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Seamless Integration of ZigBee Wireless Ambient Detectors with ESP32-Based Systems Using ThingSpeak Application

***Abstract**. The Internet of Things (IoT) has witnessed remarkable growth in recent years, with countless applications ranging from smart homes to industrial automation. To achieve effective IoT solutions, the integration of various sensor devices with connectivity platforms is crucial. This paper focuses on the integration of ZigBee wireless ambient detectors, which measure PM2.5, temperature, humidity, and illuminance, with ESP32-based systems using the ThingSpeak application. The sensors employed in this integration include the current transformer (CT) for electric current level detection, the PMS5003 for particulate matter measurement, the DHT22 for temperature and humidity sensing, and an LDR for illuminance measurement. This comprehensive approach leverages the capabilities of the ESP32-based system, including the MEGA Pro2560 microcontroller, to collect, process, and display sensor data via a 16x2 LCD screen in real-time. Additionally, the data is seamlessly transmitted to the ThingSpeak cloud platform for further analysis and remote monitoring.*

***Streszczenie.** Internet rzeczy (IoT) odnotował w ostatnich latach niezwykły rozwój i obejmuje niezliczone zastosowania, od inteligentnych domów po automatykę przemysłową. Aby osiągnąć skuteczne rozwiązania IoT, kluczowa jest integracja różnych urządzeń czujnikowych z platformami łączności. W artykule skupiono się na integracji bezprzewodowych detektorów otoczenia ZigBee, które mierzą cząstki PM2,5, temperaturę, wilgotność i natężenie oświetlenia, z systemami opartymi na ESP32 wykorzystującymi aplikację ThingSpeak. Czujniki zastosowane w tej integracji obejmują przekładnik prądowy (CT) do wykrywania poziomu prądu elektrycznego, PMS5003 do pomiaru cząstek stałych, DHT22 do wykrywania temperatury i wilgotności oraz LDR do pomiaru natężenia oświetlenia. To kompleksowe podejście wykorzystuje możliwości systemu opartego na ESP32, w tym mikrokontrolera MEGA Pro2560, do gromadzenia, przetwarzania i wyświetlania danych z czujników na ekranie LCD 16x2 w czasie rzeczywistym. Dodatkowo dane są bezproblemowo przesyłane do platformy chmurowej ThingSpeak w celu dalszej analizy i zdalnego monitorowania. (**Bezproblemowa integracja bezprzewodowych detektorów otoczenia ZigBee z systemami opartymi na ESP32 za pomocą aplikacji ThingSpeak**)*

Keywords: IoT, ZigBee, home monitoring, WSN.
Słowa kluczowe: IoT, ZigBee, monitoring domu, WSN.

Introduction

The Internet of Things (IoT) has brought about a new age of connectivity and data-driven insights, reshaping how we engage with our surroundings. In this fast-changing environment, blending various sensor technologies and strong connectivity platforms is crucial to unlock the complete capabilities of IoT [1]. The IoT configuring hardware, establishing communication protocols, and utilizing cloud's capabilities for data management and visualization. By seamlessly connecting these components, users can collect, analyze, and monitor data from ambient detectors with ease [2]. Security measures should be in place to safeguard data transmission. This holistic approach empowers individuals and organizations to harness the full potential of IoT for enhanced environmental monitoring and data-driven insights, contributing to more informed decision-making and improved efficiency [3].

As we analyze the current IoT cloud landscape, some points emerge; namely, selecting the right IoT cloud platform is key to the success of our project. The amount of scalability, data processing, and integration is different in this platform. One should account for features, i.e., data security, analytics tools needed and the adoption of the platform to support the needs of our room monitoring solution [4]. Through the application and selection, an appropriate IoT cloud platform will ensure that our system is always agile in terms of adaption as well as responsive in delivering usable insights to users allowing us to realize enhanced results from our room monitoring efforts.

One of the strengths of ThingSpeak is an open-source IoT application and Application Programming Interface (API) which performs a convenient task in storing and retrieving sensor data from the internet following the communication protocol, Hyper Text Transfer Protocol (HTTP). It functions as a cloud and IoT analytics platform, facilitating a strong service for the aggregation, visualization, and analysis of real-time stream data in clouds. This feature, in particular, imparts ThingSpeak a priceless status within the IoT projects, because not only allows collecting data from sensors but also means that users possess many functionalities useful to gain actionable knowledge through visualization and analytic capabilities. In terms of managing the IoT applications that have been stated to be rudimentary, for instance, when implementing monitoring systems involving the environment, this will help in regulating such projects based on how open and flexible physical platform is. industrial automation and smart home systems [5].

In our earlier work [6], we developed on ambient monitoring aspect focusing mainly on critical meters such as the PM2.5 particulate levels, temperature humidity and illuminance among others. Our solution adopted a set of sensors, including the high-precision PMS5003 for concentration primarily of particulate matter dust and pollen particles, the accurate DHT22 for temperature humidity parameters; using Light Dependent Resistor (LDR) which measures illuminance. These sensors operated together as a highly reliable sensory channel, feeding invaluable information to our IoT system. In this case, we used MEGA Pro2560 to coordinate sensor fusion, data processing and execution. In the pedal board, real-time information was available through a 16x2 LCD screen that delivered the basic user interface. With no conflict, our ambient detectors that are based on the ZigBee wireless technology yielded data flowing smoothly and communication was connected through Narrowband Internet of Things (NB-IoT).

Currently, we are replacing ESP32 with the role of NB-IoT due to ESP32's lower budget requirements. Moreover, it has better wireless control capabilities at a shorter distance and flexibility, making the ESP32 a good choice [7]. The ESP32 operates in several IoT-related developments and has higher capabilities than the Arduino microcontroller board. It also has Arduino IDE and Python support, making it popular among developers [8]. This adjustment aligns our technology with the evolving objectives. It emphasizes the adaptability and versatility of IoT solutions to meet space-constrained environmental monitoring needs, delivering higher IoT system performance.

This paper integrates the wireless system details about the software and hardware infrastructures. We consider particulars of data flow and coordination with the ThingSpeak cloud services, explaining that this integration brings our IoT system to new heights. Furthermore, we test the practical implications of this integration in various scenarios, such as home automation, environmental monitoring, and industrial sensing.

System design

System design and architecture play a crucial role in the successful implementation of IoT solutions, such as the integration of ZigBee wireless ambient detectors with ESP32-based systems using the ThingSpeak application. This section outlines the key components and their interactions within the system design and architecture. The system architecture shows in Figure 1.

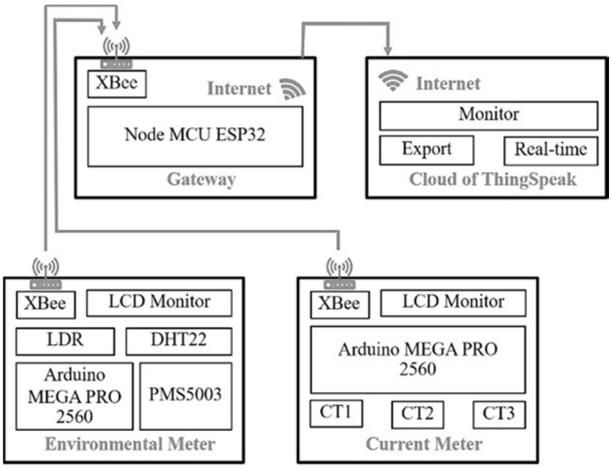

Fig.1. System architecture.

Hardware: sensing section

The domain of ZigBee wireless ambient detectors, a suite of sensors has been deployed to comprehensively measure key environmental parameters. These sensors encompass the quantification of PM2.5 particulate levels, temperature (utilizing the DHT22 sensor), humidity (also monitored by the DHT22 sensor), and illuminance (tracked through the Light-Dependent Resistor, or LDR). To facilitate the orchestration and control of these sensors, a pivotal role is played by the MEGA Pro2560 microcontroller, which serves to not only assist but also manage the intricate tasks associated with data acquisition and actuation. The devices are show in Figure 2 and 3.

Within the framework of Gateway (GW) operation, its primary function is to act as a pivotal nexus for the reception, aggregation, and dissemination of data generated by environmental meters and flow meters. These meters systematically transmit data to the GW at one-minute intervals. Once received, the GW assumes the responsibility of routing this incoming data to two essential destinations: real-time display and secure archival within ThingSpeak's cloud infrastructure.

ThingSpeak cloud environment, this data is made instantly accessible over the internet, thereby affording users the capability to observe and scrutinize real-time data trends. Additionally, ThingSpeak provides a valuable feature for historical data retrieval, allowing users to extract data seamlessly and compile it into an Excel file. This, in turn, facilitates in-depth analysis and examination of historical data trends and patterns, contributing to informed.

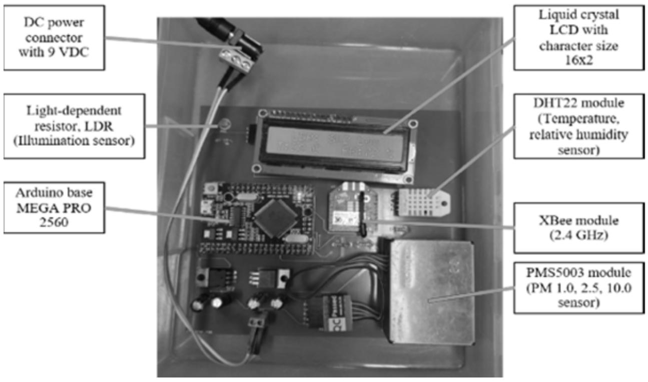

Fig. 2. A wireless ambient sensor device.

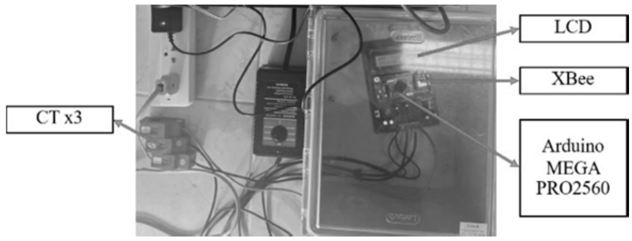

Fig. 3. A wireless electric current level detector.

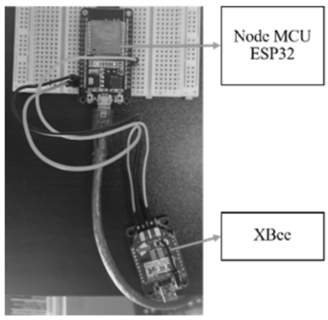

Fig.4. Wiring connection between a GW and a XBee.

Hardware: gateway section

Figure 4 shows the GW with the connected XBee wireless module, well-known for its miniaturization and multi-functionality. A General Purpose Input/Output (GPIO) pin of XBee simulates the capability of a microcontroller to control external devices. Operating in the 2.4 GHz Industrial, Scientific and Medical (ISM) radio band, it is the leading option in wireless communication. The versatility of XBee is extended by the user-configurable settings that enable fine-tuning for diverse applications. Its compatibility with a wide range of communication protocols makes it a multi-purpose tool within the wireless communication industry.

This versatility augments its utility, enabling its integration into a diverse range of applications and scenarios. In practical deployment, the XBee module can assume the role of a stand-alone microcontroller, functioning autonomously as a proficient communication module. Alternatively, it can be seamlessly incorporated into a broader system architecture by interfacing with an external microcontroller. This characteristic extends the module's inherent capabilities and amplifies its versatility, making it an ideal choice for intricate systems. Notably, in certain deployments, a GW featuring an ESP32 microprocessor is employed to bridge communication with an XBee receiver. This integration further exemplifies the adaptability and utility of XBee communication in the realm of wireless connectivity.

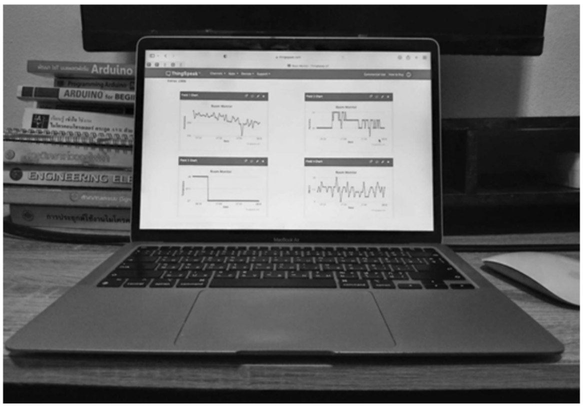

Fig.5. Demonstration of the ThingSpeak screen.

ThingSpeak clod platform

In the world of IoT, data management and visualization are extremely crucial. ThingSpeak proves itself as a versatile cloud service provider, tailored to store data originated by IoT devices such as sensors and GW. Spite its limitations that involve the storage data constraint for Arduino and Raspberry Pi, ThingSpeak remains a major resource in the IoT domain. ThingSpeak serves as a very important part within the IoT data ecosystem. As a cloud service provider, it provides a dedicated platform for storing data generated from IoT devices. Although ThingSpeak is a free service with some restrictions, it exceeds the mere data storage capability. It has one of its outstanding features which is the ability to turn raw data into visual insights. The collected data can be expressed as graphical representations, and thus one can visualize the trends and patterns as they happen in real-time. Besides, ThingSpeak allows data export which provides for further analysis and application. Furthermore, it is capable of accumulating server data, leading to real-time data visualization through dynamic graphs.

Depicted in Figure 5 is the ThingSpeak webpage, demonstrating the potent result when the ThingSpeak is connected with XBee communication in the realm of IoT. ThingSpeak provides cloud-based data storage and visualization functionalities, while XBee adds wireless communication capability to the system, that is between the sensors and the GW, including those based on ESP32 microprocessors. This integration provides intelligent IoT data management and subjective decision-making with advanced data visualization and analysis.

a. Experiment Setup

1) XBee Connectivity: XBee wireless communication modules were integrated into the experimental setup to facilitate wireless data transmission between sensors and data visualization platforms.

2) Firmware uploading: Firmware specific to the sensors and the XBee modules was uploaded onto the respective microcontrollers to enable data collection and transmission.

3) Sensors recording via ThingSpeak: The following sensors were employed to collect environmental data, and the recorded data was transmitted and visualized in real-time using the ThingSpeak platform:

a) PM2.5 Particulate Matter Sensor
b) Temperature and Humidity Sensor (DHT22)
c) Illuminance Sensor (LDR)

4) Data export via varios format files: The collected data from the sensors, including PM2.5 levels, temperature, humidity, and illuminance, were exported in an eXtensible Markup Language (XML), a JavaScript Object Notation (JSON), a Comma-Separated Values (CSV) file formats. This allowed for offline data analysis and further research.

b. Results

The room monitor demonstration showcases an integrated system designed for real-time environmental monitoring within indoor spaces. The system reports critical parameters at 15-second intervals, ensuring a continuous assessment of the room's conditions. Illuminance, measured in lux, is maintained within a range of 17-19 lux, ensuring appropriate lighting levels for occupants. Temperature is consistently maintained at 25 degrees Celsius, providing a comfortable and stable room temperature. Humidity levels are monitored within a range of 49-51% relative humidity, contributing to a balanced and pleasant indoor environment. The system also assesses air quality through the measurement of PM2.5, with values ranging from 5-8 μg/m^3. This range signifies good air quality, minimizing health risks associated with fine particulate matter. The results show in Figure 6.

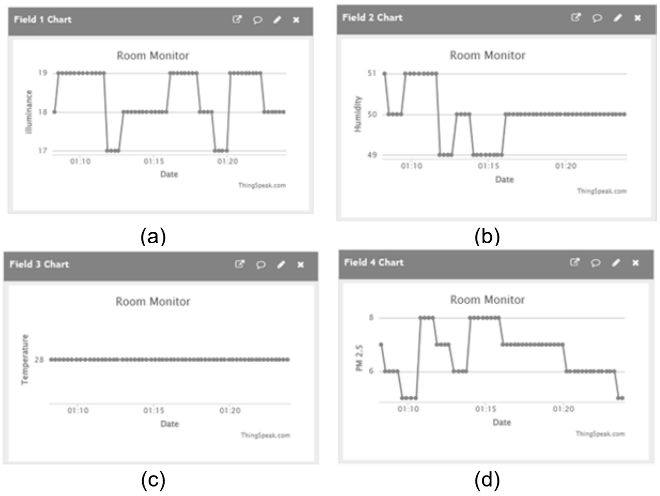

Fig.6. Sensor results via ThingSpeak plotted.

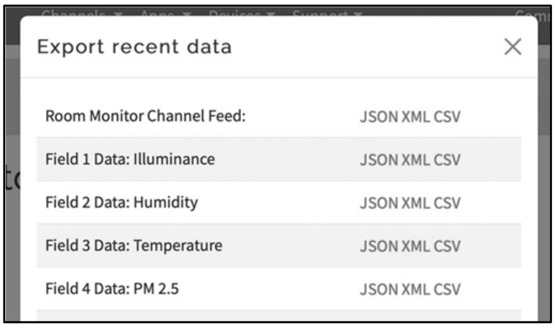

Fig.7. ThingSpeak export interface.

The offered system exhibiting an up-to-date function of regular monitoring of the indoor ambient conditions. These integrated monitoring systems are multi purpose and can be used in the residential, commercial and industrial areas to increase comfort, health and safety. Moreover, the tool proficiently logs sensor values over time using ThingSpeak's potent data export API, which serves as a source for data that is imported to analytical packages such as Excel. The system's increased analytical reach is facilitated by this feature, which makes a detailed analysis possible by keeping the historical log. The data export process see Figure 7 and 8 create sequential time stamped datasets is also cause of a structured collection of sensor measurements. This gathering of the past data is the key basis for the comprehensive analysis, the revealing of trends, and decision-making which has influence on room conditions and overall ecological management in general.

created_at	entry_id	field1	field2	field3	field4
2024-02-06 12:31:08 UTC	11158	8	52	30	8
2024-02-06 12:32:08 UTC	11159	7	53	30	8
2024-02-06 12:33:08 UTC	11160	7	53	30	6
2024-02-06 12:34:08 UTC	11161	7	53	30	8
2024-02-06 12:35:08 UTC	11162	6	53	30	7
2024-02-06 12:36:08 UTC	11163	7	53	30	9
2024-02-06 12:37:08 UTC	11164	6	53	30	8
2024-02-06 12:38:08 UTC	11165	7	53	30	7

(a)


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{
  "channel": {
    "id": 2066984,
    "name": "Room Monitor",
    "latitude": "0.0",
    "longitude": "0.0",
    "field1": "Illuminance",
    "field2": "Humidity",
    "field3": "Temperature",
    "field4": "PM 2.5",
    "created_at": "2023-03-15T10:36:38Z",
    "updated_at": "2024-02-12T15:11:23Z",
    "last_entry_id": 13896
  },
  "feeds": [
    {
      "created_at": "2024-02-08T09:21:04Z",
      "entry_id": 13797,
      "field1": "732",
      "field2": "48",
      "field3": "28",
      "field4": "10"
    },
```


(b)


```
<channel>
    <id type="integer">2066984</id>
    <name>Room Monitor</name>
    <latitude type="decimal">0.0</latitude>
    <longitude type="decimal">0.0</longitude>
    <field1>Illuminance</field1>
    <field2>Humidity</field2>
    <field3>Temperature</field3>
    <field4>PM 2.5</field4>
    <created-at type="dateTime">2023-03-15T10:36:38Z</created-at>
    <updated-at type="dateTime">2024-02-12T15:11:23Z</updated-at>
    <last-entry-id type="integer">13896</last-entry-id>
    <feeds type="array">
        <feed>
        <created-at type="dateTime">2024-02-08T09:21:04Z</created-at>
        <entry-id type="integer">13797</entry-id>
            <field1>732</field1>
            <field2>48</field2>
            <field3>28</field3>
            <field4>10</field4>
        </feed>
        .
        .
        .
    </feeds>
</channel>
```


(c)

Fig.8. Export formats for sensor data on ThingSpeak: (a) CSV, (b) JSON, and (c) XML.

Figure 8 presents three different data export formats provided by ThingSpeak for sensor data dissemination. Part (a) shows a CSV file with timestamped entries in a table format, part (b) displays a JSON format offering a nested, attribute-value pairing, and part (c) depicts an XML format which structures data in a tree-like hierarchy, suitable for complex document structures. Each format serves distinct data handling and integration purposes, catering to various applications and user preferences in data analysis and software environments.

Conclusion

In our quest for efficient electrical energy utilization, this research conducted a thorough exploration of data management, utilizing diverse hardware and communication protocols. The primary goal was optimizing energy consumption through data-driven insights. Our investigation commenced with a comprehensive evaluation of IoT devices, environmental and current measurement tools. We meticulously selected sensors and hardware to capture critical data, including environmental parameters and current usage. The cornerstone of our data system was the versatile Arduino MEGA PRO 2560 microcontroller, facilitating seamless data integration. Data converged through ZigBee communication at a dedicated GW, working alongside the ESP32 microprocessor, to transmit unified data to ThingSpeak. ThingSpeak, a cloud-based service, enabled real-time data visualization and historical analysis, aiding informed decision-making. Exporting data to Excel expanded analytical capabilities and long-term retention.

Future Work

The future work is to decrease traditional meters reliance by using sensor data. If a relation is built between the data of the sensors and of the meter, we can study the possibility of using sensors instead of the meter. The goal of this strategy is to unify data collection, as well to regard costs and complexity in designing energy management systems.

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