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Development of a Remotely Controlled Distributed Display System for Information Dissemination

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ABSTRACT
This research focuses on a remotely controlled distributed display system for information dissemination for public consumption. It demonstrates a proof-of-concept for a cost-effective system utilising ZigBee communication. The display system is specifically targeted at displaying information for campus activities at the Federal University of Technology, Akure, Nigeria. The system is comprised of two custom-designed 8-row-by-16-column LED matrix displays controlled by ZigBee-enabled microcontrollers. One display forms a ZigBee network that the other finds and joins. Information is composed in an application software at the control centre and downloaded to the master controller. The master controller drives the master display to display the received information; then it transmits the information over ZigBee to a remote slave controller which subsequently displays the received information as well. Performance evaluation revealed that inter-display communication ranges between 29 and 41 metres in closed environments and open spaces respectively. This project successfully validates the feasibility of the proposed system; future works could add ZigBee routers to extend the range of communication between displays.

Keywords: LED matrix, Distributed Display System, ZigBee, CC1352R1

INTRODUCTION

Light-emitting diodes (LEDs) have revolutionized various sectors, finding applications in indication, animation, illumination, and display backlighting (Du, 2020). Among these applications, LED matrix displays, which utilise LEDs arranged in a matrix configuration, are widely used for signage and information dissemination. Wireless communication protocols like ZigBee, Bluetooth, and Wi-Fi offer seamless data transmission and have been extensively utilized in building automation systems. However, while Bluetooth- and Wi-Fi-based implementations of LED matrix displays are common, exploring ZigBee for distributed displays remains underexplored. This gap in research highlights the need for cost-effective and efficient display systems capable of real-time information dissemination. This study addresses this gap by designing a proof of concept distributed display system using ZigBee. Specific objectives include developing LED matrix display boards, designing display-driving circuits, integrating ZigBee communication, and evaluating system performance. By demonstrating ZigBee-based communication between two LED matrix displays, this study seeks to illustrate the potential of ZigBee as a practical solution for real-time, low-power information dissemination. The applications of distributed display systems span various sectors, including transportation, advertising, and large-area communications, and this promises transformative impacts on information sharing.

LITERATURE REVIEW

Related LED Matrix Display Projects

Many engineers and researchers have looked into improving the design of LED matrix displays. In this section, a few examples of such LED matrix display projects are cited.

Popoola *et al.* (2014) presented a programmable display system that shows multi-coloured text with variable speeds and properties. The system utilises assembly language and PIC microcontroller 16F877, and is designed to be battery-powered for uninterrupted operation. The paper features a PS2 keyboard interface for programming and can display up to 32 letters, with the potential for expansion using external memory. The display comprises 784 LEDs for enhanced visibility and is described as having advantages such as low power requirements and greater visibility over other technologies. The paper also discusses the hardware development process, including the selection of components and the design of the voltage regulator.

Moreover, Babu *et al.* (2019) discussed the significance of information sharing in various types of businesses, emphasizing the role of digital advertisement as a modern requirement for promoting services and products. The focus was on scrolling LED dot matrix displays, commonly used in diverse locations such as international airports, stock exchanges, metro railway stations, shopping complexes, and bus stations. The challenge highlighted was making the message displayed dynamic, requiring a connection between the LED display and a computer for content changes. The proposed solution introduced a wireless-based dot matrix display that established a connection between a user's mobile device and the LED display. This wireless connection enabled real-time message display, allowing users to change message content without the need for dedicated and complex wiring. The project's goal was to develop a wireless scrolling message board, providing users the flexibility to update message content through Bluetooth or Wi-Fi, eliminating the need for a physical connection to a computer or laptop.

Furthermore, Zarina *et al.* (2021) discussed the development of a wireless LED matrix display that could be used for advertising, scoreboards, and general messaging. It highlighted the use of Bluetooth and Arduino microcontroller for wireless communication and the DS3231RTC for time display. The system was divided into two parts: a message transmission section controlled by an Android phone and a reception/display section. The paper detailed the use of the MIT App Inventor for creating the Android application and the hardware components involved. It also outlined the process of sending messages from the Android application to the LED display via Bluetooth, and how the Arduino processed and displayed the information.

In addition, Firoz Pervez *et al.* (2016) presented a novel scanning technique for LED dot-matrix displays that aimed to reduce flicker, which was particularly beneficial for large displays. It analysed the drawbacks of traditional scanning methods, such as flicker, lower luminous intensity, and the need for high-speed LED drivers. The authors presented mathematical models for both conventional and new scanning methods, demonstrating the advantages of the new approach through simulation. The research provided valuable insights for LED driver circuit designers, helping them estimate various design parameters and improve display performance.

ZigBee-Based Application Examples

Mustafa *et al.* (2022) emphasize the utilization of ZigBee technology in enhancing power grid control systems through the deployment of smart meters. The article introduces the installation of smart meters driven by ZigBee technology to conserve electricity and improve convenience within the power grid. Smart meters, integrated into the framework of a smart grid (SG), facilitate automated monitoring and reporting, predominantly relying on wireless

ZigBee connectivity networks. The article emphasizes the importance of ZigBee in the proposed approach, which includes the simulation of smart meters utilizing ZigBee-based clustering methods and artificial intelligence. These smart meters not only collect data efficiently but also introduce innovative communication methods, while ZigBee plays a central role in enabling this transformation. The utilization of ZigBee, along with other key contributions like reduced energy consumption and digitization of the energy sector, underscores the significance of the ZigBee protocol in shaping the future of power grid systems.

Another paper authored by Hussein *et al.* (2020) introduces an affordable and efficient weather station with a monitoring system, leveraging the ZigBee communication technique as a primary communication channel. ZigBee, employed alongside other communication methods like Bluetooth and WLAN, serves to transmit and receive data within the weather station system. This approach is particularly suitable for short-range communication (1-10 meters) and addresses limitations often associated with WLAN, such as delays and insufficient bandwidth for handling extensive data volumes, especially in regions with limited internet coverage. The system's implementation and design involve the utilization of an Arduino Uno board and five sensors providing data readings related to rain state, wind level, air pressure, dust density, temperature, and humidity. The collected data can be efficiently stored on an SD card, accessible from a central processing unit or cloud storage, via multiple transmitter nodes within the ZigBee network. This enables data retrieval at any time and date, ensuring real-time and continuous data monitoring without noticeable delays, and offering valuable insights for various applications.

Moreover, Dong and Bin (2015) discussed the design of a ZigBee-based LED streetlight control system that aims to improve energy efficiency in urban lighting. Their article outlines the system's architecture, which includes ZigBee wireless network technology, GPRS connectivity, and a monitoring centre to manage streetlights remotely. The hardware design features the CC2530 chip for ZigBee modules and an 8-bit AVR microprocessor for street lamp nodes. The software design enables energy-saving control by adjusting streetlight operation based on the time of day and traffic conditions. The authors highlighted the system's potential to contribute to a low-carbon economy and address urban lighting maintenance challenges.

In response to the accelerating global industrialization, ShuYu Ding and co-authors (2021) address the shortcomings of traditional control technology in industrial automation, such as low accuracy, high energy consumption, and significant delays. The study focused on developing a novel industrial automation control system, incorporating ZigBee wireless communication technology for enhanced efficiency. The paper detailed the design and implementation of a wireless monitoring system, exploring the hardware and software structures of the ZigBee wireless communication module. The proposed system was evaluated in the context of a pharmaceutical factory's production workshop, demonstrating superior working stability and data transmission efficiency compared to wired systems. Experimental results revealed that the ZigBee wireless transmission model exhibits lower temperatures and better stability during operation. The system's temperature remained consistently lower than that of traditional wired control systems, showcasing a minimal temperature difference of 0.1°C. The research further examined the effectiveness of data transmission, revealing a maximum effective distance of 40 meters with a low packet loss rate in obstacle-free scenarios, ensuring timely data transmission. The paper concludes that the ZigBee- based system proves suitable for industrial automation control, offering insights applicable to the design of control systems in various industrial settings. Notably, ZigBee's characteristics, such as low power consumption, low data rate, and cost-effectiveness, position it as an ideal technology for short-range wireless sensor networks, automatic control, and remote control applications. The research underscored ZigBee's potential to advance the industrial market without directly competing with technologies like Wi-Fi.

In the research titled "ZigBee Radio Frequency (RF) Performance on Raspberry Pi 3 for Internet of Things (IoT) based Blood Pressure Sensors Monitoring," conducted by Adi and Kitagawa (2019), the primary focus is on establishing a Wireless Sensor Network (WSN) utilizing Zigbee RF modules in conjunction with Raspberry Pi 3. The aim is to create an efficient system for monitoring blood pressure in real-time, allowing patients to check their blood pressure from home and enabling prompt and accurate data reception by medical professionals. The study investigates the performance of sensor nodes and analyses the Quality of Service (QoS) they provide. The Raspberry Pi 3 serves as the internet gateway, facilitating the transmission of blood pressure data to a database and real-time display on the internet. The prototype aims to offer real-time systolic and diastolic blood pressure data, aiding in the early detection of symptoms related to various diseases, including anaemia and hypertension. Zigbee communication plays a crucial role in transmitting blood pressure data in real time from the sensor nodes to the database, with a specific focus on communication distances. The study includes simulations and experiments at distances of 5 meters and 100 meters, measuring Received Signal Strength Indication (RSSI) values. The simulations show RSSI values of -29 dBm at 5 meters and -55 dBm at 100 meters, while the experiments yield values of -40 dBm at 5 meters and -86 dBm at 100 meters. This research demonstrates the potential of ZigBee RF modules and Raspberry Pi 3 in creating a robust WSN for real-time blood pressure monitoring, providing valuable insights into the system's performance under different communication distances.

Tran *et al.* (2023), in their article, explored ZigBee communication technologies and their applications, particularly in the context of wireless sensor networks (WSNs). Mobile agents and their routing protocols in various scenarios within WSNs were considered, offering insights into the versatility of ZigBee in different deployment scenarios. Their simulation results highlighted the scalability of ZigBee networks, providing a foundational understanding for future ZigBee application development within the context of Wireless Sensor Networks.

Pereira *et al.* (2020) proposed a communication protocol for Unmanned Aerial Vehicles (UAVs) using ZigBee technology, conducting a thorough review of Flying Ad-hoc Networks (FANETs) and comparing communication technologies like LTE, WiFi, and ZigBee. ZigBee emerged as a promising alternative, particularly in infrastructure-limited scenarios. The authors practically implemented the proposed protocol on a UAV model, DJI Phantom 3 Standard, using a Raspberry Pi 3 Model B board and the XBEE PRO S3B 915 MHz module. Successful tests demonstrated ZigBee's capability to send and receive images between the UAV and a ground station, showcasing its reliability in real-time data transfer. Real-world tests on a flying aircraft affirmed the protocol's accuracy and robustness, with a brief analysis revealing consistent performance across various scenarios, establishing ZigBee as a viable communication solution for UAVs in FANETs.

This comprehensive review establishes a contextual understanding of LED matrix displays and ZigBee technology, drawing insights from seminal research papers and innovative project endeavours. These insights serve as a foundation for the subsequent discussion on methodology and implementation strategies.

METHODOLOGY

The implementation of this project involves development of two LED matrix display boards, designing display-driving circuits, integrating ZigBee communication, and evaluating the performance of the display system.

System Overview

The distributed display system (DDS) is comprised of two LED matrix displays, each equipped with its controller and driving circuits. Figure 1 offers a top-level illustration of the DDS architecture, delineating the flow of information between the master and slave displays. The master display serves as the primary hub for receiving messages from a PC application via its controller's UART peripheral, subsequently relaying the information to the slave display through the ZigBee network.

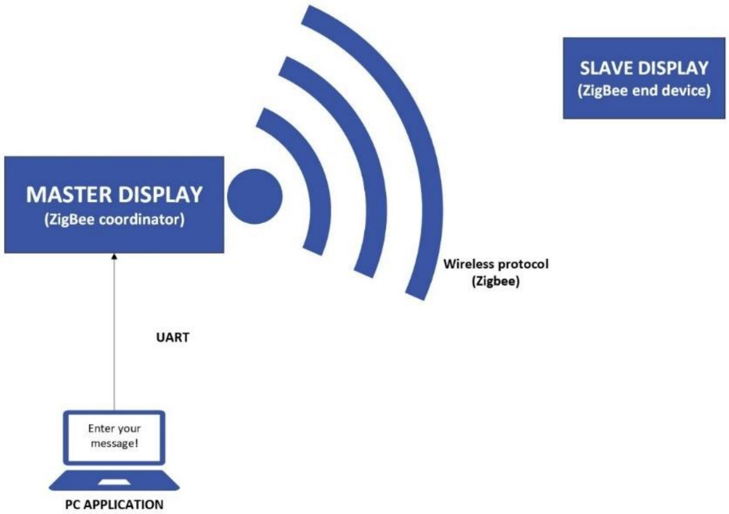

Figure 1: Top-level view of the DDS

Figure 2 provides a comprehensive block diagram representation of a standalone display—master or slave. These essential components are the controller, common-line driver, access-line driver, and the LED matrix.

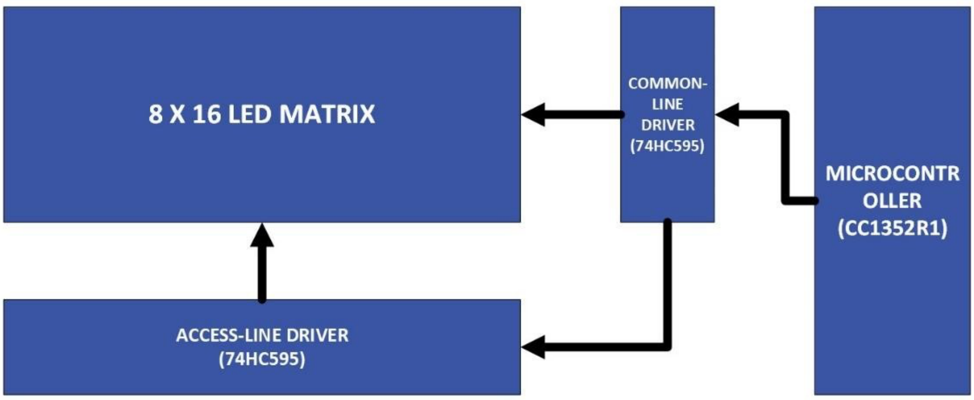

Figure 2: Block diagram of a standalone display system

Circuit Diagram

Figure 3 portrays the circuit diagram for an 8-by-16 LED matrix display, detailing the interconnection of row and column pins with shift registers. The schematic is universally applicable to both master and slave displays.

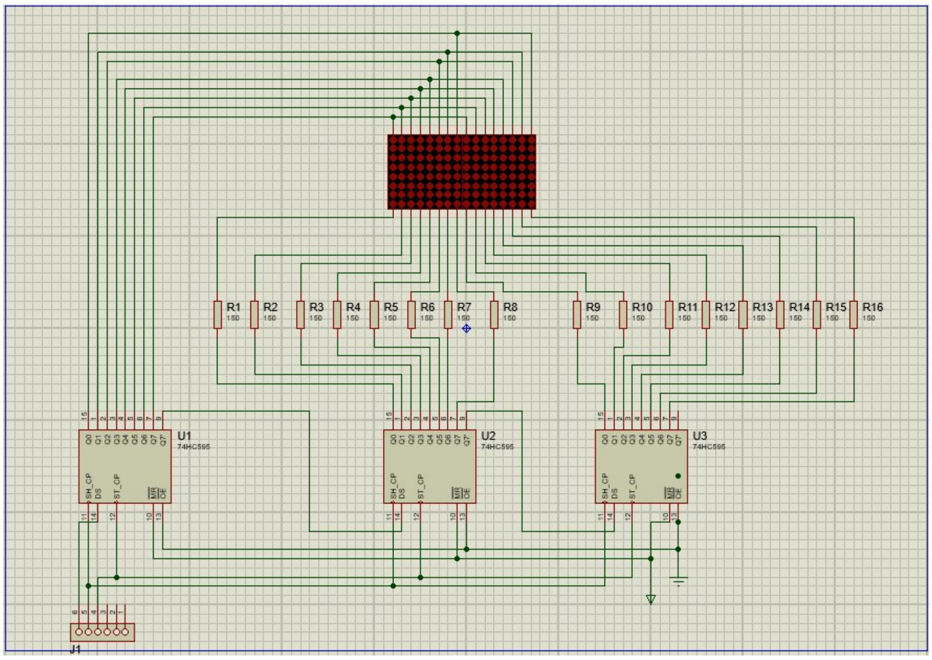

Figure 3: Circuit diagram of an 8-by-16 LED matrix display

Construction Procedure for the DDS

Step 1: Master Display Construction

The first step involved creating a master display. This was achieved by selecting and soldering 128 red 5mm LEDs in an 8-by-16 matrix configuration on a perf board. The LEDs were soldered such that each row contained sixteen LEDs and each column contained eight LEDs. All the anodes of the LEDs in a single row were soldered together, and likewise, all the cathodes of the LEDs in a single column were soldered together. This resulted in a total of 24 input pins for the display: 16 cathodes and 8 anodes. This process, known as multiplexing, reduces the number of input/output (I/O) lines required to drive the display. (It's important to note that later in the project, two pre- built 8-by-8 LED modules were used to replace both the master and slave displays for convenience).

Step 2: Driving Circuit Assembly

The second step involved assembling the driving circuit for the LEDs. This was achieved by soldering 150 ohm resistors and 74HC595 shift registers. Each 74HC595 shift register provides eight outputs. To control the sixteen columns of the master display, two shift registers were cascaded (daisy-chained) due to the higher number of columns.

Sixteen 150 ohm resistors were used in total. Each resistor was connected in series with a single LED in a column. The other end of the resistor was then soldered to an output pin on one of the two cascaded shift registers responsible for controlling the columns.

While there are alternative driver options for the rows of the display, a shift register was also chosen here to leverage its data-shifting capability. All three shift registers (two for columns and one for rows) were daisy-chained. This connection simplified the driving software, as data can be sent serially to one register and then shifted through the others sequentially.

Step 3: Slave Display Construction

The slave display was constructed by replicating the steps used for the master display (Steps 1 and 2). In essence, 128 red 5mm LEDs were soldered in an 8-by-16 matrix configuration on a perf board, with all anodes in a row and all cathodes in a column being soldered together. This resulted in the same driving circuit design as the master display, utilizing 150-ohm resistors and two cascaded 74HC595 shift registers for column control and one for row control. All three shift registers were daisy-chained for simplified software implementation.

Step 4: Firmware Development

The fourth step involved developing the firmware program to control the driving circuits for the displays. This program was written in C using the Code Composer Studio IDE from Texas Instruments. The firmware focused on displaying messages as a series of characters moving across the display. A message was defined as a simple string of characters, where each character in C programming is a data type. Since the display only supported ASCII characters, the firmware utilized a pre-defined font table stored in the microcontroller's memory. This font table contained the display pattern for each character, allowing the program to translate the ASCII code of each character in the message to its corresponding LED pattern for display.

Table 1: ASCII code for a few of the letters of the English Alphabet

Letter	ASCII Code	Letter	ASCII Code
a	97	A	65
b	98	B	66
c	99	C	67
d	100	D	68
e	101	E	69
f	102	F	70
g	103	G	71
h	104	H	72
i	105	I	73
j	106	J	74

The full ASCII table encompasses all uppercase and lowercase letters of the English alphabet, numbers 0-9, various punctuation marks and symbols, and additional special characters. Table 1 only shows a sample for illustrative purposes.

The ASCII codes in the table are in decimal format, and the program used these codes to index the font table and retrieve the corresponding LED pattern for each character. Within the firmware, the message was stored as a character string, and a pointer was used to access each character. In C, a string is terminated by a null character, which also has its own unique ASCII code. The program was written to iterate through each character in the string until encountering the null character, signifying the string's end.

Step 5: Desktop Software Development

The fifth step involved developing desktop software for sending messages to the displays, enabling remote control functionality. This software was written in C# using the Visual Studio IDE.

The software provided a user-friendly interface for interacting with the displays. Users could type messages directly into the interface and send them to the master display for remote viewing. To enhance functionality, additional buttons were implemented within the software. These buttons allowed users to display the current date and time on the display.

Step 6: ZigBee Communication Implementation

The sixth step focused on establishing communication between the master and slave display using ZigBee technology. ZigBee offers three device types: coordinator, router, and end device. This project leveraged this differentiation between the displays:

i. Master Display: The master display was configured as a ZigBee coordinator. This role entailed forming the ZigBee network, allowing other devices (like the slave display) to join.
ii. Slave Display: The slave display was configured as a ZigBee end device. This end device functionality enabled it to join the network established by the master display coordinator.

These configurations were implemented within the respective firmware programs of each display.

The CC1352R1 microcontroller used in this project has built-in support for ZigBee communication. To expedite development, Texas Instruments (TI) provides various code examples for ZigBee applications. One such code example, supplied by TI, was utilized in this project. This example offered APIs (Application Programming Interfaces) that facilitated the sending and receiving of data packets over the air using the ZigBee protocol.

Testing

Display Testing: Each display was tested with simple messages. For example, the firmware was programmed to scroll the following text at start-up: Electrical and Electronics Engineering.

Maximum Distance Testing: Tests were carried out to evaluate the maximum distance that ZigBee packets can go over the air. This was done by keeping the master display stationary and incrementally moving the slave display away from the master. Each time the slave is moved farther, new messages from the desktop software are sent to the master, and the slave is observed to see if it got the new message. These tests were done for both line-of-sight communication and when there were wall barriers between the two displays.

RESULTS AND DISCUSSION

This section presents the findings of the project and explores their significance in the context of wireless communication using ZigBee technology.

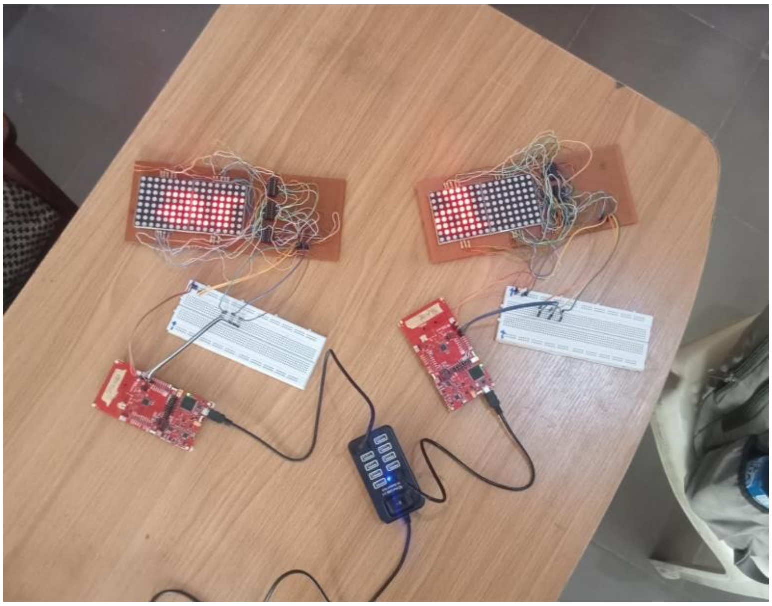

Figure 4: The two displays in operation

System Development and Functionality

The development process commenced with a breadboard prototype to verify data transmission from the CC1352R1 microcontroller to the LED display driver circuits. This initial testing phase ensured the functionality of the core circuit before permanent assembly. Subsequently, components were transferred and soldered onto perf boards, resulting in a more robust design.

The final system functioned as designed. Upon startup, both displays scrolled a pre-programmed message ("Electrical and Electronics Engineering") as shown in Figure 4. The PC application successfully transmitted messages to the master display, which then displayed the message and forwarded it wirelessly to the slave display.

ZigBee Communication Range

Testing focused on evaluating the maximum communication range achievable between the displays using ZigBee. The results (summarized in Table 2) revealed a dependency between communication distance and the presence of obstacles. In a line-of-sight scenario (without barriers), the maximum achievable range was 41.45 meters. Conversely, the presence of wall barriers reduced the maximum range to 29.26 meters. These findings provide valuable insights into the real-world performance of ZigBee communication within an indoor environment.

Table 2: Evaluation of ZigBee range

Test number	Test mode	Distance measured (in metres)
1	Line-of-sight	6.71
2	Line-of-sight	15.24
3	Line-of-sight	41.45
4	With wall barriers	19.20
5	With wall barriers	25.30
6	With wall barriers	29.26

Message Length Limitations

A crucial limitation identified during the project relates to message length. The microcontrollers have limited memory capacity, and transmitting excessively long messages can lead to memory saturation. This, in turn, can cause unintended system behaviour, such as the display of corrupted messages. Future iterations of the system should explore methods to address this limitation, as detailed in the recommendations section (Section 5).

ZigBee Performance Evaluation

The project successfully achieved its objective of developing a functional distributed display system utilizing ZigBee for wireless communication. While the ZigBee specification suggests a theoretical range of 10 to 100 meters, the project demonstrably achieved message transmission within a line-of-sight range of 41 meters and a range of 29 meters with intervening walls. Notably, this transmission occurred with minimal latency. These findings are relevant to researchers and developers exploring the real-world applicability of ZigBee technology for short-range wireless data transmission.

RECOMMENDATIONS FOR FUTURE WORK

This project served as a proof-of-concept (POC) for a distributed display system utilizing ZigBee communication. Here, we explore potential advancements to expand its capabilities and functionality.

Scalability and Network Expansion: The system can be scaled by incorporating additional LED matrix modules with enhanced current sourcing circuitry to increase the display area of a single unit.

Furthermore, the ZigBee protocol can be leveraged to facilitate communication between multiple displays dispersed over a wider area. This necessitates the introduction of ZigBee routers to function as range extenders, effectively amplifying the reach of the ZigBee mesh network. These routers would essentially be standalone displays with the added capability of routing messages (packets) from the coordinator (master display) to more distant displays, thus fostering a large- scale network. This concept presents a promising direction for future research efforts. Additionally, LoRaWAN could be used if longer distances are desired and ZigBee routers present cost challenges.

Wireless Communication Enhancements: The project currently utilizes UART, a wired communication protocol, for message transmission from the PC control software to the master display. Future work could explore replacing UART communications with Bluetooth Low Energy (BLE), another wireless protocol implemented by the CC1352R1 microcontroller. This would eliminate the need for a wired connection entirely, further enhancing system flexibility. Notably, ZigBee communication between displays could be maintained, resulting in a hybrid wireless communication system.

Memory Optimization: Currently, font data for various characters are stored within the microcontroller's memory, consuming significant space. Future iterations could investigate the utilization of an external Read-Only Memory (ROM) for font data storage. This approach would alleviate memory constraints on the microcontroller and subsequently allow for potential system enhancements.

User Interface Integration: The implementation of an alarm system within each display unit presents a potential avenue for future development. This system could utilize a buzzer to sound an alert whenever new messages are received for display. Such an alert system would draw users' attention to the nearest display, ensuring important information is not missed.

By incorporating these recommendations, future research endeavours can build upon the foundation established by this project, leading to the development of more sophisticated and scalable distributed display systems employing ZigBee communication technology.

CONCLUSION

This project aimed to develop a proof-of-concept (POC) for a remotely controlled distributed display system utilising ZigBee communication. The project successfully achieved its core objectives:

Hardware Development: Two 8-by-16 LED matrix displays were constructed with custom-designed driving circuits.

Embedded Software Design: Embedded software was developed to control the displays and integrate with ZigBee communication for wireless message transmission.

Desktop Software Integration: Desktop software was created to facilitate the updating of display content remotely.

Performance Evaluation: The system underwent performance evaluation, demonstrating a maximum communication range of 41.45 meters in a line-of-sight environment. While message length limitations were identified, the project successfully validated the feasibility of a low-cost solution for real-time text transmission.

The project's success in achieving its objectives paves the way for further development of scalable and versatile distributed display systems utilizing ZigBee technology. Potential applications include displaying information in restaurants, banks, transportation terminals, and university campuses. In these settings, a network of ZigBee-enabled display units can be remotely controlled from a central location to effectively communicate critical information to a dispersed audience.

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