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PORTABLE ELECTRONIC NODES FOR A SENSOR NETWORK

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Abstract: To capitalize on the research on metal oxide-based sensors that is being intensively studied by our research team, there is a need to connect these sensors into devices capable of receiving, storing and, if necessary, transmitting measured data. We are also investigating the mechanics of sensor detection using chemistry and applied physics. To achieve this goal, there are some impediments that must be overcome, such as the method of data acquisition, the power consumed by the device, the stability over time with a subsequent correction, the distance to which measured data will be transmitted and others. Another aspect is the size and portability of these devices with built-in sensors. This paper presents some concepts that provide solutions to the problems presented. These devices are important for monitoring environmental parameters with application in agriculture, cellars, production halls. Another possible use is to incorporate them into drones, which will potentially increase their mobility and detection range.

Keywords: sensor, electronic nodes, embedded systems, sensor network, battery powered.

Introduction

Devices that detect explosive gases in hazardous environments prevent accidents and save lives. They are crucial to safety in different domains such as automotive, agriculture, and industry, where explosive gases pose a significant risk. For example, this feature is used extensively in the case of huge batteries in electric vehicles. And as known our department is developing nanostructure-based sensors capable of detecting such gases. Specific examples of gases that our sensors can detect include: nitrogen dioxide (NO_2), hydrogen (H_2), hydrogen sulfide (H_2S), ammonia (NH_3), volatile organic compounds (VOCs), and others [1].

Earlier, numerous advances have been made in this area under the leadership of Professor Oleg Lupan with the help of our researchers and global collaboration. Dual-mode ZnO:Eu based nanosensors have been created that can detect gases and ultraviolet radiation at the same time [2].

The aim of this research is to develop electronic nodes for applied use of sensors in monitoring the state of different environments by combining these nodes into a wireless network. Several prototypes have already been implemented, such as a self-operating measuring device that has proven its effectiveness when working with sensors. On the Figure 1 you can see the response of several sensors example. Detailed information about this is described in our previous articles [3, 4].

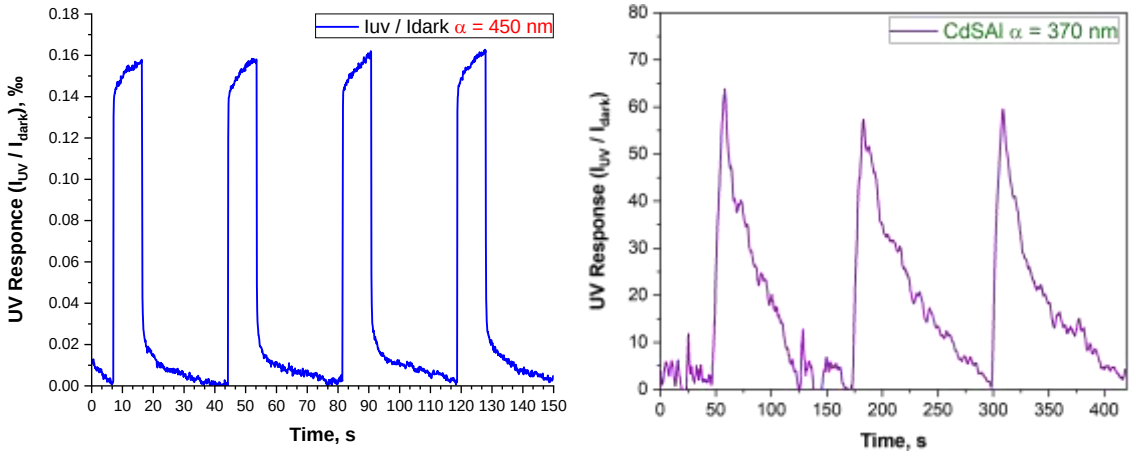


Figure 1. Response in UV of different material thin film sensor [3, 4]

The next step is to improve this prototype and create a network of such nodes. And according to the goal of improving the device, the new electronic unit will have significantly smaller dimensions and optimized energy consumption, in addition, it will help in solving some environmental problems.

Theoretical aspects of nodes

One sensor node consists of: power source, microcontroller, transceiver, sensor and external memory, as optional feature, it shown on the structure diagram, Figure 2.

Each block of the diagram has its own role:

1 Power supply - responsible for providing power to all components of the system. In the case of networks, this is usually a battery or energy harvesting system. Requires optimization so that the system has enough energy resources to operate and at the same time, the resources must be spent economically.

2 Microcontroller - manages the operation of the system, monitoring all peripheral devices. As a rule, it processes data from sensors, performs the necessary calculations and decisions on their transmission to the network, and also manages the energy efficiency of the node.

3 Transceiver - responsible for data exchange (reception and transmission). Sensor networks use various wireless technologies, such as radio modules, Wi-Fi, Zigbee, Bluetooth, LoRa.

4 Sensor - collects information from the environment, such as data on temperature, humidity, illumination, the presence of gases, etc. The signal from the sensor usually requires amplification, filtering or other transformations that depend on both the sensor itself and the measured value.

5 Memory element - additional memory may be required for storing and processing data. In addition, settings, firmware, or results of intermediate data processing on the node can be stored there.

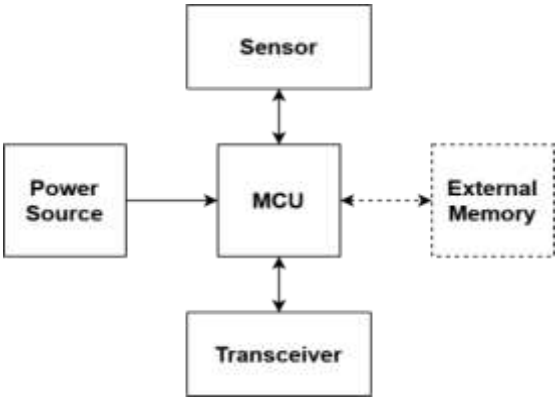


Figure 2. Node structure diagram [1]

The sensor network contains many such nodes, the data from which is transmitted to a base station or gateway (central node), then transmitted to a server in the database for further analysis and processing.

Problems and solutions

Disposable vapes are designed in a very unwise way. They are meant to be used only until they are empty. Then, unlike refillable devices, they are simply thrown away. And it is important to emphasize here that it is not only the plastic case that is sent to the landfill, but also the lithium battery that is inside, despite the fact that this battery is still usable (such battery can be recharged = reused: 300 recharge cycles). The situation is exacerbated by the growing demand for vapes, a trend that sources say will continue to grow as shown in Figure 3 [5].

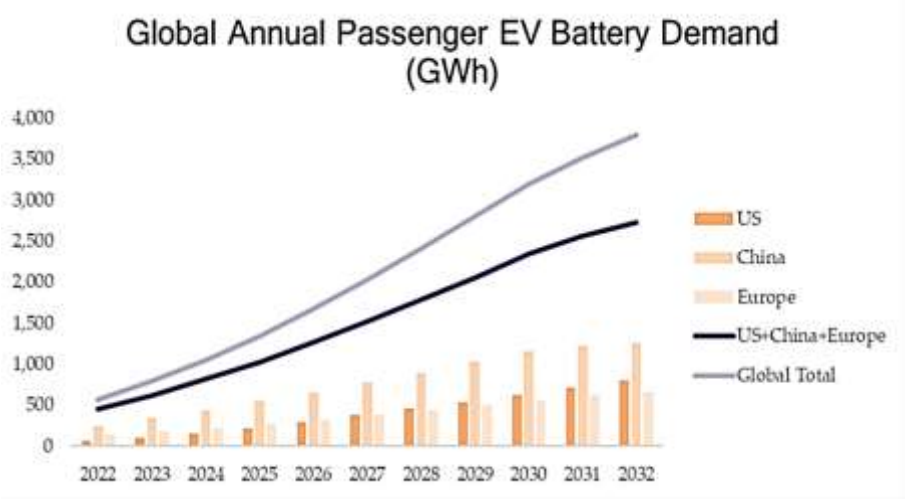


Figure 3. Growing trend and forecast [5]

For example, around five million disposable vapes are thrown away or discarded in the UK every week, which is almost equivalent to eight vapes being thrown away every second [6,7].

The behavior of disposable e-cigarette users is also monitored, of which:

- 68% throw devices in the trash,
- 13% place devices in recycling containers,
- 9% throw devices away on the ground,
- 8% try to recycle their devices through specialized enterprises [8].

Thus, most lithium-ion batteries end up in landfills, where they can leach heavy metals into the soil and groundwater. This poses a serious environmental hazard. Despite the fact, that while lithium mining itself often results in extensive land degradation:

- it requires clearing large areas of vegetation,
- it poisons ecosystems because mining uses hazardous chemicals such as sulfuric acid and sodium hydroxide that can leach into soil and groundwater,
- and it is also a very water-intensive process (for example, producing one ton of lithium can require up to 2 million liters of water) [9].

To return to the UK example, in 2022, over 40 tons of lithium was released from disposable vapes [6,7].

We recycled about 300 batteries from vapes, which will be integrated into electronic nodes (Figure 4).



Figure 4. Battery recycling

The new dimensions of our node are significantly reduced (Figure 5). Let's compare the prototype node (Figure 5(a)) and the network node (Figure 5(b)).

As you can see from the Figure 5(b) the central node is the largest, and the peripheral nodes are much smaller, as are the heating elements for operating the sensors. Small dimensions and the use of batteries meet the requirements of portability of the device. The selected electronic modules are energy efficient, as they have low consumption, and in combination with control algorithms aimed at saving energy resources (for example during periods when nodes are not actively sensing or transmitting data, they can go into sleep mode), the batteries fully meet the requirements for the required power for safe and reliable data collection.

(a) (b)

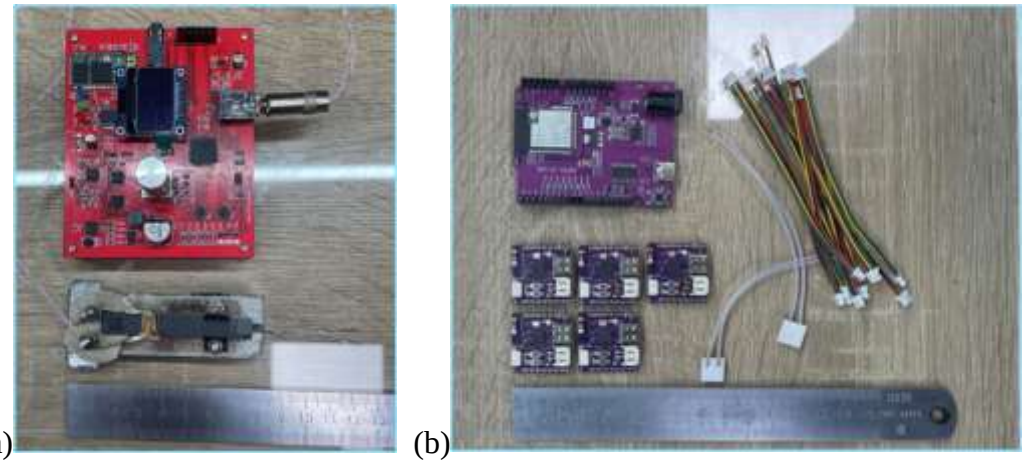


Figure 5. Dimensions comparation: (a) node-prototype, (b) components for new nodes

In addition, it is important to select the type of topology used to effectively scale the network, potentially extend its service life, and prevent data loss when some nodes fail or are affected by environmental conditions. A comparison of topologies is presented in the article [1] and according to the analysis, the mesh topology is combined with the use of the MQTT protocol provides network flexibility and reliability. This type of topology allows for adaptation to the appearance of obstacles or increasing distances between nodes. The system analyzes which node is nearby and transmits information to the nearest accessible one at its address [10]. That is, the data flow can pass not only along one predetermined path, as, for example, in a tree or ring topology, but also along any path that can be discovered and built during the data transfer process. The publish/subscribe model used by MQTT facilitates scalability, as

new devices can be easily added to the existing infrastructure without significant changes. In addition, it allows you to implement security through authentication, encryption and access control [11].

When receiving data from sensors, it is also necessary to ensure stability over time with subsequent correction, which is due to the specificity of the sensors. According to the normal concentration, the sensor produces a response, respectively. Over time, the sensor degrades and the response may give an error - in this case, compensation is necessary. Data on the degradation time and error can be stored in memory so that the system can control the process itself thanks to built-in calculation algorithms.

Another disadvantage is the high resistance of the sensors, so some conversion is needed to read the signal. To solve this problem, an operational amplifier circuit with a T-network in the feedback path is suitable, Figure 6. The advantage of choosing such a configuration is a high gain without introducing significant thermal noise (due to the use of low resistance values). Since the circuit can provide high gain, performance and stability, it is recommended to be used for audio processing, sensor signal generation, etc.

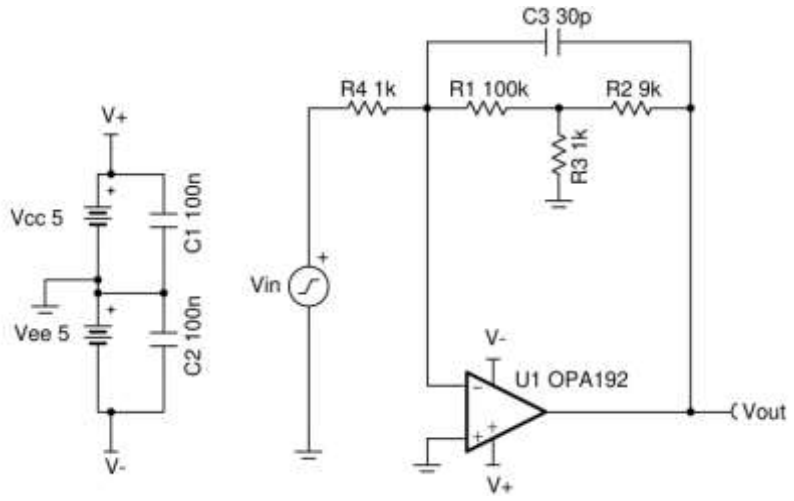


Figure 6. Inverting amplifier with a T-network feedback circuit configuration [12]

The gain of the circuit is determined by the formula:

$$\text{Gain} = \frac{\frac{R_2 * R_1}{R_3} + R_1 + R_2}{R_4}$$

The desired cutoff frequencyis set by selecting the appropriate values of resistors and capacitors (feedback components).

Conclusions

This article discusses some aspects of implementing nodes for sensor networks. Optimal solutions for implementing an improved version of an already implemented prototype are analyzed, which will have the following main features: portability and small dimensions, low power consumption, wide application, reusable power source, intelligent energy-saving algorithms. Technologies and components for implementing the device design were selected to ensure the reliability of the future sensor network, versatility and possible adaptation to environmental conditions. The portability of the nodes will speed up the network testing process, as well as deployment in various locations. The areas of application of such sensor nodes can be very diverse: agriculture, environmental monitoring, industry, robotics (for example, drones can scan forests in the summer to prevent the spread of fires), automotive, health monitoring, smart home or IoT devices, since they meet such important characteristics as portability, flexibility to changing environmental conditions, efficient energy consumption.

Future plans include possible refinement and testing of nodes in practice in various environmental conditions. It is possible to test the performance of the devices in new areas, for example in collaboration with researchers of the TUMnanoSAT project for testing in space conditions.

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