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Design and Development of a Low Cost IoT Based Sensor Network for Environmental Monitoring. A Technical Analysis.

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ABSTRACT

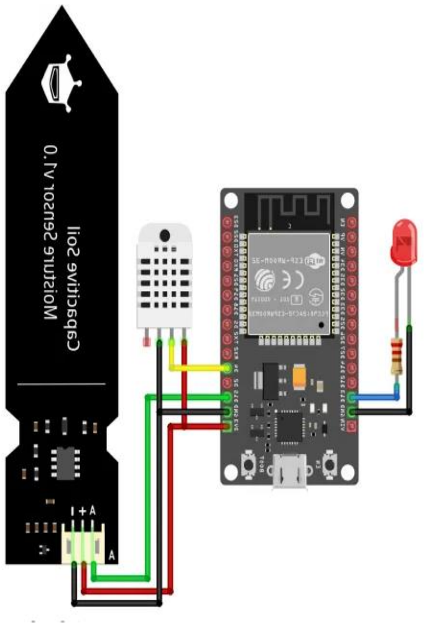
The Internet of Things (IoT) has resulted in the development of a wide range of sensor networks that can monitor and control physical environments. These IoT sensor networks are used in many fields, such as industrial automation, smart cities, as well as health care. This paper seeks to give a detailed review of IoT sensor networks, and above all, it seeks to highlight future research directions. The establishment of IoT sensor networks for environmental monitoring offers a promising avenue for enhancing the understanding of physical environments. The review will highlight the significance of these networks across various applications and propose a low-cost system that leverages real-time data for effective monitoring.

Keywords: environmental monitoring, Internet of Things, Sensor networks,

1. INTRODUCTION

This review paper focuses on designing a low-cost IoT-based sensor network to be applied in environmental monitoring. The proposed system consists of combination of sensors for temperature , humidity soil moisture monitors environmental parameters in real time. The sensor data is transmitted to a cloud-based server using the Wi-Fi communication protocol. It can be accessed and analysed using a mobile app(Narayana *et al.*, 2024). The proposed system is evaluated using a comprehensive technical analysis, including performance metrics ,data analysis and energy efficiency

2. System Overview



ESP32 connected to sensors

In industrial automation, IoT sensors monitor equipment performance, environmental conditions, as well as energy consumption, leading to improved efficiency and reduced downtime. Urban environments, or smart cities, utilize IoT sensor networks for traffic management, waste management, and ensuring public safety,as a result contributing to enhanced quality of life for residents. In healthcare, IoT devices track patient vitals and environmental conditions in hospitals, enabling better patient monitoring and timely interventions.

This paper proposes a low-cost IoT-based sensor network specifically designed for environmental monitoring. The system integrates different sensors to capture real-time data on various environmental parameters. The main features of the proposed system include the integration of , humidity, temperature, air quality, and moisture level sensors to gather comprehensive environmental data, the other feature is the transmission of sensor data to a cloud-based server using Wi-Fi communication protocols, ensuring accessibility and ease of use. Users could access and analyse the collected data through a dedicated mobile application, providing insights into environmental conditions and trends.

Future research directions could focus on the need for enhanced security, scalability, and the integration of advanced analytical techniques to further improve the functionality and effectiveness of IoT sensor networks. As we continue to harness the potential of IoT technology, we can expect significant advancements in environmental monitoring that will benefit both individuals and communities across the globe.

The development of technology has opened the way for new solutions to monitor and manage environmental conditions. One such a solution is the use of low-cost Internet of Things (IoT) based sensor networks for monitoring the environment. These networks are comprised of interconnected sensors that collect data on different environmental parameters such as temperature, humidity, air quality, and more. The data collected is then transmitted to a central system for analysis and action.

The Internet of Thinks (IoT) has drastically changed how humans interact with physical environment. IoT sensor networks are an important component of IoT systems, as a result insures real time monitoring as well as control of the physical environment. These IoT sensor networks consist of a vast number of sensors which are linked to the internet and consequently are essentially able to communicate with each other as well as

with the cloud.

3. REVIEW METHODOLOGY

This review is derived from a qualitative synthesis of peer-reviewed articles, conference proceedings, including technical reports published in the period 2018 and 2024. Sources were identified using academic databases such as ScienceDirect, IEEE Xplore, and SpringerLink. The inclusion criteria focused on studies that discussed IoT applications in environmental monitoring, smart agriculture, fire detection, motor and transformer health management, and cloud-based integration. The review emphasized technologies involving sensor networks, microcontrollers (e.g., Arduino, ESP-32), wireless communication modules, and cloud platforms like ThingSpeak and MATLAB.(Pasha, 2016)

The system could be made up of the following components:

Sensors: Temperature, humidity air quality, level sensors are used to monitor environmental parameters. The sensors used are Temperature sensor for example the DS 18B20 (+/-0.5 C accuracy). Humidity sensor: DHT11(5% accuracy) Air quality sensor:MQ135(10% accuracy Noise Level sensors: LM393 (5% accuracy).

Microcontroller, An ESP32 microcontroller has a clock speed of 240MHz and a memory of 520KB.

c.

The ESP32 microcontroller operates at 240MHz with 520KB of memory, while the ESP8266 Wi-Fi module supports a data transfer rate of 150Mbps to establish communication between the microcontroller and a cloud-based server. It is advisable to double-check specifications and compare them with what you intend to use.

4. LITERATURE REVIEW

Several studies have explored the deployment of IoT systems across diverse domains. Laha et al. (2022) reviewed the role of sensor-based IoT systems in environmental monitoring, while Mamat et al. (2022) discussed deep learning techniques in agriculture for crop health and yield estimation. Vasconcelos et al. (2024) emphasized integrating deep learning and remote sensing for early wildfire detection. Alqourabah et al. (2020) suggested an IoT-based fire detection system that leverages real-time sensor data to activate water sprinklers and alert services. Transformer and motor monitoring systems using ESP-32 and cloud dashboards have also been proposed for predictive maintenance

There have been many approaches and advances in the field of IoT remote monitoring sensors. Many IoT environmental monitoring systems are required to be robust and readily available. Such systems must tolerate the hardware or software failure of nodes and hence should be able to establish communication failures between nodes. However, node failure is inevitable due to environmental and human factors. For example, battery depletion in particular is a major contributor to node failure. The existing failure detection algorithms do not consider the problem of node battery consumption. In order to improve this, a low-power failure detector (LP-FD) is suggested as a solution that can provide an acceptable failure detection service and would save on the battery consumption of nodes.

Classification of water contamination has been studied and water was classified as clean or polluted water, using machine learning methods and IoT devices.(Nandagiri and V, 2021)

Various applications of this technology are proposed for multiple purposes, aiming to serve particular occasions, which may comprise weather reports, acid precipitation control, contaminated water control & monitoring, and crop damage assessment. A cloud-based system that connects IoT devices and various suitable sensors is one example of an intelligent environment system. Such a system could monitor water quality, air quality, waste management, and control. Such systems can be shown in situations which depict contaminated water, pollution of air, waste management (waste collection and disposal), and its control. The organization involved in such monitoring gets to the cloud through accumulation from various sensors connected to it via the internet. The existing literature on SEM methods does not contain many surveys or reviews. A survey published in a peer-reviewed journal on quick-witted agricultural systems (Lezcano, Supervisor and Benítez, no date)(Alqourabah, Muneer and Fati, 2021), intelligent home technologies, innovative health monitoring systems (Ullo and Sinha, 2020), an Internet of Things (IoT)-based ecological system (Ullo and Sinha, 2020) an IoT-enabled marine environment monitoring system (Tribhuwan *et al.*, no date), and a survey on pollution monitoring system design and implementation details (Ullo and Sinha, 2020) are just a few of the articles highlighting different aspects of SEM sensor networks. (Alqourabah, Muneer and Fati, 2021)

5. CHALLENGES IN IoT SYSTEMS

Hardware defects, such as physical damage, manufacturing defects as well as wear and tear, could cause hardware components to be faulty. Software faults could also cause failures. Software Bugs, such as those due to errors in software programming, could lead to crashes or system instability, preventing nodes from functioning efficiently.

Battery Drain is the most common cause, especially for battery-powered devices. Over time, batteries drain due to continuous use and sensor usage. On the other hand, environmental factors could have negative contributing factors. Harsh, extreme environmental conditions such as extreme temperatures, humidity, dust, or water exposure may harm electronic devices, resulting to failure. There could also be hardware malfunctions

Network Faults: Communication faults caused by poor connectivity, interference, or network congestion could cause nodes to appear as if they have failed yet they're simply not able to transmit data.

Accidental damage from poor maintenance activities or tampering may result in node failures.

Electromagnetic interference which is caused by other devices may disrupt functionality, especially in densely populated IoT environments. Lack of critical resources such as memory or processing power could lead to node crashes. By deeply understanding these causes, designers could implement more robust solutions such as Low Power -Failure Detection (LP-FD) to mitigate the risk of node failures and enhance the resilience of IoT systems.

6. SIGNIFICANCE OF RESEARCH

This review provides a consolidated incite into the transformative role IoT plays in real-time monitoring systems. By synthesizing research across various fields, the review highlights how IoT-driven monitoring enhances operational efficiency and enables early fault detection, and also supports predictive analytics. The review outlines the technological as well as operational gaps that future research should address. The research findings must serve as a guide for academics, industrialists, and policymakers to make informed decisions to implement smart monitoring solutions.

The typical applications that use air quality sensors such as MQ135
Sider Fusion. For example the MQ135 air quality sensor is reliably utilized in many applications, mainly for monitoring air quality in environments in such conditions were pollution levels could impact health as well as safety(Narayana *et al.*, 2024). The major objective of the IoT Environment Monitoring systems is to dispel the provocation due to unacceptable effects on the environment using intelligent monitoring such that all the indicators of growth, including a healthy society, are assured. A wide range of applications of IoT technology are suggested for multiple purposes, the aim of which is to serve particular occasions. Consequently, this may include weather reports, acid precipitation control, contaminated water control and monitoring, as well as crop damage assessment. A cloud-based system which connects IoT devices and various suitable sensors are typical example of such an intelligent environment monitoring system. This type of a system could be utilised to monitor water quality, air quality, waste management, and control. Such systems could be employed in situations, which depicts contaminated water, pollution of air, waste management (waste collection and disposal), and its control. The organization data involved in such monitoring reaches to the cloud through accumulation from many different sensors

The aforementioned research (Laha, Pattanayak and Pattnaik, 2022) elucidates the paradigmatic integration of IoT devices, facilitated by the omnipresent internet of great note , the literature on IoT methodologies is characterized by a dearth of comprehensive surveys and reviews. A recent poll, published in a peer-reviewed journal, underscored the burgeoning domain of quick-witted agricultural systems (Laha et al., 2022), intelligent home automation technologies, innovative health monitoring systems, as well as an IoT-based ecological system (Laha, Pattanayak and Pattnaik, 2022)). In addition, articles have been published on IoT-based marine environment monitoring systems and a survey on pollution monitoring system design, which include implementation details, and hence highlights the various aspects of IoT sensor networks.

Environmental monitoring applications could be adopted in controlled agriculture environments, such as greenhouses.MQ135 sensors could also help to monitor air quality to ensure optimal growing conditions and enhance crop yield. Moisture sensors can be used in environmental monitoring as such sensors are employed in weather stations and also to monitor air quality in outdoor environments, thus measuring the concentration of pollutants in urban areas and during special occasions such as during festivals or sports games. Indoor Air Quality Monitoring MQ135 sensors are also used in homes, offices, as well as public buildings to monitor pollutants such as volatile organic compounds (VOCs), carbon dioxide (CO_2), and some harmful gases. This promotes and maintains a safe indoor environment. In smart city applications, MQ135 sensors can be integrated into a network of IoT devices to provide real-time air quality data. This could help city planners and officials to implement strategies to reduce pollution.(Ullo and Sinha, 2020). Industrial Applications, such as in factories and industrial plants, use these sensors to monitor the air quality within their facilities, ensuring that pollutants stay within safe limits and complying with environmental regulations.

Health and Safety Devices like the wearable devices or personal air quality monitors often incorporate MQ135 sensors to alert individuals about poor air quality or hazardous conditions.

In Research and Academia, sensors are frequently used in academic research to study air pollution, indoor air quality, and various environmental sciences.

By incorporating the IoT sensors into these applications, organizations can enhance awareness of air quality conditions, optimize health and safety, and make informed decisions about environmental management.

7. RESEARCH OPPORTUNITIES

The research gaps identified in the literature review include
Privacy and Security concerns
The majority of the existing IoT-based environmental monitoring systems hardly provide adequate security and privacy measures, as a result, which makes them vulnerable to cyber-attacks, data breaches, or violations.
Lack of cheap and energy-efficient IoT-based environmental monitoring system since the majority of the existing IoT-based environmental monitoring systems are costly and hence require significant energy to operate.
Scalability and flexibility issues are great concern since many of the existing IoT-based environmental monitoring systems are designed for specific applications and are not scalable or flexible enough to be used in diverse environments.
Inadequate data analysis and visualisation is lacking. Most of the existing IoT-based environmental monitoring systems hardly provide adequate data analysis and visualisation tools, as a result, which makes it difficult to interpret and understand the respective sensor data.

8. DISCUSSION

The Internet of Things (IoT) has transformed the way we interact with our physical environments through the development of wide range of sensor networks. These networks make it possible for users to monitor and control various parameters in real time, providing critical data for decision-making in multiple domains. The applications of IoT sensor networks extend to various fields, which include industrial automation, smart cities, and healthcare, showcasing their versatility and importance. IoT sensor networks consist of interconnected devices that collect, transmit, and analyse data from the environment. Such networks typically include a variety of sensors, which include temperature, humidity, air quality, as well as noise level sensors. The integration of such sensors enables comprehensive monitoring of environmental conditions, thus enable timely responses to changes or anomalies.

9. CONCLUSION

The analysis and discussion of the review suggested major recommendations. The need for extensive research on deep learning, handling big data and noisy data issues, and a framework of robust classification The paper presented a critical review of research studies on various environment monitoring systems used. The main drawbacks in using smart sensors in AI and WSN must be solved to attain sustainable growth through sensor environmental monitoring (SEM). The crude quality of sensory data can be preprocessed using the right filters as well as signal processing techniques to make the data more ideal for all required applications associated with sensor-based environment monitoring. The future scope of the work aims at studying other factors of environment. Looking forward, it is evident that the future of IoT will rely heavily on advancements in AI, data security protocols, and the development of low-power, high-efficiency sensor systems.

10. ACKNOWLEDGEMENT

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