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Performance Analysis of Arduino-Based Data Acquisition Systems: A Comparative Study Between Wired and nRF24L01 Wireless Communication using LabVIEW

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تحليل أداء أنظمة الحصول على البيانات القائمة على أردوينو: دراسة مقارنة بين الاتصالات السلكية واللاسلكية (*nRF24L01*) باستخدام برنامج *LabVIEW*

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Abstract:

This study presents a performance evaluation of data acquisition systems (DAQ), focusing on data transmission via wired and wireless communication channels. It provides a comparative analysis of these two methods based on critical factors such as speed, security, and flexibility. For the experimental implementation, an Arduino Uno microcontroller was utilized to develop both wired and wireless data collection frameworks. Data was gathered from multiple sensors, including temperature, gas, and light intensity (LDR) sensors. The LabVIEW software environment was employed for data processing, real-time monitoring, recording, and simulation. The NRF24L01 transceiver module was integrated to facilitate wireless connectivity. Simulation and experimental results demonstrated that while the wired system offers higher data transfer speeds and enhanced security, the wireless system provides significant mobility, ease of installation, and sufficient accuracy for control applications. The findings indicate an average temperature difference of 0.7°C between the two transmission methods, with wireless data showing high precision despite potential signal degradation in wired cables over distance. Ultimately, the study confirms the effectiveness of Arduino and LabVIEW in building versatile DAQ systems suitable for utility and home automation sectors.

Keywords: Data Acquisition (DAQ), Arduino Uno, LabVIEW, Wired Communication, Wireless Communication, NRF24L01, Sensors, Performance Evaluation.

الملخص

تقدم هذه الدراسة تقييماً لأداء أنظمة الحصول على البيانات(DAQ) ، مع التركيز على نقل البيانات عبر قنوات الاتصال السلكية واللاسلكية .وتوفر تحليلاً مقارناً لهذين الأسلوبين بناءً على عوامل حاسمة مثل السرعة والأمان والمرونة .بالنسبة للتنفيذ التجريبي، تم استخدام متحكم Arduino Uno لتطوير أطر جمع البيانات السلكية واللاسلكية .تم جمع البيانات من مستشعرات متعددة، بما في ذلك مستشعرات درجة الحرارة

والغاز وكثافة الضوء .(LDR) تم استخدام بيئة برامج LabVIEW لمعالجة البيانات والمراقبة في الوقت الفعلي والتسجيل والمحاكاة .كما تم دمج وحدة الإرسال والاستقبال NRF24L01 لتسهيل الاتصال اللاسلكي .أظهرت نتائج المحاكاة والتجارب أنه بينما يوفر النظام السلكي سرعات نقل بيانات أعلى وأماناً معززاً، فإن النظام اللاسلكي يوفر تنقلاً كبيراً وسهولة في التركيب ودقة كافية لتطبيقات التحكم .تشير النتائج إلى وجود متوسط فرق في درجة الحرارة قدره 0.7 درجة مئوية بين طريقتي النقل، حيث أظهرت البيانات اللاسلكية دقة عالية رغم احتمالية تدهور الإشارة في الكابلات السلكية عبر المسافات .وفي الختام، تؤكد الدراسة فعالية Arduino و LabVIEWفي بناء أنظمة DAQ متعددة الاستخدامات مناسبة لقطاعات المرافق وأتمتة المنازل.

الكلمات المفتاحية :الحصول على البيانات(DAQ) ، أردوينو أونو، LabVIEW، الاتصال السلكي، الاتصال اللاسلكي، NRF24L01، الحساسات، تقييم الأداء.

INTRODUCTION

The utilities sector is full of professionals who are constantly searching for ways to optimize their communication network investments. Their key goal is to ensure that data is transmitted securely and reliably. Among the many communication technologies available, wireless technology and wired options such as copper and fibre-optic cables are the two most commonly used. Both forms of communication play a crucial role in the utility industry, but their popularity is shaped by various factors, including power consumption, flexibility, and cost-effectiveness. A deeper understanding of the issue shows that each technology has unique strengths and limitations. Transferring data from one computer system to another, whether analog or digital, is called data transfer. This process sends data in the form of bits and bytes over an analog or digital medium, using computing techniques and technology. This makes it possible to transmit data across networks and enable communication between different devices. Data transfer is another term for this entire process. Any communication method that uses actual wires and wiring to send data, audio, or video is known as wired communication. A classic example of this is the traditional home telephone, which connects to a local telephone switch through physical lines that run from the house to the switch. Despite the emergence of new technologies, wired services remain in high demand and are unlikely to disappear anytime soon. Both residential and business customers continue to rely on wired connections, which are supported by numerous local telephone networks. Fiber-optic cables are now widely used in most communication networks to provide reliable and clear signal transmission in both directions. Compared to copper wiring, fiber-optic cables can carry much more data and maintain signal quality over long distances. In contrast, wireless communication is a rapidly growing technology that offers greater mobility and freedom in today's fast-paced environment. One of the main advantages of wireless communication is the elimination of physical connections, which can be a major obstacle for certain applications. Additional benefits include lower costs and easier installation. Many of the challenges and delays associated with cables are aimed to be overcome by wireless technologies. Because of this, wireless networks are often more practical and user-friendly compared to traditional wired networks. Computers can connect to telecom devices without the use of physical cables. This technology is used for a variety of purposes, including data transfer and communication. Wireless networks use various types of waves with microwave lengths to deliver data. Infrared, microwave, and radio frequency (RF) signals can all be used for wireless communication. Infrared communication uses infrared waves to transfer data between two points, whereas Bluetooth, Wi-Fi, GPS, and GPRS rely on radio frequencies. Wireless technology makes it possible to quickly and safely send information over long distances. Therefore, the purpose of this study is to use software to simulate data collected from sensors and create transmission and receiving circuits. Both wired and wireless communication paths will be used to deliver this data to the recipient. The front panel of the LabVIEW program, which will be connected to the receiver, will be used to display and control the data. Furthermore, by comparing the performance of wired and wireless technologies, the simulated data will be analysed, and the suitability of wireless technologies for control applications will be evaluated.

BLOCK DIAGRAM OF A TYPICAL DIGITAL COMMUNICATION SYSTEM

In figure 1 the block diagram applicable to either an analogy or digital communication system is shown.

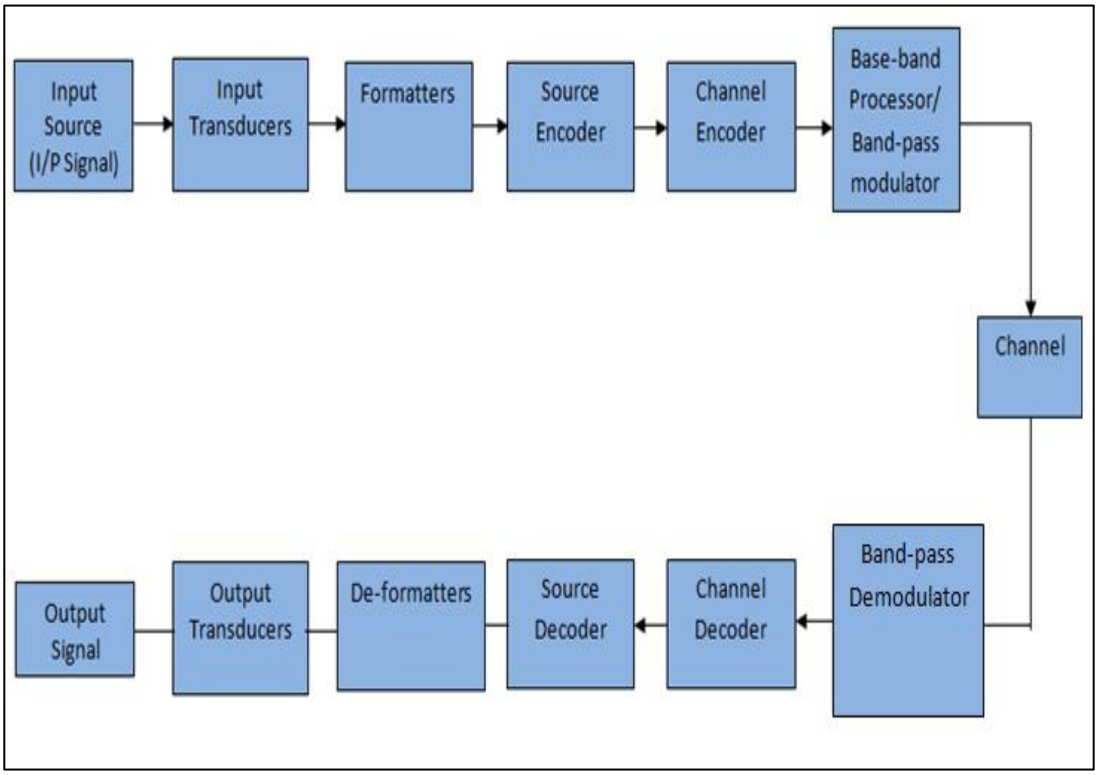

Figure 1: Block diagram of digital communication system

To get ready for sending the source messages, the source encoder usually begins by working with the original data. This process often involves using a device called an analog-to-digital converter, which changes an analog signal—like that from a microphone or camera—into a digital format. Once the data is in digital form, the next step is handled by the channel encoder. This part of the system adds extra bits, known as redundancy, which are important for detecting and correcting errors that might occur during transmission. Then comes the modulator's role, which is to provide the necessary energy to send the encoded symbols through the physical channel. The modulator takes these symbols and creates a continuous-time waveform by assigning each symbol to a specific time period, called a symbol interval (Ts). This waveform is then sent through the channel for transmission [4]. On the receiving end, the process is reversed to undo what was done at the transmitter. But this isn't a simple task because the channel can introduce various issues that change the signal. If the channel had no distortion or filtering, no noise, and no interference from other users, the process would be straightforward. However, in real-world situations, physical channels often have some or all of these problems, which can degrade the signal quality [4]. The type of material used to carry the modulated signal plays a big role in how the channel behaves. For guided media such as optical fiber, coaxial cable, and twisted pair wire, the background noise is typically Gaussian. Similarly, in wireless channels like satellite communications, Gaussian noise is usually the main type of noise affecting the received signal. The same applies to terrestrial microwave channels, although factors like reflection, diffraction, and refraction can also influence the transmitted signal. Fading is a common issue in mobile communications and is often caused by these factors. Fading occurs when the path between the transmitter and the receiver changes rapidly, leading to signal degradation [4].

INTRODUCTION TO LabVIEW

Every single day, software developers create programs that help make work more efficient and productive in various fields and situations. One powerful tool used by software developers is called LabVIEW. LabVIEW stands for Laboratory Virtual Instrument Engineering Workbench, and it is a type of programming language that is especially useful for achieving these goals. LabVIEW is a development platform and environment that allows users to design and build systems using visual programming. This platform was created by a company called National Instruments. LabVIEW has a wide range of uses, including data collection, controlling instruments, and automating industrial processes, among other things. All of these tasks can be performed across different types of computer systems and platforms. LabVIEW uses a special kind of programming called dataflow programming. This means that how a program runs depends on how the programmer arranges the graphical components in the program. In LabVIEW, the programmer creates a visual layout, and uses wires to connect different parts of the program, like functions or code blocks. These wires carry data between different parts of the software. Once all the necessary data is available, a LabVIEW node can start working. This is important because it allows the program to run multiple parts at the same time, which can significantly improve performance by letting different parts of the program work simultaneously. LabVIEW also includes tools to help software developers create user interfaces as part of the programming process. Programs and procedures developed using LabVIEW are often referred to as virtual instruments, or VIs, for short. Each VI has three main parts: the front panel, the block diagram, and the connection panel. The front panel is where the user interacts with the software. It includes controls and indicators. Controls are inputs that let the user provide data to the program, while indicators are outputs that display the results of the program based on the data provided. The connection panel helps link different VIs together so that data and functions can be shared between different parts of a larger system. The actual code of the program is stored in the block diagram, which is often called the back panel. On the back panel, every item that appears on the front panel shows up as a terminal. The back panel also includes the structures and functions that process the input data from the controls and produce the output data. When the front panel acts as the user interface and the block diagram is connected using cables, the VI can run as a standalone program.One of the major benefits of LabVIEW is that it allows users to create programs using a graphical interface, even for those who do not have formal programming training. This is made possible by enabling users to drag and drop virtual models of lab equipment—tools that people are already familiar with. This method makes the programming process more intuitive and easier to grasp for beginners. Additionally, LabVIEW is capable of connecting to various types of hardware instruments and devices, such as cameras and sensors. Users can connect to these devices either through high-level device-specific drivers or through direct commands for communication buses. These drivers help make it easy to control physical equipment from within the LabVIEW environment by providing specialized function nodes that can be used to manage the connected devices. [5].

SYSTEM DESIGN

The following charts show the project structure as shown in figure 2 and figure 3

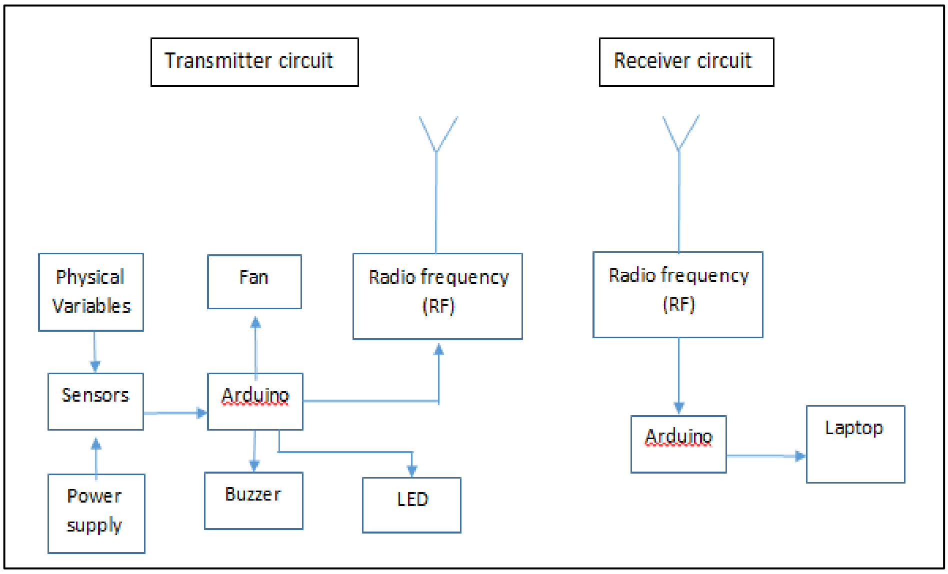

Figure 2: Circuit of data acquisition via wireless communication.

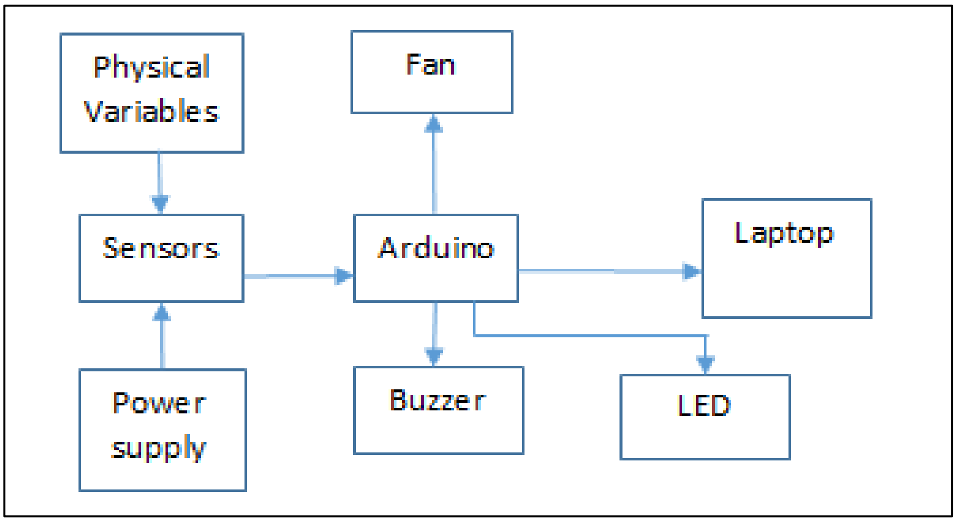

Figure 3: Circuit of data acquisition via wired communication.

The project's physical setup, which mainly depends on using an Arduino board to handle and manage all the functions, is clearly shown in the block diagram. Along with a detailed explanation of how each part will be connected to the Arduino board, it also includes a complete list of all the electronic components that will be used in the project. This physical layout helps to make the project's actual design clear, shows the tools that will be used, and explains how to connect them in a way that improves the overall quality of the design and minimizes the chances of mistakes due to incorrect wiring. Because of its straightforward and precise structure, this physical layout is easy to understand and refer to whenever needed, without dealing with complex or confusing elements. It also provides a detailed overview of the input and output ports on the Arduino control panel, which helps in understanding how data flows through the system.

– **Arduino**

Arduino is an open-source platform that allows people to build electronic projects. It consists of two main parts: a physical board, often referred to as a microcontroller, and a software program called an Integrated Development Environment, or IDE. The software is used to write and send code to the physical board. The Arduino platform is popular among electronics enthusiasts because it simplifies the process of creating projects. One of the advantages of using Arduino is that you can upload new code to the board without needing extra hardware like a programmer. Instead, you can simply connect the board to your computer using a USB cable. Another reason why Arduino is favored is that its IDE is user-friendly, especially for beginners, since it uses a simplified version of the C++ programming language. The Arduino Uno is a specific type of microcontroller board based on the ATmega328 microprocessor. It has fourteen digital input/output pins, of which six can be used to produce PWM (pulse width modulation) outputs. Additionally, the board features six analog input pins. [6] A picture of an Arduino Uno board is shown in Figure 4.

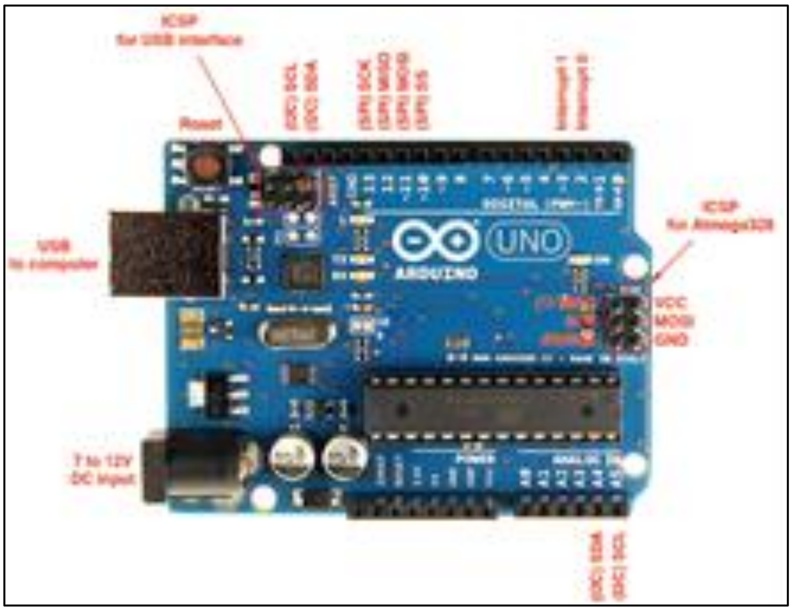

Fig 4: Arduino Uno

– **NRF24L01 Transceiver Module**

NRF24L01 is a single chip radio transceiver for the worldwide 2.4 - 2.5 GHz ISM band and which can operate with baud rates from 250 kbps up to 2 Mbps. If used in open space and with lower baud rate its range can reach up to 800 meters (line of site). Figure 5 shows the NRF24L01 Transceiver Module [8].

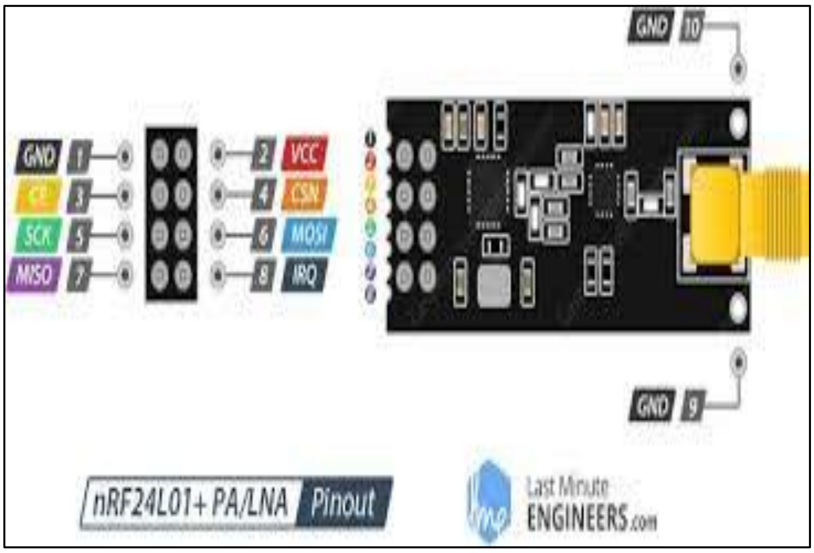

Figure 5: NRF24L01 Module

To allow the chip to send and receive data wirelessly, it will be linked to the Arduino Uno board, which is part of the overall setup. This chip has eight pins in total. Out of these, three pins need to be connected to the correct SPI pins on the Arduino board because they are used for SPI communication. It's important to keep in mind that the SPI pin layout might be different on various types of Arduino boards. Additionally, any digital pin on the Arduino can be used to connect to the CSN and CE pins of the chip. These pins are essential for switching between sending data and sending commands, as well as for putting the module into standby or active mode. The final pin can be used as an interrupt pin, but it's not mandatory to use it. A detailed explanation of the function of each pin and how to connect them to the Arduino Uno board is provided in Table 1.

Table 1: NR24L01 Pin

Pin	Name	Function	Description	Wiring to Arduino
1	GND	Power	Ground	GND
2	VCC	Power	Power Supply (3.3V)	V3.3
3	CE	Digital Input	Chip Enable (RX/TX mode)	Pin 9
4	CSN	Digital Input	SPI Chip Select	Pin 10
5	SCK	Digital Input	SPI Clock	Pin 13
6	MOSI	Digital Input	SPI Slave Data Input	Pin 11
7	MISO	Digital Output	SPI Slave Data Output	Pin 12
8	IRQ	Digital Output	Maskable interrupt pin	-

– **Sensors**

In this study, three different types of sensors are used for home automation systems. These include a MQ2 gas sensor, a DS18B20 temperature sensor, and a Light Dependent Resistor, also known as an LDR. The DS18B20 temperature sensor is a sealed digital probe that is capable of accurately measuring temperature even in environments that are moist or damp. As shown in Figure 6, this sensor uses a simple 1-Wire interface, which makes it very easy to work with. The DS18B20 can be configured to provide temperature readings with a precision ranging from 9 to 12 bits, which means it can offer highly accurate data. Its design, which only requires a single wire and a ground connection, makes it very effective and straightforward to integrate into the main microprocessor of the system, as mentioned in reference [6].

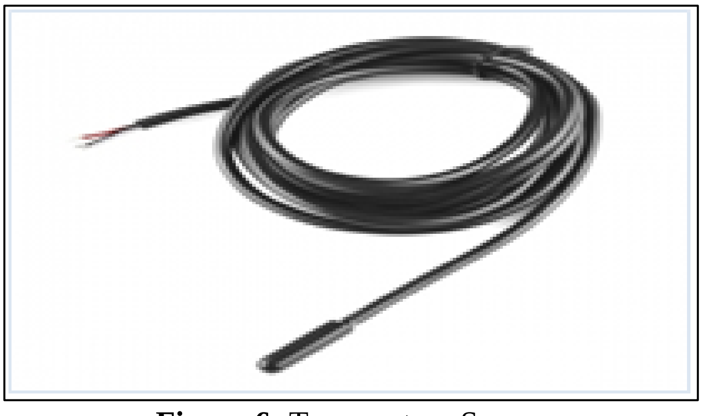

Figure 6: Temperature Sensor

LPG, alcohol, propane, hydrogen, butane, carbon monoxide, and even methane can all be identified and measured by the MQ2 gas sensor. This specific version of the sensor module, which is illustrated in figure 7, includes a digital pin that allows it to function without the need for a microcontroller. However, when the goal is to measure the concentration of gas in parts per million (ppm), the analog pin of the sensor should be used instead. The analog pin is compatible with most common microcontrollers because it operates at 5 volts and follows TTL standards. [7].

Figure 7: MQ-2 sensor

An LDR, which stands for light-dependent resistor, is a type of electronic component that changes its resistance based on the amount of light it receives. The lighter it is exposed to, the lower its resistance becomes, and when there is very little light, its resistance increases. Because of this unique property, LDRs are commonly used in circuits that are designed to detect or measure the presence and intensity of light, as illustrated in figure 8. While these components can be connected to microcontroller boards like the Arduino, it is essential to make sure they are properly connected to a power source so that they can function correctly.

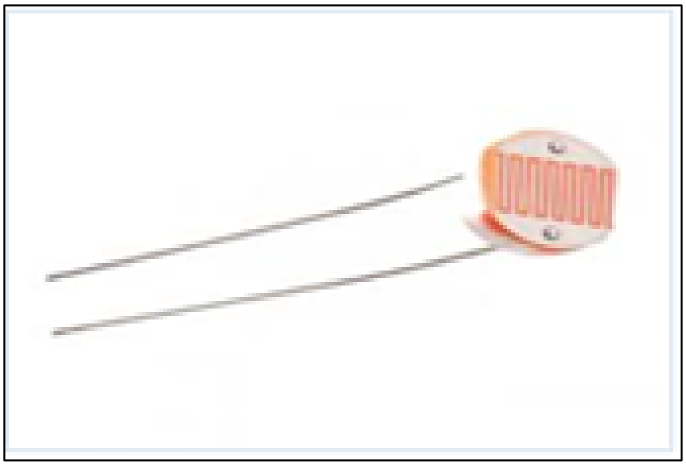

Figure 8: LDR sensor

- **Receivers**

A buzzer is a kind of device that makes a beeping or buzzing sound. Specifically, an electrical buzzer is shown in Figure 10. Light-emitting diodes, which are also called LEDs, are semiconductor components that produce light when an electric current flows through them. In order to manage and control the temperature, both the fan and the relay work together. The fan and the relay are illustrated in Figure 9 -12.

Figure 9: Relay & Fan

THE FRONT PANEL

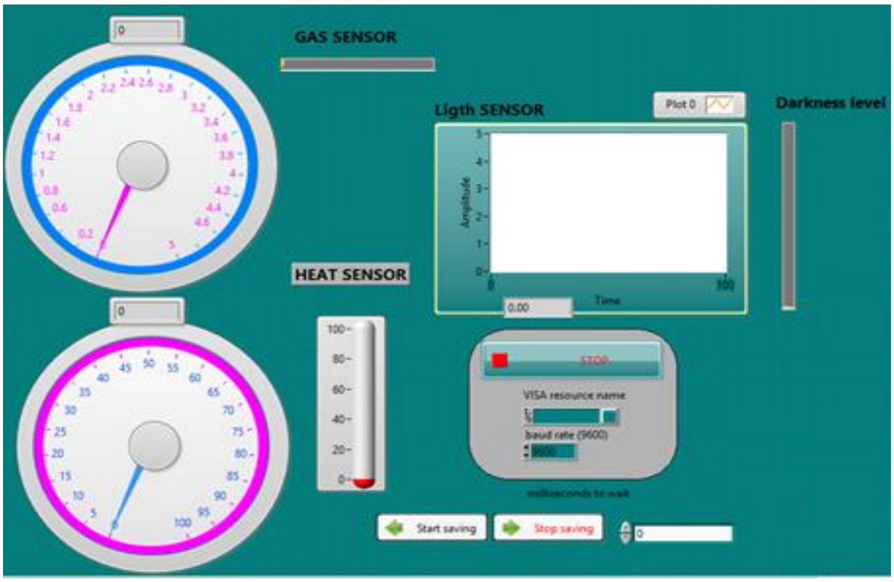

Figure 10: Front panel design.

On the front panel, there are two gauges that display the information gathered from the temperature sensor and the gas sensor respectively. There is also a thermometer that shows the temperature readings from the temperature sensor, and a horizontal progress bar that reflects the data collected from the gas sensor. In addition, there is a vertical progress bar that indicates the level of darkness, as well as a chart that illustrates the light intensity measured by the LDR sensor. The panel also features buttons related to the NI-VISA and database setup, including one for starting data recording, another for stopping the recording process, and a third button that allows the user to set the duration of data recording in milliseconds.

Final form of the project

Implement data acquisition system using wired and wireless communication.

– Send and Receive data via wireless

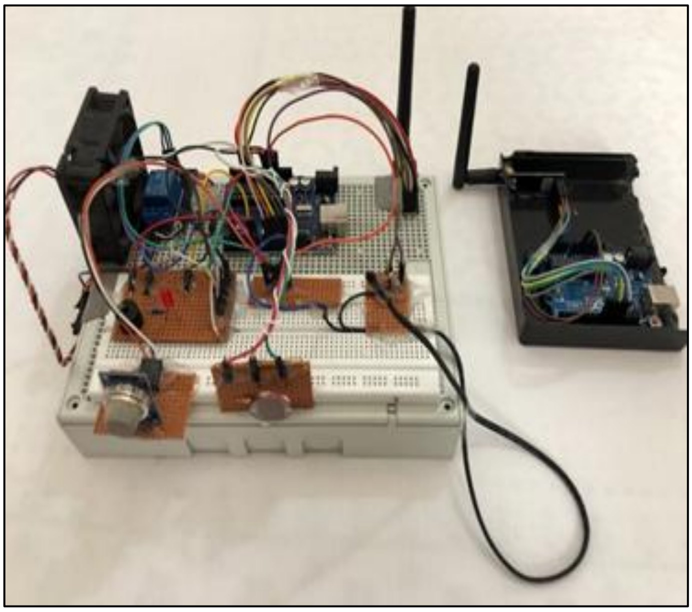

Figure 11: Final form circuit to Send and receive data via wireless

- **Send and Receive data via wired**

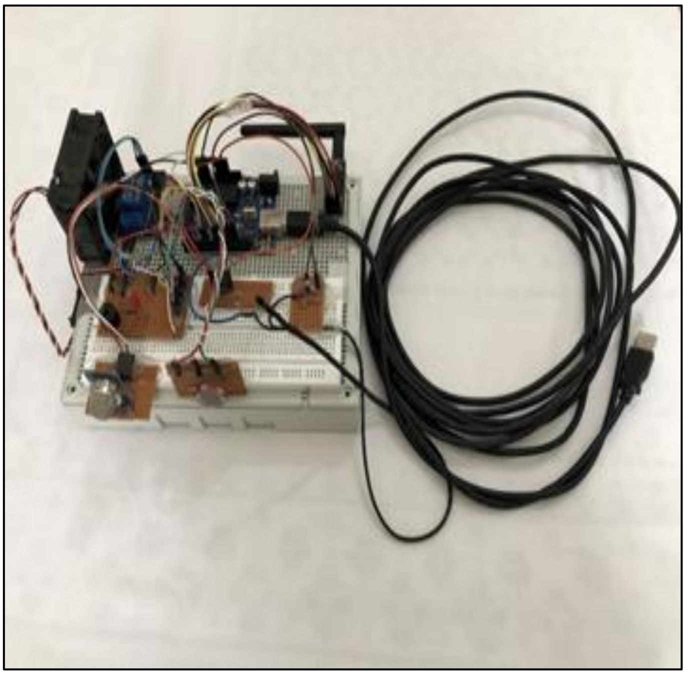

Figure 12: Final form circuit to send and receive data via wired

RESULTS

A LabVIEW program will be used in this section to simulate data from three different types of sensors—temperature, light intensity, and gas. This tool helps to present the findings in a clear and interactive way, making it simpler for users to understand and work with the data through a visual interface. By using this approach, it becomes easier to observe how effectively wired and wireless communication systems perform together. Additionally, a thorough comparison between the two will be conducted to highlight their strengths and weaknesses, allowing for a better understanding of their respective benefits and limitations.

- **Comparison of data acquired using wired and wireless communications based on reference measurements**

In order to conduct this comparison, a laboratory thermometer was used to measure different temperatures under the same conditions. These measured temperatures were recorded as reference points. These reference values were then used to compare the temperatures obtained through two different methods: wired and wireless communication. The temperatures that were recorded using both wired and wireless transmission at a distance of 4.5 meters, as well as the actual temperature readings from the temperature sensor and the laboratory thermometer, are summarized in Table 2. It was found that the temperature readings from the wireless transmission and the laboratory thermometer differed by an average of 3.32 degrees Celsius. In contrast, the readings from the wired transmission had an average difference of 4 degrees Celsius. The LabVIEW application can help ensure the accuracy and reliability of the data by reducing this difference by 3.32 degrees Celsius. It was observed that the data from the wired and wireless transmission varied by an average of 0.7 degrees Celsius. It was also discovered that the temperature measured using wireless communication was higher than the temperature recorded via wired communication. This difference is most likely due to energy or signal loss through the connection. Because the necessary laboratory equipment was not available, it was not possible to measure the intensity of light or the presence of gas in this comparison.

Table 2: The practical measurements

Data Acquired	Reference Measurement Device	Reference Measurements	Wireless Measurements	Wired Measurements
Temperature	Laboratory Thermometer	25.8°C	22.7°C	21.7°C
		22.5°C	20.0°C	19.4°C
		25.1°C	21.4°C	20.9°C
		28.3°C	24.7°C	24.0°C
		30.3°C	**26.6°C**	**26.0°C**
Gas	-	-	0.05 V	0.06 V
Light Intensity	-	-	4.5 V	4.8 V

- **Comparison of data acquired using wired and wireless communications based on database designed**

Every second, the system checked to ensure that the data stored was accurate and up to date. At the beginning of the process, there was a noticeable shift in the ratio of gases, which was clearly visible on the front panel of the system. After that, the brightness of the light was adjusted again, and finally, the temperature was changed. For this specific task, a special database was created to store all the information collected from three different sensors. These changes were carried out twice—once using a wired connection and once using a wireless connection. After both methods were used, the results from each were compared to see how they differed. The data collected during the wired and wireless communications are illustrated in Table 2 and 3, respectively. For each sensor, there were 10 recorded observations, each taking 10 seconds to measure. However, because the physical conditions being measured weren't the same during each test, the results might not be entirely reliable or consistent.

Table 3: Wireless Data Acquisition Results (Database Log)

Temperature (°C)	Light Intensity (V)	Gas (V)
24.90	3.92	0.06
25.15	3.90	0.22
25.76	3.94	1.03
24.78	3.95	1.77
25.51	3.91	2.44
26.00	3.89	2.96
25.39	3.89	3.27
25.15	3.95	2.06
25.15	3.97	0.17
25.02	3.89	0.14
25.15	3.88	0.10
25.51	3.88	0.09
25.02	4.94	0.09
25.39	4.94	0.08
25.15	4.94	0.08
25.15	4.94	0.08
25.15	4.95	0.07
25.02	4.94	0.07
25.39	4.95	0.07
25.27	4.94	0.07
25.88	4.43	0.06
26.25	4.40	0.05
25.64	4.30	0.06
25.76	4.31	0.06
25.76	4.59	0.07
26.13	4.45	0.06
26.25	4.56	0.06
26.13	4.44	0.06
26.13	4.45	0.06
26.13	4.42	0.06

Table 4: Wired Data Acquisition Results (Database Log)

Temperature (°C)	Light Intensity (V)	Gas (V)
24.54	3.95	0.84
24.41	3.99	1.40
24.66	4.00	1.75
24.66	3.95	1.71
24.66	3.98	1.66
24.53	4.00	1.96
24.53	3.98	1.68
24.78	3.97	2.03
24.66	3.99	2.41

24.66	4.00	2.73
24.29	3.86	0.07
24.17	4.95	0.07
24.54	4.95	0.06
24.29	4.95	0.06
24.29	4.95	0.06
24.29	4.95	0.05
24.41	4.96	0.05
24.54	4.96	0.05
24.17	4.95	0.05
24.41	4.95	0.05
24.90	4.53	0.05
25.39	4.57	0.05
25.39	4.32	0.04
25.88	4.59	0.04
26.86	4.48	0.05
28.08	4.55	0.04
28.69	4.62	0.04
28.57	4.53	0.04
28.44	4.64	0.05
28.32	4.45	0.04

In order to evaluate the data collected by the sensors when they were placed at a distance of 4.5 meters, the same setup and conditions were kept consistent throughout the testing. When comparing the results from the wireless transmission method with those from the wired communication, it was observed that the wireless method provided more accurate data. This difference occurred because the cable used for the wired connection caused significant signal degradation, which affected the quality of the data being transmitted. As shown in Table 5 and 6, the wireless transmitter performed more precisely and reliably under these conditions. It is important to note that this comparison does not suggest that wireless connections are universally better than wired ones. Both types of connections have their own unique advantages and characteristics, and a detailed analysis and comparison of these features will be conducted to fully understand their respective strengths and weaknesses. Table 5: Data base for wireless communication.

Table 5: Data base for wired communication

Temperature (°C)	Light Intensity (V)	Gas (V)
25.39	4.57	0.05
25.39	4.32	0.04
25.88	4.59	0.04
26.86	4.48	0.05
28.08	4.55	0.04
28.69	4.62	0.04
28.57	4.53	0.04
28.44	4.64	0.05
28.32	4.45	0.04

- **Comparisons between wired and wireless communications based on the data acquired**

There are several features that are common to both wired and wireless communication systems, and Table 6 highlights the most significant ones among them. A number of these characteristics have been evaluated and proven to be accurate through testing.

Table 6: a comparison between wired and wireless communication

Sr. No	Characteristics	Wired Networks	Wireless Networks
1.	User connectivity	Connectivity is possible only to or from those physical locations where the network cabling extends.	Connectivity is possible beyond the bounds of physical network cabling.
2.	Mobility	Limited (because it operates only on connected computers linked with the network).	Outstanding (enable wireless user to connect to network and communicate to other users any time).
3.	Security	Good	Weak
4.	Reliability	High	Reasonably high (because if a major section such as the router, breaks down the whole network will be affected).
5.	Speed and Bandwidth	High (Up to 100mbps)	Low (Up to 54mbps)
6.	Connection setup time	Less	More
7.	Cables	Ethernet, copper and optical fibers.	Works on radio waves and microwave.
8.	Quality of service	Better	Poor (Delays and longer connection set up times).

Conclusion

The main goal of this research was to explore how effectively wired and wireless communication systems operate, with the intention of identifying their key advantages and limitations. To do this, the study focused on various types of wireless technologies and physical transmission media that are commonly used in these systems. The researchers discovered that the Arduino platform was both flexible and effective for developing a data gathering system, which made it a suitable choice for the project. After the data was gathered, it was transmitted through either a wired or wireless connection and then processed using the LabVIEW software. The results indicated that wireless systems provided a better option for situations where movement was needed and for delivering precise data. In contrast, wired systems were found to be more dependable, secure, and capable of managing larger amounts of data. To ensure a thorough understanding of how each method functions, the data collected from both wired and wireless configurations was carefully examined and incorporated into the final findings.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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