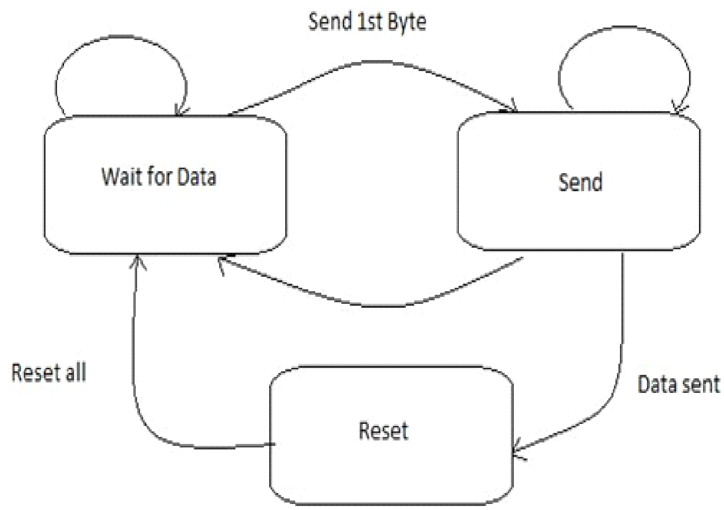

Figure 2. Transmit Finite State Machine

The Receive (RX) FSM, as depicted in Figure 3, manages the reception of messages. It begins in the "Wait for Start Bit" state, where it watches for the start of a message by detecting the start bit. After locating the start bit, it transitions to the "Receive Byte" state, where it checks the data bits at the midpoint of each data period using a counter. If it successfully identifies the stop bit, it moves to the "Store Byte Reset" state. Here, it stores the received data, particularly the first byte, and then returns to the initialization state, ready for the second byte. Upon receiving the second byte, the data is sent to the RX separator module for storage and acknowledgment. This process optimizes the data reception procedure, making it more efficient.

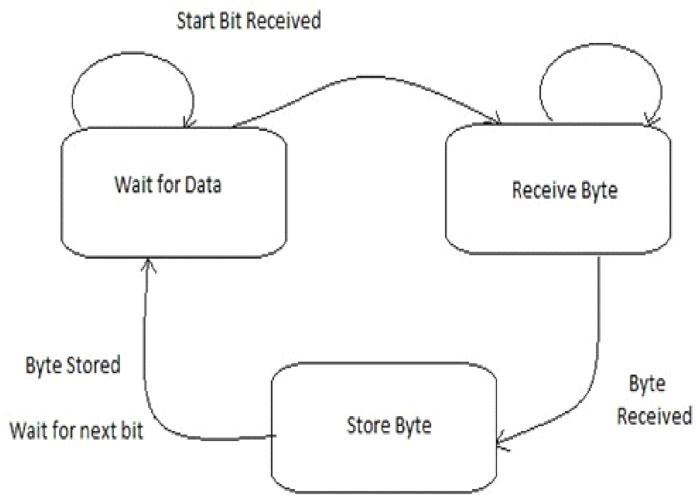

Figure 3. Receive Finite State Machine

This system entails programming a Configurable hardware device for UART-based communication, the reception of external data for device control, and the strategic application of Finite State Machines to guide the functioning of individual modules. The specifics of device control and other particulars may differ based on the distinct requirements of the system.

Experimental Results

To validate the working of this Home Automation System, the entire system is simulated and synthesized on a specific processor, i.e., an Elbert V2 Spartan 3A board as the central controller. We conduct extensive simulations to validate the system's behavior by testing the test bench with various scenarios. The simulations demonstrated the successful integration of GSM communication, UART modules, and FSMs, ensuring proper data transmission and processing. Additionally, the synthesis results confirmed the hardware's optimized utilization, highlighting the system's efficiency and resource management. We validate the efficiency of the control mechanism by utilizing hexadecimal codes to remotely operate devices in specific rooms.By sending designated 8-bit GSM codes via SMS, users could activate or deactivate the devices. The system exhibited consistent and accurate responses to the transmitted codes, confirming its ability to precisely control devices remotely.

To validate the controlling mechanism, we have taken different test cases by sending the 8-bit GSM code. For example, if we sent 01 as the GSM code, the binary code that corresponds to the GSM code is 00000001. The first 3 bits (LSB) of this binary code are used for room selection. Here the first three bits are 001, which will select Room-1 as a controlling port. The next 5-bits (MSB) (00000) are used for device selection; for example, if the bit is 1, then the device that corresponds to that bit position is turned on, and if the bit is 0, then the device that corresponds to that bit position is turned off. In this way, we tested this home automation system by sending the following GSM codes for each room:

Room 1: 01,09,11,21,41,81,F9

Room 2: 02,0A,12,22,42,82,FA

Room 3: 03,0B,13,23,43,83,FB

Room 4: 04,0C,14,24,44,84,FC

Room 5: 05,0D,15,24,45,85,FD

The above GSM codes will perform turning all the devices ON,turning each device OFF, and turning all the devices ON actions for each room. This is illustrated in figure 4 below:

Figure 4. Simulation Results

The above figure 4 illustrates the simulation results of the Home Automation system; here each room is labeled as r1, r2, r3, r4, and r5, and each device is labeled as l in the range of 1 to 25 (l1 to l25). Figure 4 clearly depicts the controlling action performed in room 5 by our controller. If the signal is pulled high, then that device is said to be in the ON state; otherwise, the same device is said to be in the OFF state.

Conclusion

This novel system represents a significant advancement in the realm of home automation. It enables users to seamlessly manage their entire household with the simple installation of a single wire originating from the main power supply. The main goal of this project is to make the most efficient use of the FPGA's capabilities. To achieve this, we're working on designing a special integrated circuit (IC) that comes with built-in GSM features. This IC will have just the right number of ports needed to control various aspects of a home. With this specially designed IC and some basic connectors, homeowners can easily link their FPGA to different rooms using cost-effective wiring solutions. This setup brings the promise of complete home automation within reach. The core advantage of this innovative solution lies in its ability to monitor and manage household appliances in real time. To ensure security, we've implemented a pairing mechanism that helps prevent unauthorized access to the network. The benefits of this system are numerous: it allows remote control of a variety of home devices from anywhere; it's easy to use; it's cost-effective; and it's highly accessible.

Future Scope

In this paper, we have tested the Home Automation System to control five rooms, each with five devices. This may be extended to a certain number of rooms and devices. This system may also be extended beyond individual homes to cover larger living spaces like apartment buildings. The abundance of input and output ports makes it possible to efficiently manage an entire apartment's functions, making home automation simple and affordable. If successful testing of this design on hardware leads to the availability of the Integrated Circuit (IC) in markets, this envisaged development of a specialized IC with embedded GSM capabilities, optimized port count, and simplified connectivity opens doors to an ubiquitous home automation. This system, coupled with its inherent scalability and economic viability, positions it as an adaptable solution for various housing setups.

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