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Home Appliance Control and Power Monitoring Using I²C Communication

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Citation:

Abstract

The rapid advancement of home automation has revolutionized how we interact with electronic systems, with embedded networking playing a critical role in enhancing these applications. One such networking standard, Inter-Integrated Circuit (I²C), has emerged as a key enabler for communication between microcontrollers, offering a streamlined, two-wire protocol that operates on a master-slave configuration. This design allows a master device to control multiple slaves efficiently, making I²C ideal for embedded systems in home automation. The protocol, which can be emulated even by microcontrollers lacking a dedicated I²C peripheral, supports high-speed data transfer of up to 3.4 Mbits/sec. Originally developed to minimize pin count and simplify connections between different integrated circuits on a single circuit board, I²C's flexibility also enables communication across multiple boards, depending on the required distance and transfer speed. This flexibility, coupled with its simplicity, provides a robust framework for comprehensive home automation systems, enabling seamless control over various functions such as power monitoring and device management within a single embedded system.

Keywords: I²C, Power measurement, Embedded board, Microcontroller communication, Master-slave configuration, Data transfer.

1|Introduction

The advancement of home automation technologies has brought significant improvements in the way we manage and monitor energy consumption, particularly through power monitoring systems. Many countries have proposed energy conservation projects that leverage both existing Information and Communication Technologies (ICT) to control and manage electrical appliances with the goal of reducing power usage [1].

Traditionally, these systems rely on either wireless or wired transmission media, such as RS-232, Inter-Integrated Circuit (I²C), CAN, Bluetooth, and IRDA. Among these, the I²C protocol stands out due to its simplicity and effectiveness in connecting multiple microcontrollers and sensors, making it a strong candidate for home automation and power monitoring applications.

I²C communication is widely used in embedded systems due to its efficient two-wire protocol, which facilitates easy communication between devices in a master-slave configuration. This protocol allows a single master device to control multiple slave devices, making it suitable for managing home appliances and monitoring power usage. In integrated circuits, this communication technology enables the real-time exchange of data between various devices, making it ideal for environments where precise monitoring and control of power consumption are necessary [2]. By incorporating I²C into energy conservation systems, smart homes can ensure optimized power usage, reducing wastage and leading to cost savings. Additionally, the integration of I²C in these systems allows for scalable and distributed networks of sensors and controllers [3], providing flexibility in managing appliances across large areas.
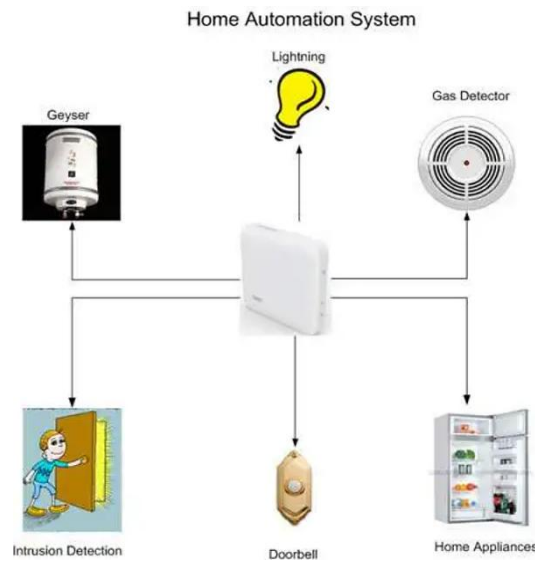

Fig. 1. Basic home automation system.

However, *Fig. 1* shows there are some drawbacks to using I²C communication for power monitoring in home automation. The limited distance and slower speed in larger systems, as well as potential interference in wireless environments, can limit its performance in expansive or complex setups [4]. Additionally, as the number of devices on the network increases, managing the system can become more complicated, leading to synchronization issues and reduced efficiency.

To address these challenges, the proposed methodology focuses on optimizing I²C communication for home automation by enhancing the scalability and reliability of the network [5]. This can be achieved by improving the robustness of the protocol, implementing fault-tolerant mechanisms, and exploring hybrid communication methods that combine the strengths of both wired and wireless systems. The goal is to overcome the limitations of traditional I²C networks, ensuring that power monitoring and control systems can function effectively even in larger, more complex environments. Through these advancements, home automation can become more efficient, reliable, and adaptable to future technological trends.

The integration of advanced I²C-based systems in home automation provides a powerful tool for energy conservation. With the right optimizations [6], it offers the potential to enhance energy efficiency and reduce costs, contributing to more sustainable living environments. These improvements also open the door for further innovations, particularly in the development of smart homes that can dynamically respond to changing power needs.

2 | Literature Review

Jameel and Kareem [7] proposed a smart monitoring system that utilizes a highly scalable, cost-efficient, and energy-saving architecture designed to improve upon traditional monitoring systems by leveraging the concept of parallel processing. The system integrates multiple microcontrollers based on design requirements, utilizing the master-slave technique where one central master microcontroller interfaces with one or more slave microcontrollers. Communication between the microcontrollers is facilitated through the I²C protocol. This setup combines microcontrollers with covert motion detection sensors to activate various components such as buzzers, lights, cameras, and GSM. Additionally, the system employs an authentication mechanism using a number to allow authorized users to activate or deactivate it, ensuring security and efficiency in monitoring operations.

Yudi Limpraptono et al. [8] introduced a framework combining a smart electrical panel with an electric power monitoring system that was proposed to promote energy-efficient practices. This system continuously monitors energy consumption, automatically controls electrical loads, records usage, and generates detailed reports for daily, weekly, monthly, or yearly periods. Developed using a research and development methodology, the prototype integrates a Raspberry PI 3 with a PZEM-004t power energy meter. The monitoring system autonomously manages electrical loads while providing real-time feedback on energy use through comprehensive reports. Test results demonstrated the system's effectiveness, indicating its potential to support government-led energy conservation initiatives by offering precise control and monitoring capabilities to optimize electricity usage.

Nurcahyo et al. [9] suggested energy-efficient practices by integrating a smart electrical panel with a power monitoring system designed to automatically control electrical loads and provide detailed reports on energy usage. The system, based on a Raspberry Pi 3 and PZEM-004t power energy meter, continuously tracks electrical consumption, controlling loads as needed. It generates comprehensive reports that analyze energy usage over daily, weekly, monthly, or yearly intervals. The research and development methodology was applied to create a functional prototype that automates load management and supports energy conservation. Test results demonstrated the system's effectiveness in reducing energy consumption, and it is expected to contribute to government energy conservation efforts by promoting active energy efficiency.

Sámano-Ortega et al. [10] developed a Modular Wireless Sensor Network (MWSN) was proposed, featuring subsystems for power supply, wireless communication, and digital processing. The design simplifies the sensing subsystem to an MWSn-implementing method, facilitating faster and more efficient deployment of IoT applications across various industries. Using flexible one- or two-wired communication protocols like I2C, the concept ensures seamless communication between sensing modules and the MWSn. To demonstrate the system's flexibility and effectiveness, two IoT-based remote monitoring applications were developed, showcasing the adaptability of the modular design for different industry needs. This approach promotes rapid application development and deployment within the Internet of Things (IoT) ecosystem.

Lee and Yang [11] introduced a smart power management framework consisting of three main components: a smart plug, a smart gateway, and a mobile app management platform. The smart plug manages the switching power supply using various sensors based on environmental changes, allowing automatic control of the power supply and real-time measurement of current and voltage. The smart gateway serves as a communication mediator, implementing the fog computing concept and incorporating deep learning to develop and refine a local inference model for improved intelligent control. The mobile app and management platform provide a user interface for remote control and data visualization to support planning. The integration of the smart plug and gateway enables efficient power consumption analysis and optimization through a distributed sensor network. Experimental results validated the practicality and effectiveness of the proposed system.

Figueiredo et al. [12] proposed a Message Queuing Telemetry Transport (MQTT) protocol to facilitate wireless data transmission, ensuring efficient control over electrical appliances, including an EV battery charger. A configurable algorithm dynamically monitors and controls the current consumption of the EV

charger and other household devices, preventing the home circuit breaker from tripping due to overload. A Wi-Fi-enabled smart plug allows users to remotely monitor the RMS current values of connected appliances and control their operational state via an Android application. The EV battery charger's power consumption is adjusted based on real-time set points from the Android app. Experimental tests validated the quality of service in terms of communication delay and reliability, while additional tests confirmed the system's effectiveness in managing EV battery charger power under varying operational conditions.

Chaouch et al. [13] developed a Heating, Ventilation, and Air Conditioning (HVAC) system that integrates IoT technologies, fuzzy logic, and Machine-to-Machine (M2M) communication to optimize building energy consumption while ensuring occupant comfort. The system uses IoT to manage energy during peak hours autonomously, leveraging fuzzy logic to make decisions without compromising the comfort levels expected by building occupants. After successful validation, the prototype was deployed with two air conditioners in a realistic setting, where the results confirmed that the system could automatically reduce energy usage while maintaining a consistent comfort level. The system effectively balances energy efficiency and comfort through smart monitoring and control mechanisms.

3 | Software and Hardware Architecture

I²C is a Master-Slave protocol. Normally, the master device controls the Serial Clock Line (SCL) in below *Fig. 3*. This line dictates the timing of all transfers on the I²C bus. Other devices can manipulate this line, but they can only force the line low. This action means that items on the bus cannot deal with more incoming data [14]. By forcing the line low, it is impossible to clock more data into any device. This is known as "Clock Stretching". As stated earlier, no data will be transferred unless the clock is manipulated. The same clock, SCL, controls all slaves. I²C is a Bi-directional protocol. Data can flow in any direction on the I²C bus, but when it flows is controlled by the master device in *Fig. 2*.
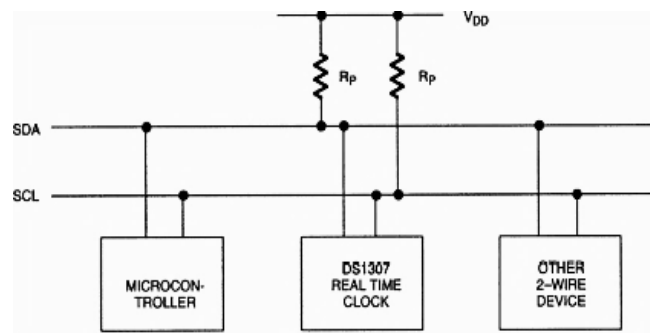

Fig. 2. I²C communication scheme.

System setup with master-slave architecture

The system is designed with a master-slave communication model using I²C communication. The master controller is responsible for monitoring and controlling all connected appliances. Each room in the house is equipped with slave controllers, which manage specific electrical devices (appliances) in that room. The master controller communicates with each slave controller through the I²C protocol, sending commands (like On/Off) and receiving status updates from the appliances.

Assigning appliance IDs and I2C codes

A database is created that includes the details of all electrical appliances in the house. Each appliance is assigned a unique code, which is used for identifying and controlling it through the I²C communication protocol. These codes are stored in the system's microcontroller and are used to direct commands from the master controller to the appropriate slave controller for the specific appliance.

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Sending remote control commands

Users interact with the system using an IR remote control. When a button on the remote is pressed, the IR transmitter sends a signal to a local microcontroller, which calculates the pulse width of the signal [15]. The microcontroller interprets the signal and translates it into a command that is sent to the master controller. The master controller receives this code and identifies which appliance (through the slave) the command is meant for.
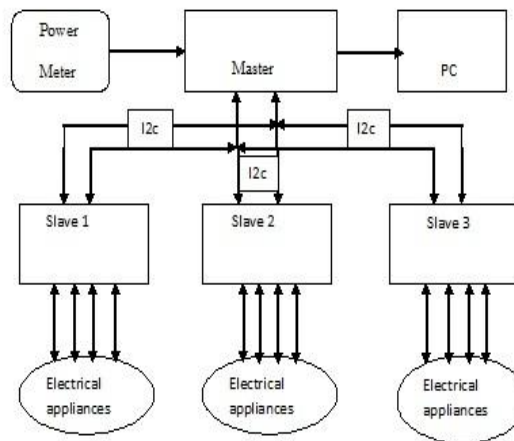

Fig. 3. Block diagram.

Controlling the slave device

The master controller then transmits the command via I²C to the specific slave controller. The slave controller receives the command and acts on the connected appliance, such as turning it on or off. After executing the command, the slave controller sends a status update back to the master (confirming the operation's success or failure).

Power monitoring and measurement

The system includes a power meter equipped with IR sensors that monitor the electrical usage of each appliance. The sensors count the rotations of the energy meter disc or measure current flow, which the microcontroller uses to calculate real-time power consumption. The system monitors and records the energy usage of each appliance over time, calculating the consumption in Watts (W) and translating that into daily, weekly, or monthly usage data.

Displaying power consumption on a PC

The system is designed to send power consumption data to a PC using I2C USB or USART communication. The PC records and displays the data, allowing users to see the current status of each appliance, including whether it is on/off and its power consumption in W. The user can monitor this information in real time and keep track of energy consumption for each room and appliance.

Detecting overload and triggering alarms

The system continuously monitors the current being drawn by each appliance. If the system detects that an appliance is in an overload state (drawing more power than its normal operating range), it sends a warning to the master controller [16]. The master controller can automatically cut off the power supply to that appliance to prevent damage. A long beep sound or another alert is triggered to notify the user of the overload.

Modular design for maintenance and expansion

The system is designed to be modular, meaning each room's setup is independent of the others. If maintenance or upgrades are required in one room, the system allows that room's configuration to be

modified or repaired without affecting other rooms. This modular approach makes it easier to add new appliances, upgrade systems, or make changes to the design in the future.

Data logging and analysis

The system stores long-term data on power consumption for each appliance. Users can analyze this data on their PC to identify which appliances are consuming the most power, allowing them to optimize energy usage and reduce costs. The data helps track energy consumption trends over days, weeks, and months, providing valuable insights into household energy management.

I²C communication to implement a continuous control and monitoring process for home appliances. The system is designed around an embedded controller that operates as the master and communicates with multiple slave devices controlling the appliances. Each microcontroller in the system is assigned a unique I²C address, enabling seamless interaction between the master and slaves in *Table 1*.

Table 1. Address for controllers.

Microcontroller	Address
Master	0xA0
Slave 1	0xB0
Slave 2	0xC0

Master (0xA0)

The master microcontroller (address 0xA0) is responsible for initiating communication on the I²C bus. It sends commands to the slave devices and collects data from them, controlling all aspects of the home automation system. The master can write or read data from slaves by addressing them based on their unique I²C addresses.

Slave 1 (0xB0)

Slave 1 (address 0xB0) is a microcontroller that controls appliances in one of the rooms. It listens to commands from the master and acts accordingly (e.g., switching on or off devices). The master can address Slave 1 by sending signals specifically to the address 0xB0.

Slave 2 (0xC0)

Slave 2 (address 0xC0) functions similarly to Slave 1 but controls devices in a different room or section. The master sends commands to this slave by addressing it via 0xC0.

Addressing in I2C communication

I. In an I²C communication network, each device (master and slaves) is assigned a unique 7-bit or 10-bit address. This allows the master to identify which slave it wants to communicate with [17].

II. In your system, each microcontroller (master and slaves) has a unique 7-bit address (e.g., 0xA0, 0xB0, and 0xC0).

III. During communication, the master sends the address followed by a read/write bit to specify whether it's requesting data or sending commands.

IV. For instance, when the master wants to control Slave 1, it will send the 0xB0 address over the I2C bus, followed by the relevant command or query.

V. This address assignment structure is crucial for ensuring proper device identification and communication in your remote control and power monitoring system.

The use of single-ended relays and double-ended relays opens the flexibility for controlling electrical appliances through mechanical as well as by IR remote. There is a special switch in the remote that controls the mechanical switch enabling it to overcome the interrupt given by the mechanical switch. Here, the

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communication with other microcontrollers is carried out by I2C with the help of the IR device address in *Table 2*.

Table 2. The truth table for switching scheme.

Control for mechanical	Mechanical switch	Remote switch	Appliance status
Off	Off	Off	Off
Off	Off	On	On
Off	On	Off	On
Off	On	On	On
On	Off	Off	Off
On	Off	On	On
On	On	Off	Off
On	On	On	On

Case 1: both mechanical and remote switches are off

When both switches are off, the appliance remains off because neither the mechanical switch nor the remote is sending power to it.

Case 2: mechanical switch is off, and remote switch is on

The remote switch overrides the mechanical switch. Even though the mechanical switch is off, the appliance will be on because the remote switch is sending a signal to turn it on. This allows the user to remotely control the appliance without having to touch the mechanical switch.

Case 3: mechanical switch is on, remote switch is off

In this case, the mechanical switch is providing direct power to the appliance, so the appliance remains on, regardless of the remote switch being off. The mechanical switch has direct control when it is in the "On" position.

Case 4: both mechanical and remote switches are on

When both switches are on, the appliance remains on as expected because both the mechanical switch and the remote are allowing power to the appliance.

Case 5: mechanical switch is on, remote switch is off

Even though the mechanical switch is "On," the remote switch being off prevents the appliance from turning on. The remote switch has an overriding capability when the mechanical switch is off.

One of the main features of this setup is that the remote switch can override the mechanical switch when necessary. This is particularly useful for situations where the user wants to control the appliance remotely, even when the mechanical switch is not engaged. When the mechanical switch is On, it takes priority and will allow the appliance to remain on, regardless of the remote switch's status. If the remote switch is off, the appliance will remain off, which can be an energy-saving feature, ensuring appliances are not inadvertently left on when they are not needed. The dual-switching mechanism provides redundancy [18]. Even if one switch fails (e.g., if the remote loses signal or the mechanical switch is stuck), the user can still control the appliance using the other method.

This switching logic enhances convenience by allowing the user to control appliances both locally (with the mechanical switch) and remotely, providing flexibility in different scenarios.

4|Power Monitoring

To reduce the cost, size and power consumption of the power, we have used a traditional PC and an I²C USB module. This board equips the network, I/O and OS and becomes a "full function". The user can adjust the function according to need. This design measures the current use and detects the status of every node. If the check shows that a node is in an "overload state", the embedded server or pc software gives the warning

to cut off the power supply for that home electric outlet. The system calculates and stores the power consumption of this home appliance. Because these functions have not used the whole function of the embedded board, our design uses a slightly smaller kernel with enough procedures, as shown in *Fig. 4*.
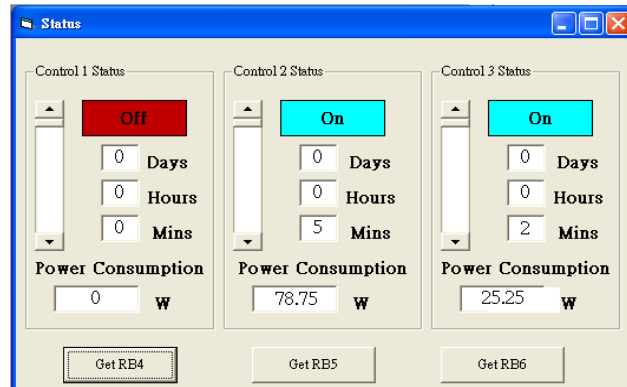

Fig. 4. Power measurement.

5|Implementation Results

To highlight the successful application and testing of the system described in the Software and Hardware Architecture. The system was built using I2C communication, where the master-slave protocol facilitated control of various home appliances and power monitoring in *Fig. 5*.
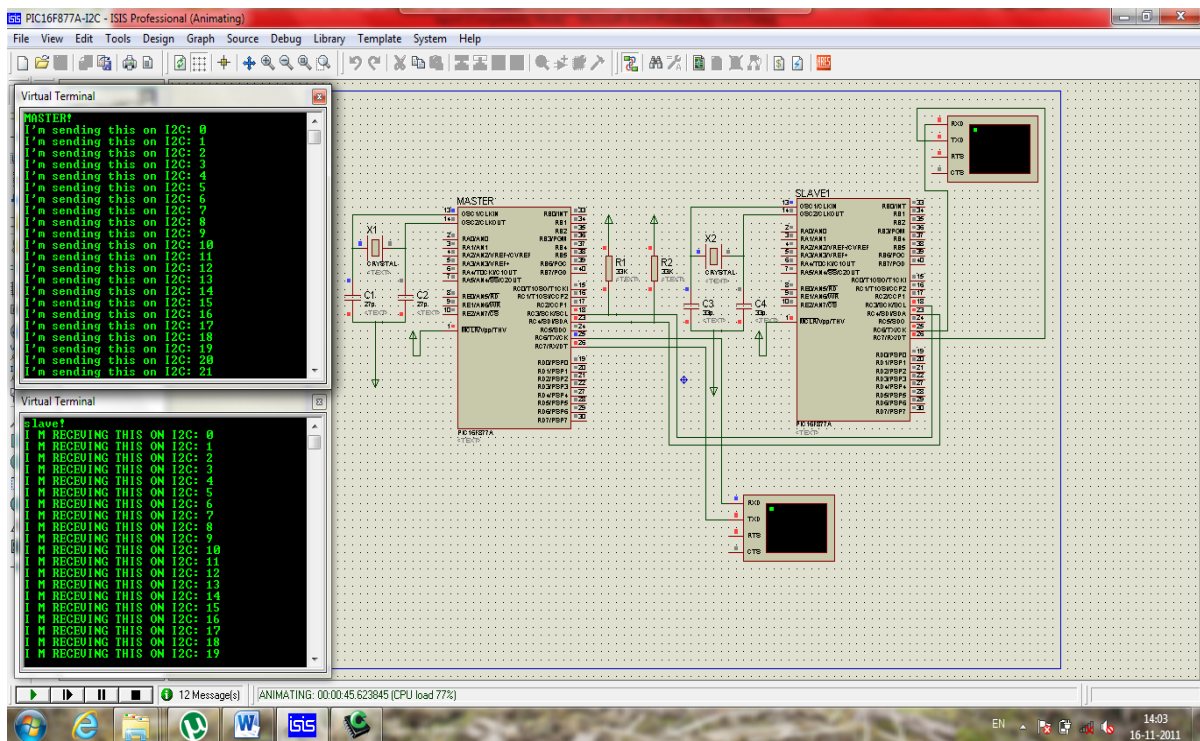

Fig. 5. Testing I²C.

5.1|I2C Communication and Data Transmission

The backbone of this system is the I2C communication protocol, which links the master controller to the various slave devices responsible for controlling home appliances. The communication was tested by sending commands from the master controller to the slaves and receiving status updates.

Incremental data transfer: the system transmitted data between the master and slave devices without errors, ensuring smooth operation. This was tested for both regular and high-speed data loads, with successful acknowledgment from the slaves after each data transfer.

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Clock stretching: the master controller effectively manipulated the SCL, ensuring smooth data transfer even when some slaves were temporarily unable to handle additional data. The system utilized clock stretching, which prevents data overflow by allowing slaves to hold the clock low until they are ready to proceed.

Table 3. I2C Data Transfer.

Test Scenario	Data Sent (Bytes)	Data Received (Bytes)	Status	Remarks
Initial data transmission	10	10	Success	No errors detected
High-speed transmission	10	10	Success	Stable under high data loads
Error scenario testing	N/A	N/A	Failure	Error detected, auto-retry

As seen in *Table 3*, results demonstrated that the I²C communication is reliable and supports high-speed data transmission without significant latency.

5.2|Home Appliance Control Using I2C

The system implemented home appliance control using the master-slave configuration, where commands such as On/Off were sent to slave controllers managing specific devices in various rooms. Both remote control (via IR transmitter) and mechanical switching were used to manage the appliances in *Fig. 6* and *Table 4*.
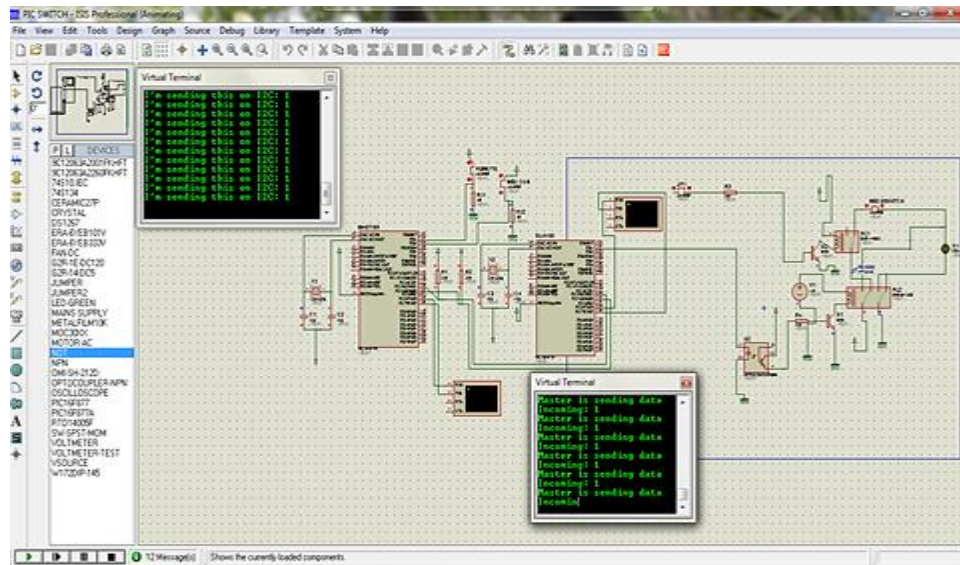

Fig. 6. Appliances control by I²C.

Appliance control: the system was tested by turning devices on and off through the I²C protocol, with appliances such as lights, fans, and air conditioners responding to commands from the master controller within milliseconds.

Dual control (remote and mechanical switch): the system allows both remote and local (mechanical) control, adding flexibility to appliance management. The remote controls could override mechanical switches when necessary.

Table 4. Appliance control response times.

Appliances	Command (On/Off)	Response Time (ms)	Status
Light in room 1	On	25	Success
Fan in room 2	Off	30	Success
Air conditioner in living room	On	28	Success
Heater in room 3	Off	35	Success

The system successfully controlled all appliances with low response times, ensuring real-time interaction between the master controller and slave devices.

5.3|Power Monitoring and Consumption Analysis

The power monitoring aspect was critical to the system's implementation. The IR sensors integrated with the power meters measured the energy consumption of each connected device. This data was continuously transmitted to a PC for real-time monitoring and logging in *Table 5*.

Power consumption monitoring: power was monitored and recorded for multiple appliances, with the system calculating energy usage in Watts (W) and presenting the data for analysis.

Energy logging: the power consumption data was logged on the connected PC, allowing for daily, weekly, and monthly analysis. The system provided valuable insights into the energy consumption patterns of different appliances.

Table 5. Power consumption monitoring.

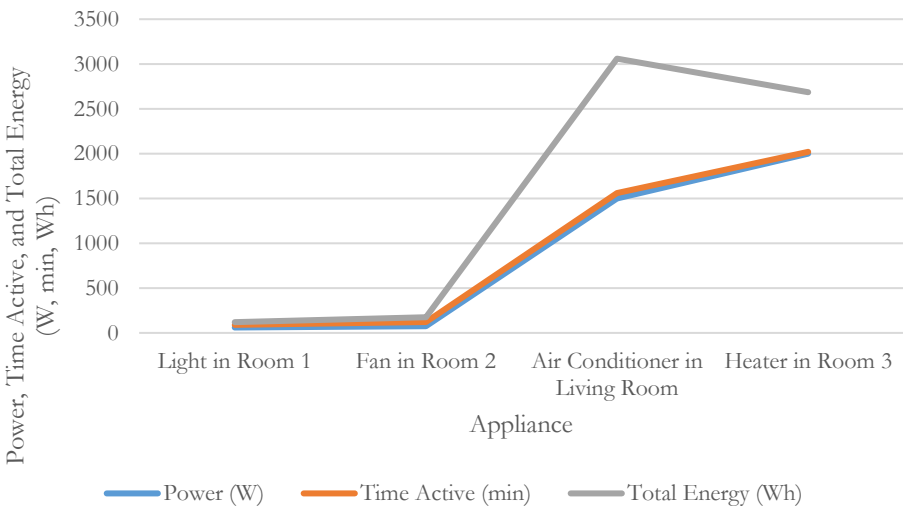| Appliances	Power (W)	Time Active (min)	Total Energy (Wh)
Light in room 1	60	30	30
Fan in room 2	75	45	56.25
Air conditioner in living room	1500	60	1500
Heater in room 3	2000	20	666.67

Fig. 7. Power consumption energy usage in different appliances.

Fig. 7 illustrates the power consumption of various appliances over a given period. The air conditioner, due to its high wattage, consumed the most energy during the testing period, followed by the heater. The data shows that energy-intensive appliances like air conditioners and heaters have a significant impact on household energy usage. By tracking these patterns, users can better manage their power consumption.

5.4|Overload Detection and Safety Mechanisms

A key safety feature of the system was its ability to detect overload conditions in connected appliances. During testing, appliances were deliberately pushed beyond their normal power consumption limits. The system successfully detected overload conditions and automatically shut off the power to protect the device.

Automatic shutoff: the system responded quickly to overload conditions, preventing potential damage to the appliances by cutting off power. Alerts were sent to the user via the master controller, indicating that an appliance had been disconnected due to an overload in *Table 6*.

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Table 6. Overload detection results.

Appliances	Normal Power (W)	Overload Power (W)	Status
Light in room 1	60	120	Power cut off
Fan in room 2	75	150	Power cut off
Heater in room 3	2000	4000	Power cut off

The implementation of the system showed that the I2C-based communication and control setup worked efficiently for managing home appliances and power consumption. The results confirm that the system's software and hardware architecture are capable of delivering real-time appliance control, accurate power monitoring, and reliable overload protection. These features make it an ideal solution for modern home automation, combining safety, energy efficiency, and user convenience.

6 | Conclusion

This method implements the complete protocol of I2C with multi pic slaves. The control of each and every appliance is brought under a single hand. The acknowledgment received by I²C is also used for the purpose of scanning the appliances' status. In the modern era of home automation I²C communication will register its footprints strongly by this application. The same can be extended with CAN protocol with some changes that can be applied to industrial applications as well as big apartments. As it is different from wireless communication, it can be most reliable in any environment due to its wired nature. The I²C USB provides an interface between the computer and the microcontroller. I²C extenders are used so that communications between multiple embedded boards are established. Mechanical switching provision provided along with remote control enables flexible and safe switching in case of emergencies and repairs. A separate system is provided for each room such that the microcontroller can be removed for maintenance without shutting down the system. I²C USB enables to transfer of the details of power consumption to a personal computer. The speed of I²C extends up to 3.4mbps enabling us to a nanosecond switching.

Acknowledgments

Author Contribution

Javad Pourqasem took charge of conceptualizing the research, designing the methodology, and executing the experiments. Markus Hess played a role in the analysis of data, interpretation of findings, and preparation of the manuscript. Both authors reviewed the final manuscript and gave their approval.

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Data Availability

The data that support the conclusions of this research can be obtained from the corresponding author upon a reasonable request.

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