Wireless automated environmental monitoring system

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Abstract. Advancements in compact integrated circuit fabrication have allowed the amalgamation of wireless transceivers, signal processing, and sensors into a unified unit. This breakthrough enables seamless interaction with the physical realm, with applications spanning security, production oversight, and environmental monitoring. Herein, we investigate the design nuances of a distributed sensor network, where each node operates under energy and communication constraints. The integration of existing wireless technologies, computational capabilities, and organic polymers into a new breed of intelligent devices stands as a pivotal aspect. Within this article, we scrutinize the deployment of a wireless sensor network utilizing the Bluetooth Low Energy protocol. Leveraging organic polymers as a sensing stratum enhances energy efficiency and selective sensitivity in monitoring applications. Notably, the expeditious and cost-effective production of electronics rooted in organic polymers constitutes a substantial advantage. Flexible organic electronics, hinging on the semiconductor and flexible traits of organic materials, represent a foundational element of our technology. We delve into key performance prerequisites for operational devices, along with accomplishments and technical hurdles in the realm of designing and fabricating next-generation devices, targeting the optimization of products.

1 Introduction

Persistent air quality issues, gas leaks, food freshness, and medical diagnostics demand highly efficient sensors. Organic sensors, cost-effective and versatile, offer prospects for various devices, including environmental monitoring. Technological advancements in sensors, including MEMS, wireless communication, and embedded systems, have transformed Wireless Sensor Networks (WSNs). WSNs are actively used in agricultural and environmental monitoring, providing real-scale data on air quality, movement, and weather conditions. Wireless communication, including IoT, significantly expanded the scope of influence, and the use of organic polymers reduced sensor costs and accelerated monitoring deployment [1-2]. Using Wi-Fi and Bluetooth Low Energy (BLE) for data transmission simplifies setup and enhances energy efficiency. This is an effective and affordable solution for monitoring, where organic sensors enable the detection of chemical compounds. The combination of wireless technologies and organic polymers provides a simple and compact monitoring solution [3].

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2 Polymer organic sensors

Organic field-effect transistors (OFETs) or organic thin-film transistors (OTFTs) utilize organic semiconductors (OSCs), such as covalent organic frameworks (COFs) and metal-organic frameworks (MOFs), as materials for active channels, enabling the high-speed fabrication of electronic devices on flexible plastic substrates at economical costs [4,5,6,7,8,9]. OFETs have a wide range of applications, including flexible displays, smart labels, intelligent packaging, various types of sensors, wearable electronics, implantable electronics, and more. Sensors based on OFETs offer low cost and integration capabilities with other electronics, making them in demand for the Internet of Things (IoT), wearable electronics, and medical applications.

One key challenge is the development of sensor coatings based on organic polymers. Organic sensors possess numerous advantages, which will be discussed in detail later. They are successfully used in the detection of various gases such as carbon dioxide, ammonia, methane, as well as other harmful compounds. To create an efficient wireless sensor system, a production process ensuring commercial viability needs to be developed. Organic polymers provide a simple production cycle due to their straightforward synthesis. The use of Bluetooth Low Energy protocol simplifies the data transmission system development.

This study proposes the use of multilayer thin-film structures based on organic compounds. Organic sensors come in different types: capacitive, resistive, and transistor-based, all of which have low power consumption [10-11]. These sensors can monitor temperature, air humidity, and detect various harmful gases, making them valuable for many applications.

Thin films of soluble polymers such as polyaniline, polyindole, fullerenes, as well as their composites with carbon nanotubes and graphene oxides, serve as active sensors (Figure 1). Electrode films are fabricated from aluminum or copper by thermal vacuum deposition, and polymer layers are formed by centrifugation from a solution.

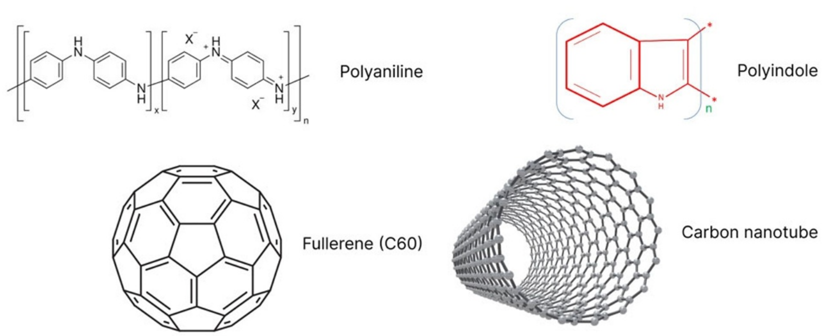

Fig. 1. Organic compounds: polyaniline (PANI), polyindole, fullerene, carbon nanotube.

The multifunctionality of polyaniline (PANI) nanocomposites has found remarkable applications in various fields. Their ability to detect various combustible and toxic gases with high selectivity and sensitivity, as well as to incorporate bioreceptors, makes them valuable for biological sensors. Studying the mechanisms of PANI nanocomposites expands their range of applications.

Due to their low cost and ease of production, organic materials have become key in the development of electronics. They can be processed at low temperatures, enabling various deposition methods, including inkjet printing and film deposition. This allows for the creation of various types of sensors (Figure 2).

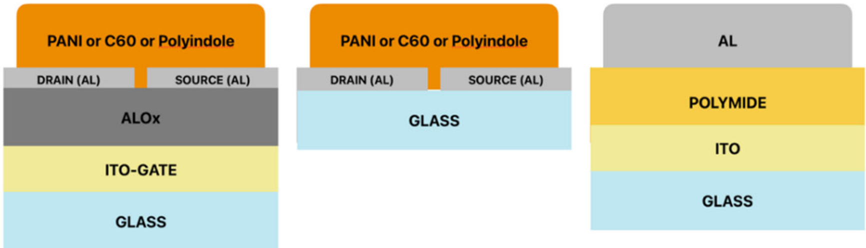

Fig. 2. Types of organic sensors: transistor-based, resistive, and capacitive.

3 Software and hardware

Data exchange in systems, especially wireless and portable ones, plays a significant role, posing specific requirements to ensure the effective operation of the system. Maintaining optimal distance and efficient power consumption during data transmission are important tasks. Long-range communication (more than 50 meters) requires significant energy consumption, which contradicts the concept of portability. Modern solutions based on the Internet of Things (IoT) technology provide wireless data transmission with low energy consumption.

The software component of the complex is associated with many aspects. In the market, there are numerous Bluetooth Low Energy (BLE) modules from various manufacturers available in different price ranges. Each of these modules has its own libraries for working with this protocol. For example, modules from Nordic Semiconductor are characterized by high quality and detailed documentation, but their cost exceeds that of many alternatives. Due to the global economic situation, access to such solutions is not always openly available, especially in the case of mass production. More affordable alternatives include Chinese models, such as the ESP32 from Espressif Systems. However, these modules may have less stable technical characteristics. Thus, the choice of communication controller is possible in a wide price range, not creating barriers for further development.

For data transmission and reception, it is proposed to use Wi-Fi or Bluetooth technologies, which are already widely used for creating Internet of Things devices. Compact embedded sensors are widely used in everyday life in various areas, such as wearable devices, home appliances, and electronic healthcare systems. Bluetooth Low Energy (BLE) combines good performance, low power consumption, and wide distribution. The key aspects of BLE efficiency include a throughput of up to ~230 kbit/s, a practical throughput limit of ~100 kbit/s for real applications, a maximum communication range of several tens of meters depending on the radio station's power, a maximum number of nodes in the network usually not exceeding 10, and power consumption, depending on many parameters, requiring strict experimental assessments.

Of interest is the Bluetooth Mesh technology, allowing data transmission between devices and building mesh networks "one to many" or "many to many," increasing the communication range and providing network self-recovery capabilities in case of failure of one of the elements. BLE Mesh operates in advertising mode and uses specific frequency channels. BLE's energy consumption is the main advantage compared to Classic Bluetooth and other wireless technologies. AES-CCM cryptography with 128-bit encryption ensures data transmission security. The dimensions and weight of the sensor are minimal, ensuring its ease of placement and operation. The use of rechargeable batteries provides a long operating life for a device on Bluetooth Mesh technology.

4 Application scenario

In the Russian Federation, the annual level of incidents in the oil refining and petrochemical industry ranges from 9 to 35 thousand, covering areas from 500 thousand to 3.5 million hectares. According to the Federal Service for Environmental, Technological, and Nuclear Supervision, 251 incidents were recorded from 2004 to 2018, including 104 explosions, 50 releases of hazardous substances, and 97 emergency situations. The dynamics of emergency events are also presented, and the economic damage is assessed. The highest economic damage from incidents to the national economy was recorded in 2016 and amounted to 155$ million [20].

Scientists and conservation agencies can take preventive measures to prevent incidents in the oil industry by collecting and analyzing sensor data from various sections of facilities. These data include parameters such as temperature, humidity, illumination, and the quality of the surrounding air. Such information can be used to detect the initial stages of incidents in the oil industry, helping to monitor the situation before they worsen and to understand changes in industrial facilities over time.

There are various approaches to incident detection, where data from sensors are transmitted to base stations or command centers using wireless sensor networks. However, this work focuses on assessing the application of Bluetooth Mesh technology to create energy-efficient routing to a mobile receiver node. These nodes can be used in scenarios for incident detection in the oil industry or in other situations where data collection from a sensor network is necessary. An example of the conceptual system scheme is presented in Figure 3.

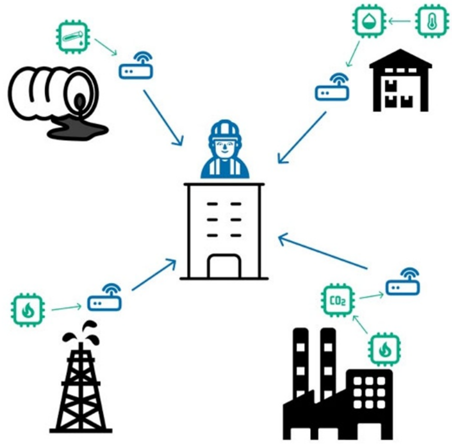

Fig. 3. Conceptual diagram of the system operation.

5 Conclusion

Data exchange in systems, especially in wireless and portable ones, plays a crucial role and poses specific requirements for efficient functioning. These requirements include maintaining an optimal distance and ensuring effective energy consumption during data transmission. Modern solutions, based on the Internet of Things (IoT) technology, facilitate wireless data transmission with low energy consumption.

An important aspect is the selection of a communication controller, which can be done within a wide price range, not limiting the possibilities for subsequent development. Wi-Fi and Bluetooth technologies offer efficient methods for data transmission and reception, particularly in the realm of Internet of Things (IoT) devices. Bluetooth Low Energy (BLE) combines performance, low energy consumption, and widespread use. Bluetooth Mesh

technology provides the capability to create energy-efficient mesh networks, which is crucial for data transmission in various applications.
The utilization of data collection and analysis technologies, including sensors, holds significant importance for monitoring and preventing incidents across various industries, including the oil and gas sector. Data gathering from sensor networks enables early detection and analysis of the initial stages of incidents, facilitating timely actions to prevent their escalation. Data collection systems can be employed in diverse scenarios, encompassing agriculture and monitoring industrial facilities.

Thus, the integration of wireless technologies, particularly Bluetooth Low Energy and Bluetooth Mesh, into data collection systems represents a promising direction across various applications, ensuring efficient information transmission.

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