Development of a Wireless Sensor Node for Early Fire Detection

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***Abstract*—In the recent years, there has been a growing interest in the planting and growing of large arrays of fruit trees in Bulgaria. One of the dangers that threaten farmers is the occurrence of fire, especially during the hot summer months. Very often the fire occurs at a time when there is no human presence on site and alternative methods of monitoring the relevant territory are needed.**

In the article, a wireless sensor node for early warning of fire is developed. It includes three sensors - to measure temperature and humidity, to measure carbon monoxide and to measure the concentration of particulate matter. Each sensor has been adjusted individually as well as whether they are functioning properly. Exemplary experiments were conducted with the configured sensor node to verify operability and timely response in the presence of a fire hazard. The measurement information collected by the sensors is transmitted wirelessly to a base station where it can be further processed for measurement purposes. The proposed sensor node will be used to build a wireless sensor network for early detection of fires in large tracts of agricultural crops and open pastures in rural areas of the country.

Keywords—wireless, temperature, CO, particulate matter, fire detection

I. INTRODUCTION

In recent years, there has been a growing interest in the planting and growing of large arrays of fruit trees in Bulgaria. The initial investment is large and this requires taking preventive measures to protect the plantations. One of the dangers that threatens farmers is the occurrence of fire. This danger is especially strong during the so-called fire season - the period of the year when fires develop in nature, especially forest fires. Because wildfires are predisposed to dry and hot weather, much of the fire season coincides with the summer months.

In the last decade, fires of high intensity affecting large areas were observed in the country. According to the General Directorate "Fire Safety and Protection of the Population" for the period 2015-2019, there was an increase in the number of fires from 30,009 to 42,141 fires [1]. One of the main reasons for this result is high temperatures, prolonged drought and strong winds. Other causes of the frequent fires in recent years include lightning, re-occurrence of a previous fire, human negligence and unknown causes, as well as deliberate arson.

Timely signaling of the occurrence or danger of fire is extremely important. There are different fire detection methods - satellite-based [2, 3], using artificial neural networks [4, 5], various mathematical models have also been developed [6, 7, 8, 9]. One alternative for detecting and preventing fires in forest and rural areas using new technologies are wireless sensor networks [10, 11, 12]. The different types of sensors involved in the sensor nodes of wireless sensor networks can measure different variables, which helps determine the direction and development of the flame [13, 14, 15].

The aim of this paper is to develop a low-cost wireless sensor node for early detection of fires in orchards. The sensor node includes three sensors – a sensor for measuring temperature and humidity, a sensor for measuring carbon monoxide and smoke (CO) and a sensor for measuring particulate matter (PM). The choice of the latter sensor is due to the fact that smoke from forest fires contains high levels of fine particulate matter. Subsequently, this sensor node will be part of a wireless sensor network for early detection of fires located along the borders of the fruit plantations.

II. MATERIAL AND METHODS

A wireless sensor node is part of a sensor network. The sensor node has the ability to process the collected sensor information and communicate with other nodes of the wireless sensor network. A sensor node includes several main components, as a microcontroller, a transceiver, an external memory, a power source, and a sensor or sensors. Thanks to the wireless communication and the small size of the sensor node, large areas such as forests, pastures, buildings can be monitored.

A. Microcontroller Espressif ESP32 DevKitC

Espressif ESP32 DevKitC is a microcontroller board. It has Bluetooth and WiFi communication, built with ESP-WROOM-32 wireless module working with ESP32 microcontroller. There is also a micro USB connector and a built-in PCB antenna. Supports SPI, I2C, UART, I2S, DAC, analog inputs, PWM outputs. Since the ESP 32 microcontroller is equipped with a wireless communication chip, it will upload measurement data online via an HTML web server. The microcontroller is preferred as the main core for the wireless sensor nodes due to its characteristics - energy-efficient computing unit, its ability to connect easily with other devices and the built-in memory.

B. Sensors

The sensors used for the project were purchased commercially as modules providing power supply and interface.

- DHT11 Temperature and humidity sensor. The temperature range of measurement is from 0° to 50°

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C, and the relative humidity range is 20% - 90%. The temperature and humidity sensor uses a digital input of the controller where it provides a data signal, powered by 5 V. Since it has a pre-calibrated digital output, it does not need calibration.

- MQ-7 gas sensor. It measures the concentration of carbon monoxide CO. The sensor interface provides two types of output signal, analog and digital. The analog output is related to the reported CO concentration, while the digital output is related to the sensitivity of the sensor. It is characterized by low consumption of the order of 170 - 220 mA.

- Sharp GP2Y1010AU0F particulate sensor. It measures fine dust particles with a diameter greater than 0.8 µm. The sensor is mounted on a board that provides the power supply. The interface consists of an analog output and an ILED trigger pin. Measuring range of the sensor - 500µg/m^3.

C. Connection diagram

Fig. 1 shows the connection diagram of the sensor node. To implement the scheme, in addition to the elements mentioned above, a breadboard, a 150 Ω resistor and a capacitor with a capacity of 220 µF were also used.

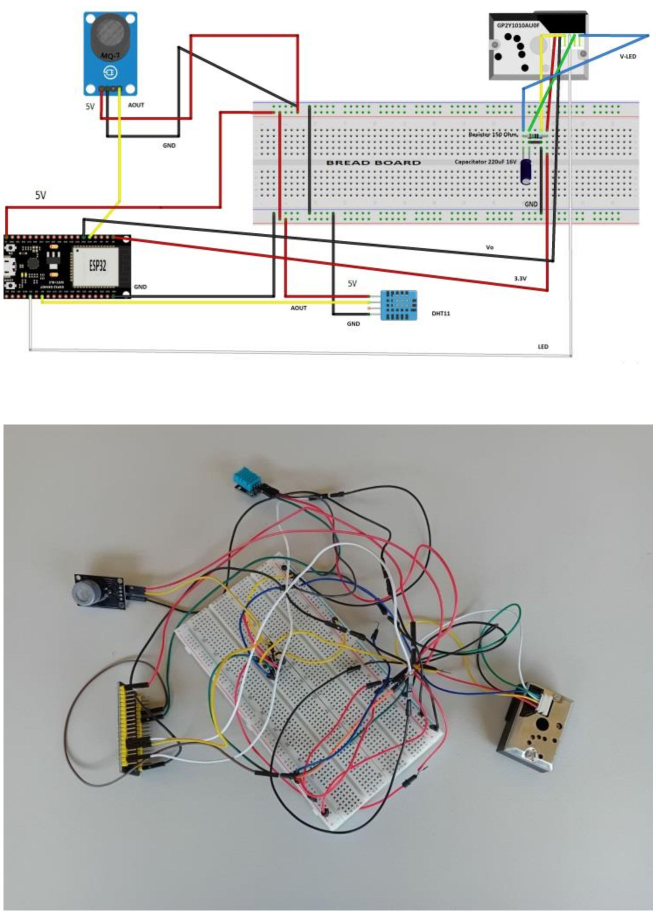

Fig. 1. Connection diagram of the sensor node

The ESP32 microcontroller is used to collect data from the sensors, transmit the data and control the power supply. The microcontroller supports 5 V input power supply and has 5 V and 3.3 V output power supply.

The MQ-7 carbon monoxide sensor uses an analog input of the microcontroller to provide data, its power supply is 5 V. The calibration of the sensor is programmatic and is based on standardized coefficients taken from an Internet source. A mathematical formula is used to convert the measurement units from ppm to mg/m^3. The correction is applied at 1 bar atmospheric pressure, nominal temperature and humidity. The MQ-7 operates with a 10-bit binary code format. Before starting the measurements, it is recommended to pre-warm the MQ-7 and after the warm-up period to start the actual measurements.

The Sharp GP2Y1010AU0F particulate matter sensor uses a 12-bit analog input of the controller and operates at a nominal voltage of 3.3 V. The calibration is done programmatically, taking into account the nominal value of particulate matter in mg/m^3 in the Sofia Region in the raw form. A conversion from ppm to mg/m^3 via a mathematical formula is included. The manufacturers of all three sensors give them a 5-year period of use.

III. Results and Discusion

After assembling the sensor node, it is necessary to program the microcontroller, set up the sensors and establish communication between all components.

The ESP32 can be programmed using a variety of firmware and programming languages, and for the purposes of this study we chose the Arduino IDE software, which is open-source. Although it is not the best IDE, it works well, is simple and intuitive and easy to use from beginners. Multiple case libraries as well as solved examples are also available.

The microcontroller should be able to read the data from the three sensors. The relevant libraries need to be installed. After the successful installation, a code is written through which the microcontroller will be able to read the information from each sensor. The code for the HTML server, where the data is sent and stored, is written in a text document or in Visual studio.

Simulated experiments were conducted with the constructed sensor node to verify the correctness of the configuration. The sensors are set to take data every 10 s. The measurement time can be changed at any time depending on the specific situation. Fig. 2 shows values for measured temperature and humidity, and fig. 3 shows values for CO and particulate matter. It can be seen that all four parameters were measured simultaneously, with no delay in data recording.

In order to be used in the field, the sensor node must be placed in a suitable box. Fig. 4 shows the assembled box with the sensor node attached. The box is quite bulky, but this is due to the peculiarities of the particulate matter sensor - enough space must be provided for the measured atmospheric air. Fig. 5 shows the contents of the box. The location of the microcontroller 1 and the particulate sensor 2 can be seen. At the bottom of the box, the breadboard auxiliary board is immovably fixed. With longer wires, the connection to the CO sensor and temperature and humidity sensor mounted on the outside of the box is made. The actual placement of these two sensors is shown in fig. 6.

The logical question is whether the sensor node placed in this box will be able to perform measurements. New measurements were made and the results of the measurements carried out are shown in figures 7 and 8.

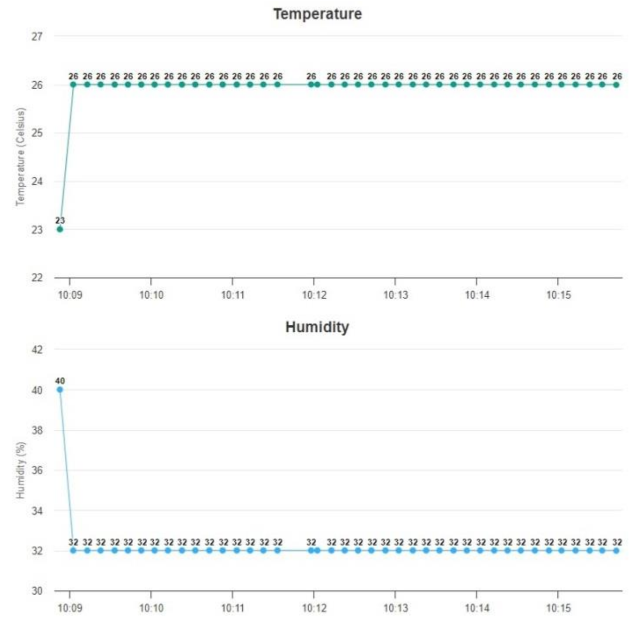

Fig. 2. Obtained results for measured values of temperature and humidity

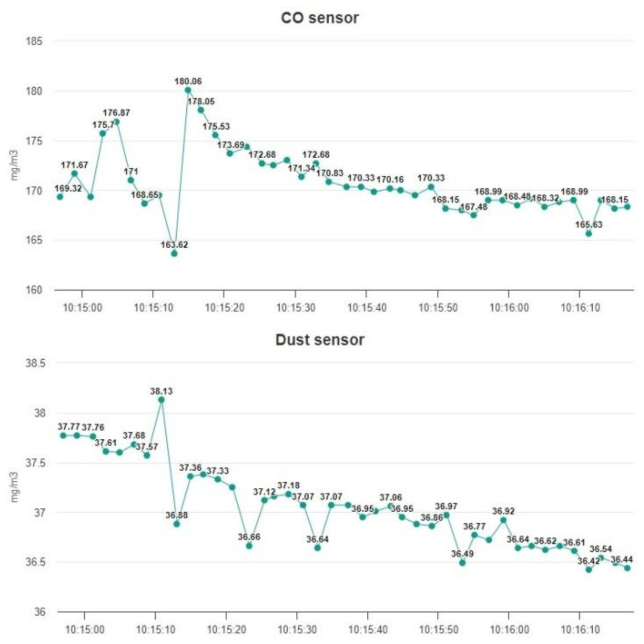

Fig. 3. Obtained results for measured values of carbon monoxide CO and particulate matter

Fig. 4. Appearance of the sensor box

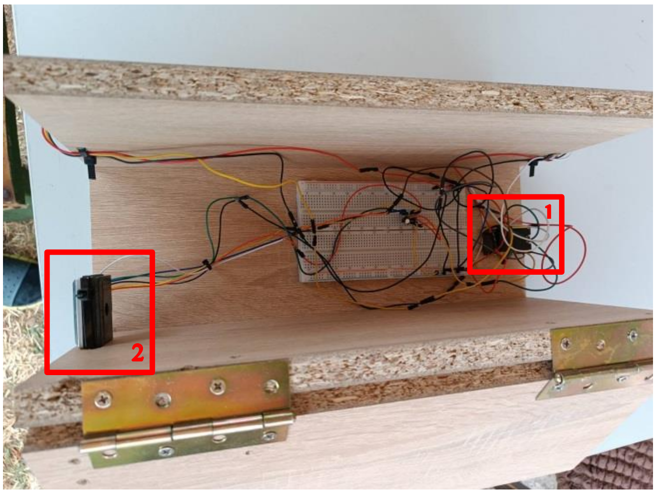

Fig. 5. The contents of the box after opening the lid. 1 – microcontroller, 2 – sensor for particulate matter

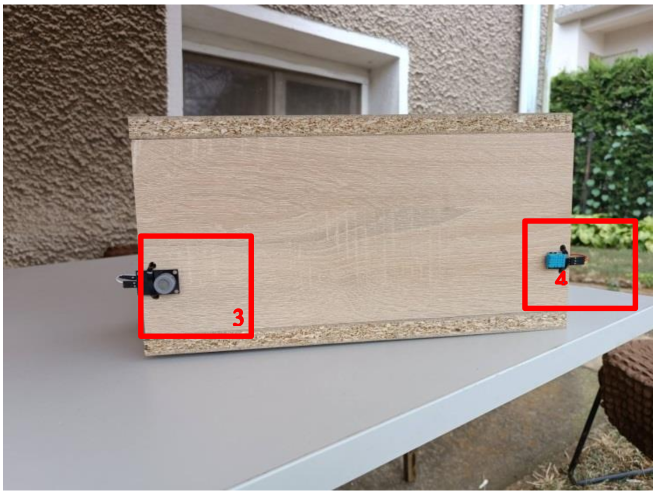

Fig. 6. Sensor box with externally attached sensors. 3 - carbon monoxide sensor, 4 - temperature and humidity sensor

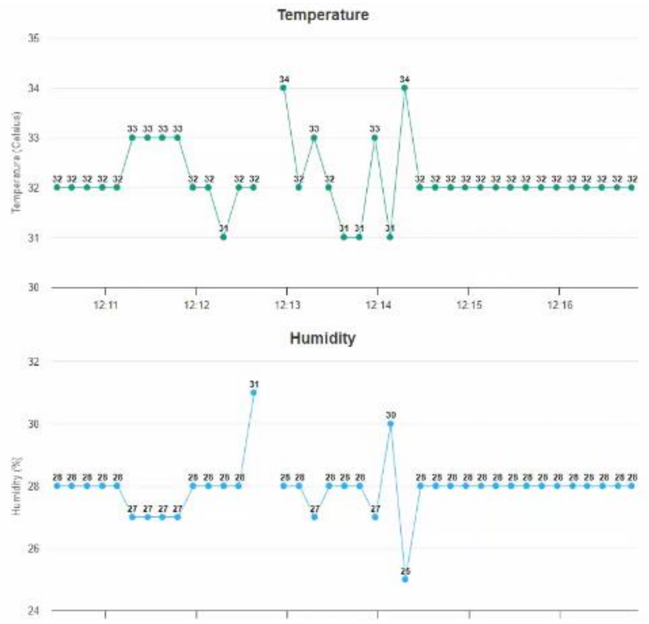

Fig. 7. Measured values of temperature and humidity after installing the sensor node in the box

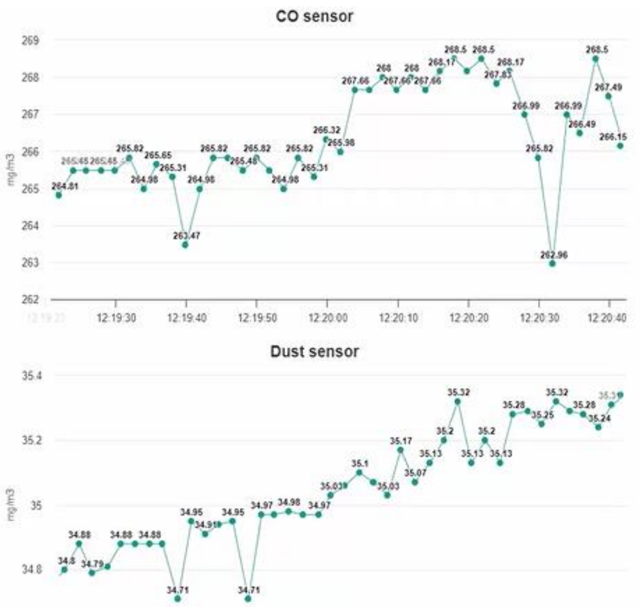

Fig. 8. Measured values of CO and particulate matter after installing the sensor unit in the box

Fig. 7 shows the measured values for temperature and humidity after installation in the sensor box. The values of these two parameters hardly change. This is due to the nature of the simulated experiment – burning papers near the sensor box. However, at the expense of this, the carbon monoxide sensor detects an increased concentration of the measured gas, as can be seen in fig. 8. The dust sensor also registers an increase in the level of particulate matter, no matter how little it is.

CONCLUSION

In this study we presented a low-cost wireless sensor node for early fire detection in fruit plantations. The sensor node is consist of three sensors – a sensor for measuring temperature and humidity; sensor for measuring carbon monoxide; sensor for measuring particulate matter. The measurement of temperature and humidity are key indicators when there is a risk of fire - high temperature and dry air are prerequisites for this. Fire smoke is saturated with carbon monoxide and contains high levels of fine particulate matter. These are the reasons for choosing these sensors to construct the sensor node. The information from the sensors is read by an ESP32 microcontroller. Through a communication module, the measurement information is transmitted to the computer, where it is recorded, visualized and stored.

The sensor node is housed in a specially made box with holes at both ends. All movable elements are properly secured so that they do not interfere with the measurement process. Simulated measurements were taken with the sensor node before it was placed in the box and repeated after it was secured in the box. From the obtained results, it can be seen that the measurement information from the three sensors is received simultaneously, without delay in recording the data. The proposed sensor node will be used to build a wireless sensor network for early detection of fires large arrays of fruit plantations and open pastures in the country's rural areas.

At the next stage, it is planned to attach the explored sensor node to a drone. In this way, along with the data from the sensors, there will also be a visual picture of the terrain that the drone is crawling and the credibility of the information collected by the sensor node will be added. The presence or absence of fire will be confirmed. Also, unlike a static sensor node, the drone is mobile and can go around inconvenient places, where it would otherwise be difficult to get timely information.

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