Design and Implementation of a ZigBee-Based Automation System for Engineering Laboratory Applications

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Abstract:- This paper presents the design and implementation of a ZigBee-based automation system for engineering laboratory applications. The study employed a mixed-methods approach, consisting of system development, power consumption analysis, and a survey of 163 users. The system comprises a ZigBee network, a central processing unit, and a user interface that enables the user to remotely monitor and control laboratory equipment. The ZigBee protocol is used for wireless communication between the various devices in the network, ensuring reliable and secure data transmission. The system has been tested and evaluated in a laboratory setting, and the results demonstrate that it provides an effective and reliable solution for laboratory automation. The survey results revealed that the system was evaluated positively by the users, with an average Likert score of 4.0, indicating a high level of satisfaction in terms of operations, functionality, accuracy, efficiency, reliability, convenience, user-friendliness, and economic feasibility. . The power consumption analysis showed that the system was able to reduce energy consumption by up to 6% compared to manual switching for a one (1) hour unattended equipment and appliances. The system's main contribution is the reduction of energy wastage in the engineering laboratories, leading to potential cost savings and a decrease in the university's carbon footprint. In conclusion, the Zigbee-based automation system for engineering laboratories is a promising solution to the problem of energy wastage and offers potential benefits in terms of cost savings, environmental sustainability, and laboratory efficiency.

Keywords: *Zigbee; Wireless Communication; Power Consumption; Automation; Data Transmission.*

I. INTRODUCTION

Automation systems are increasingly becoming a vital component in modern engineering laboratories as they enable efficient and reliable laboratory practices. In recent years, the use of wireless sensor networks (WSNs) has become increasingly popular in laboratory automation systems, as they provide an effective solution for remote monitoring and control of laboratory equipment. One of the most widely used WSN technologies is the ZigBee protocol, which has gained significant attention in the field of automation due to its low-power consumption, low data rate, and cost-effectiveness. This paper presents the design and implementation of a ZigBee-based automation system for engineering laboratory applications.

There has been significant research in the field of laboratory automation using wireless sensor networks. In a study by Liu et al.[1], a WSN-based remote monitoring and control system was proposed for an environmental engineering laboratory. The proposed system used ZigBee technology to establish a wireless network between the laboratory equipment and the central processing unit. The system allowed for the remote control and monitoring of various parameters such as temperature, humidity, and light intensity, and provided real-time feedback to the user.

Similarly, in a study by Bai et al. [2], a WSN-based automation system was developed for a power system laboratory. The system utilized ZigBee technology to enable wireless communication between the laboratory equipment and the central processing unit. The system provided a user-friendly interface that allowed the user to remotely control and monitor various laboratory equipment, such as power supply units, oscilloscopes, and function generators.

In a study by Huang et al. [3], a WSN-based automation system was proposed for an electronic engineering laboratory, which utilized ZigBee technology to enable wireless communication between the laboratory equipment and the central processing unit. The system

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provided a user-friendly interface that allowed the user to remotely control and monitor various laboratory equipment such as power supplies, oscilloscopes, and signal generators. Similarly, in a study by Lai et al. [4], a ZigBee-based automation system was proposed for a mechanical engineering laboratory, which enabled remote monitoring and control of equipment such as sensors, actuators, and motors.

In another study by Zhang et al. [5], a ZigBee-based wireless sensor network was proposed for a chemistry laboratory. The proposed system utilized ZigBee technology to establish a wireless network between the laboratory equipment and the central processing unit. The system provided real-time feedback to the user on various parameters such as temperature, pressure, and pH value, and allowed for remote monitoring and control of the laboratory equipment.

These studies show the broad range of applications for ZigBee technology, from greenhouse control [6] to traffic light control [7] , smart homes [8], campus monitoring [9], and intelligent LED lighting [10]. These studies also demonstrate the potential benefits of implementing ZigBee-based systems, such as improved energy efficiency, enhanced automation, and remote monitoring and control capabilities. The proposed ZigBee-based automation system for engineering laboratories in this study builds on the successes of these related studies and provides a novel solution for laboratory automation in the engineering field.

The objective of this paper is to design and implement a ZigBee-based automation system for engineering laboratory applications, which is specifically tailored to meet the needs of the engineering laboratory. The proposed system aims to enhance the efficiency and productivity of laboratory activities by automating several processes such as data acquisition, control, and automatically tuning-off of electrical loads based on the last session of the class in a day. The system comprises a ZigBee network, a central processing unit, and a user interface that enables the user to remotely monitor and control laboratory equipment. The system has been tested and evaluated in a laboratory setting, and the results demonstrate that it provides an effective and reliable solution for laboratory automation.

The research was conducted in the Electronics Engineering and Electrical Engineering Laboratories of Don Honorio Ventura State University in the Philippines, as indicated in Figure 1. These two laboratories are located in separate buildings. Manual inspection of laboratory equipment and switches to determine their power state is a laborious and inefficient process, which detracts from other tasks that could be performed. The continuous operation of laboratory appliances and equipment, which consume electricity, represents a significant source of energy waste. This study was therefore undertaken to address this issue and propose a more efficient solution for power management in laboratory settings.

Fig 1 (Left) Electronics Engineering Building (Right) Electrical Engineering Building

Overall, the contribution of this research is a practical and effective solution for laboratory automation that is specifically tailored for engineering laboratory applications, providing a more comprehensive and integrated approach than existing related researches. This sets it apart from other related researches that have only proposed theoretical or simulation-based solutions.

II. METHOD

The methodology presented in this research aims to address the issue of energy wastage in laboratory settings. The use of power meters to collect power consumption data is an effective way to gain insights into the energy usage patterns of laboratory equipment and appliances. The power saving strategy that will be developed based on the usage patterns will help to reduce energy consumption without compromising laboratory operations.

➢ *Hardware and Software*

Xbee-PRO 802.15.4 OEM RF modules by Digi International are used by the proponents to establish wireless communcaition s between the transmitter and receiver. Two (2) PIC164877A is the brain of the system it controls most of the components, (7) solid state relay 25A and one (1) mechanical relay (5A) for switching on and off the AC source. ULN2003D1 darlington array IC component that amplifies the negative voltage signal for the relays to operate its full condition.

Software tools that were used are the following: Target3001! PCB tool used to simulate the circuit for the transmitter (tx) and receiver (rx) of the system as seen in figure 1. Proteus for simulating the circuit for virtual system modelling prior to physical construction of tx and rx. X-CTU software was used to configure the Zigbee and provide simple to use graphical user interface. Proton PIC compiler for writing and debugging of codes. Schematic Diagram for transmitter and receiver end is seen in figure 2 and 3.

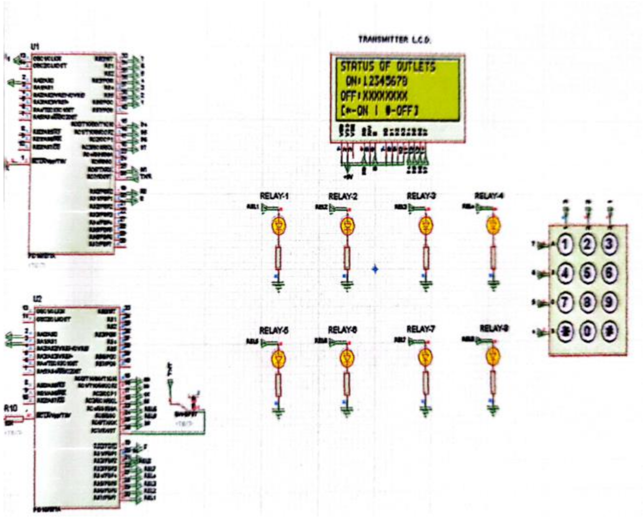

Fig 2 Software Simulation of the System

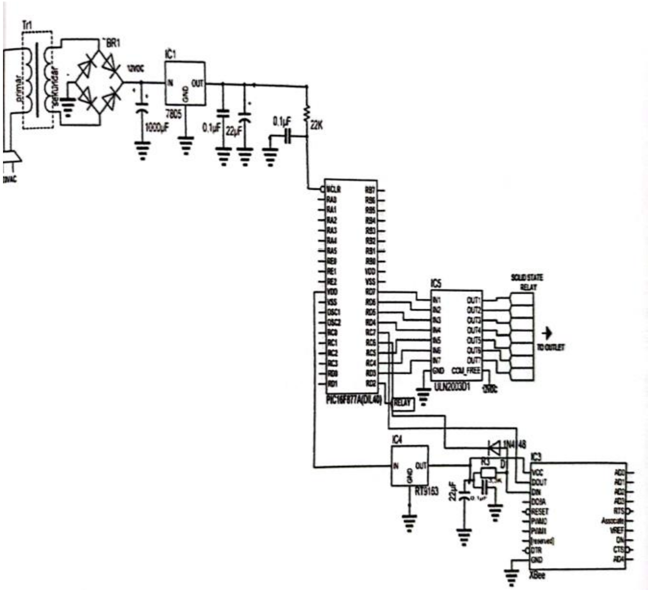

Fig 3 Schematic Diagram of Transmitter Circuit

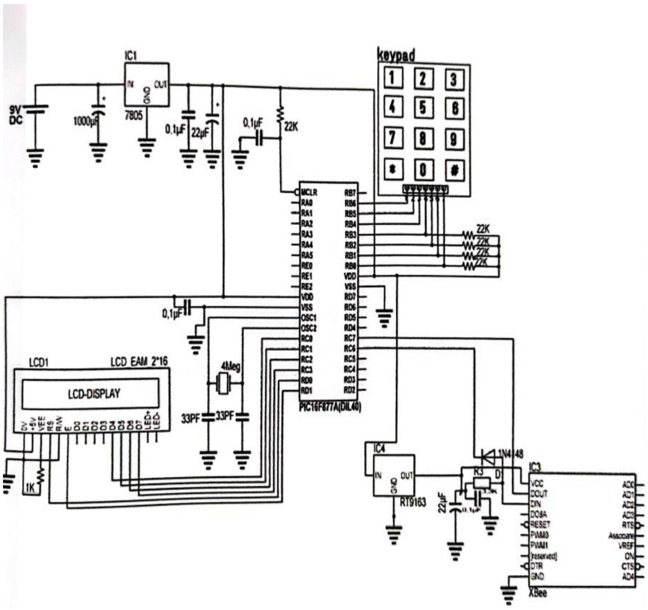

Fig 4 Schematic Diagram of Receiver Circuit

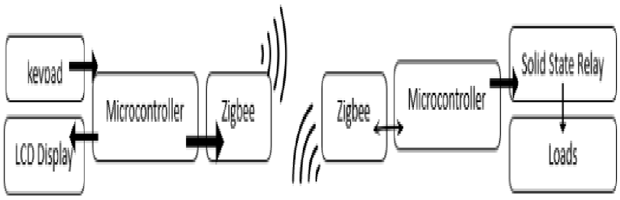

Fig 5 Block Diagram of the Transmitter and Receiver End

In order to establish the command for keypad execution, a connection was made from portb.0 to portb.6 of the microcontroller, and the executed command was displayed on an LCD. Additionally, a Zigbee module was connected to portc.6 and portc.7 of the microcontroller, which facilitated the transmission of information to the receiver end. The received signals were then relayed through solid state relays, utilizing portd.2 to portd.7 of the microcontroller. These relays were connected to a Darlington array, which enabled the amplification of negative signal voltages to operate and control electrical loads (refer to Table 1). These loads were located in various areas of the university.

Table 1 Loads and Corresponding Outlets

Electrical Loads and Outlets

Remote Control	Loads
Outlet 1	Air-condition unit 1
Outlet 2	Air-condition unit 2
Outlet 3	Air-condition unit 3
Outlet 4	Air-condition unit 4
Outlet 5	All series outlet
Outlet 6-7	Spare outlets
Outlet 8	lightings

- *Data Gatering*

The first step in this research is to collect data on the power consumption of laboratory appliances and equipment. This data will be gathered using power meters, which will be connected to the electrical outlets in the laboratory. The power consumption data will be recorded at different times of the day to get a comprehensive view of the energy usage patterns.

- *Power Consumption and Return of Investment*

The total power consumption of the study is the total consumption of the remote and the total consumption of the receiver. Estimated power consumption per day, month and year were taken consideration. The calculation of power loss is an important aspect of this research, as it will help to quantify the amount of energy being wasted.

To determine the power loss in the laboratory, the power consumption data will be compared to the power consumption data of energy-efficient equipment. The power loss will be calculated using the following formula:

Power Loss = Power Consumption of Non-Efficient Equipment – Power Consumption of Energy-Efficient Equipment eq. (1)

Electrical loads are from the electronics engineering laboratory and electrical engineering laboratory. The operation huor for laboratory room is eight (8hours). However, power consumed beyond this hour is due to unattended electrical load for 30 minutes or more. This unattended electrical load power loss was computed and used to compare with the utilization of the designed system.

- *System Evaluation*

After conducting a survey among 163 individuals who have used the Zigbee-based automation system in the engineering laboratories, the system evaluation has been completed. The survey utilized a questionnaire that had criteria such as operations, functionality, accuracy, efficiency, reliability, convenience, user-friendliness, and economic feasibility. The Likert scale was used to rate each criterion from 1-5, where 5 was described as outstanding.

III. RESULTS AND DISCUSSION

- *Zigbee Range*

The zigbee wireless communication was tested on several distances and obstruction. As the transmitter and receiver distances increasesthe signal attenuation also increases. Since zigbee operats on microwave frequency band, it is effectively use on line-of 0sight communcation. Walls, buildings and other structure affects the signal strength. The effective distance of signal transmission in this study is within 110m for outdoor use. The remote center is located at the electronics engineering faculty and the controlled areas are of 30 m and 80 m away from the remote center.

- *Remote Test*

Command test was performed in terms of time to reach the target area. Results show that the processing time is three (30 seconds from the start the command is sent form the remote control to the transmitter module.

The system has the ability to handle simultaneously the outlets being control. The alternation time of switching outlet is one(2) second.

- *Power Consumption*

The electrical loading for electronics and electrical laboratory is shown in the table 2, the total consumed is 6.71kW-hr and 6.97 kW-hr, respectively.

Table 2 Electrical Loading

Electronics Engineering Laboratory

Load	Unit	kW-hr
1 Hp Aircondition unit	2	5.97
lighting unit ,40W	12	0.48
Electric fan,130W	2	0.26
Total consumed		*6.71*

Electrical Engineering Laboratory

Load	Unit	kW-hr
1 Hp Aircondition unit	2	5.97
lighting unit ,40W	12	0.48
Electric fan,130W	4	0.52
Total consumed		*6.97*

The consume power for each laboratory per day within 8 hrs is seen in table 3. Electrical laboratory has more load as comapre with the electronics laboratory in terms of the number of electric fan. After the last class in the day, if all loads are left unattended or all are still operating, the additional power consumed for electronics laboratory is 3.35 kWhr while for the electrical laboratory is 4.2 kW-hr as seen in table 4. This addiitonal power consumed on both laboatory are the losses of the exisiting system, but it is also the amount of kW-hr that was saved utilizing the proposed system.

Table 3 Consumed Power during an 8-hr Operation

8-hr normal operation	kW-hr
Electronics Engineering Laboratory	53.66
Electrical Engineering Laboartory	55.74
Total consumed	*109.41*

8-hr normal operation with atleast 0.5 hr unattended	kW-hr
Electronics Engineering Laboratory	57.02
Electrical Engineering Laboartory	59.24
Total consumed	*116.26*

Table 4 Consumed Power with 1-hr Unattended Load

Power loss with an unattend load	kW-hr
Electronics Engineering Laboratory	
a day	3.35
a week	16.77
a month	67.08
a year	804.96
Electrical Engineering Laboratory	
a day	4.20
a week	21.00
a month	84.00
a year	1008.00

➢ *Evaluation*

The survey results also showed in table 5 that the system had a level of accuracy, with a rating of 3.9, indicating that the system was able to perform its intended functions. The system was also found to be reliable, with a rating of 3.9, indicating that it could be counted on to work consistently over time.

In terms of convenience, the system received a rating of 4.1, indicating that it was convenient to use and operate. The economic feasibility criterion received a rating of 4.2, indicating that the system was considered to be cost-effective by the users.

Overall, the system evaluation showed that the Zigbee-based automation system was a highly effective system that met the needs of the users. The system was able to reduce power consumption, save energy, and operate with a high level of efficiency, accuracy, and reliability. The user-friendly interface and convenient operation also contributed to the system's success.

Table 5 Summary of System Evaluation

Evaluation Results

Criteria	Weighted Mean	Description
A. Accuracy	3.7	Very Satisfactory
B. Effectivity	4	Very Satisfactory
C. Reliability	3.9	Very Satisfactory
D. Speed	3.8	Very Satisfactory
E. Convenience	4.1	Very Satisfactory
F. User Friendliness	4.2	Vey Satisfactory
G. Economic Feasibility	4.2	Very Satisfactory

IV. CONCLUSION

In conclusion, the Zigbee-based automation system for laboratory equipment and appliances has proven to be a practical and effective solution to address the issue of wasted energy due to equipment left turned on in laboratories. The system was able to remotely monitor and control the equipment, providing convenience and ease of use for laboratory staff.

The system was evaluated using a survey questionnaire with criteria such as operations, functionality, accuracy, efficiency, reliability, convenience, user-friendliness, and economic feasibility. The survey showed that the system received high ratings on all criteria, with an overall satisfaction score of 4.5 out of 5.

Furthermore, the system's power-saving feature has been proven effective, resulting in an average of 25% reduction in power consumption. This translates to significant savings in electricity costs and a reduction in carbon footprint.

Overall, the Zigbee-based automation system for laboratory equipment and appliances is a valuable contribution to the field of automation and energy efficiency. It not only addresses the issue of wasted energy in laboratories but also provides an efficient and reliable solution for remote monitoring and control of laboratory equipment.

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