Remote Monitoring of Toxic Gases in Mines

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***Abstract*—This paper describes application for remote monitoring of toxic gases in underground mines. The system accurately measures the concentration of several toxic gases: CO, CO_2, CH_4, H_2, NH_3 and other environmental parameters such as temperature and humidity. Data is transmitted through a wireless sensor network, making the system applicable where wired communication is a problem. The sensor system is portable and it can easily be moved from one place to another. The application provides adequate signaling based on the predetermined critical levels of certain gases.**

I. Introduction

The concept Internet of Things refers to the idea that all devices, such as household appliances or production machines equipped with sensors, can be connected and managed online through Internet in the future. Areas where this concept is applicable are smart cities, environmental protection, smart transport, health and agriculture. Examples of applications for smart cities include smart surveillance, water distribution, energy management systems, smart transport, etc.

In industry the Internet of Things offers the opportunity to optimize the maintenance of equipment and reduce production costs. Related devices in the industry will be able to recognize their own defects and signal before a problem arises which will prevent greater losses in the production process. In agriculture sensor networks in the soil and in the fields, are used for monitoring weather conditions and other factors affecting yields. Sensor networks are also used to monitor air pollution in the cities.

In mining, the Internet of Things can be implemented in a variety of ways, such as remote controlled robotized digging machines or automatic steering of vehicles for transporting ore, then automatic activation of the ventilation systems, protecting the miners through the control of the harmful gases and surveillance of the areas where there is a risk of explosion. Underground wireless networks have been created in several mines around the world to track the location of the people and equipment in order to increase safety, improve machine maintenance and ensure greater productivity. These mines use fiber-optic cables mounted on the main axes together with Wi-Fi access points [1]. In order to allow monitoring and control of the network of tunnels in the mines, it is necessary to create a computer network with a certain topology using multiple routers, adequately protected from water, falling rocks or bumps from vehicles and machines. Typically, RFID and Wi-Fi technologies are used to monitor the location of the vehicles and miners, to prevent accidents and to enable the personnel to stay connected to the surface centers.

According to our knowledge in the Macedonian mines computer networks are not widely used. Exception of this is Sasa where fiber-optic cable is installed in the main axes. Furthermore, monitoring of toxic gases in Macedonian mines has not been realized so far using a sensor network. The approach that we present in this paper uses a mobile sensor system for monitoring the concentration of methane, carbon dioxide and carbon monoxide which are very often released in underground mines. The aim was to explore the possibilities for implementation of a wireless sensor system considering the safety of the miners using available technology.

II. Structure of the System

The system for remote monitoring of toxic gases in restricted regions, such as those typically found in underground mines consists of sensor nodes and base nodes that control the wireless network and collect data from the sensors. In addition to measuring the concentration of toxic gases the proposed system monitors surrounding environmental parameters such as temperature and humidity.

The choice of the sensor network depends on several factors like error tolerance, network topology, hardware constraints, transmission medium and power consumption. The implemented system uses a mobile robot controlled through a mobile phone. The following sensors are used: DH11 for measuring temperature and humidity, MQ-2 for detecting methane (CH_4), then MQ-7 for measuring the concentration of carbon monoxide (CO) and MQ-135 for measuring the concentration of carbon dioxide (CO_2).

Several tasks have been realized: (1) Programming of a mobile robot that will operate in mine tunnels and that can be controlled through a mobile phone, (2) Detection of toxic gases emitted in a mine, (3) Measuring temperature and humidity in a mine, (4) Generating warning signals if the levels of toxic gases or temperature are higher than permitted, (5) Full control of the mobile robot using graphical user interface created for a mobile phone, (6) Data transmission over a wireless sensor network in real time, (7) Data storage in a cloud, (8) Regular display of the date, time, type and value of the toxic gases, the temperature and the humidity in the mine.

The proposed sensor network is intended to connect to a baseline mine network. In the contemporary mine networks [2-8] the integrated network is composed of an optical cable through the main shaft and Wireless Sensor Networks (WSNs) in the tunnels where monitoring is needed. WSN consists of sensor nodes and access points.

Sensor nodes are equipped with gas sensors, battery and communication interface. Access points have DH11, MQ-2, MQ-7 and MQ-135 gas sensors, microprocessor, transceivers and batteries. The transceiver receives commands from the central node and transmits the data to the central node. Central node collects the sensor data in real time and transmits them to the database located in the server through Internet.

The system is implemented using a network of ESP8266 modules connected in a mesh topology. ESP8266 is Wi-Fi module which allows TCP/IP communication and has integrated microcontroller. ESP8266 can serve as a client as well as an access point (server). The main advantage of this module is the low price that is less than $5. ESP8266 can operate as an independent unit, but it can also be connected to Arduino board. Moreover it can be directly connected to Internet without additional hardware.

Some of the modules are used only as mediators while the others are used for reading data from the gas sensors. When two ESP8266 modules are connected at least one of them has to be configured as an access point. In this mode of operation it can be discovered by the other modules. Sensor nodes are programmed to read and send data every 15 minutes. Data are sent to the nearest mediator access point. The central point (ESP8266) is configured to receive the data from the surrounding access points and to send them to the database. The central ESP8266 receives control information from the application and send them to the nodes where the mobile robot is located. Mobile robot acts as a sensor node. It can connect to the access points and send the data received from the sensors. Access points are programmed to discover the nearest access point, check the availability and send the measurements to the central point.

In applications for monitoring toxic gases in mines WSN networks have many advantages compared to the cable networks such as: expandability of the network even when nodes and tunnels are modified making it possible to monitor the mobile robot with sensors, using the existing mine network, no need to lay communication and power supply lines, sensor nodes can easily be added where additional monitoring resources are needed. The architecture of the system is shown in Figure 1.

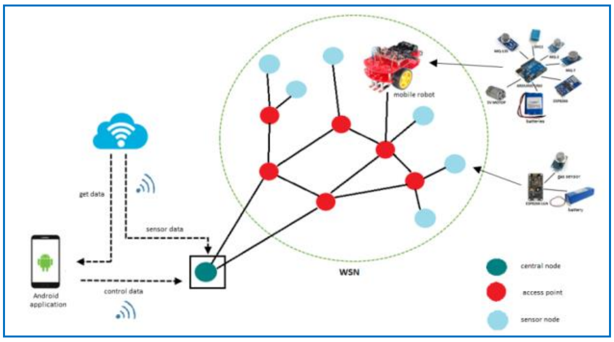

Figure 1: System architecture

The system is divided into four main layers. It consists of:

- Layer for data collection installed on the mobile robot,
- Control layer,
- Communication layer and
- Storage layer and information analysis.

A. Data collection layer

This section describes an implementation of a sensor system installed on a mobile robot. Constituent part of this module is Arduino microcontroller which is selected because of its small dimensions, high reliability and low cost. The sensors for measuring the concentration of toxic gases are attached to the microcontroller. The control data and the measured sensor values are transmitted via the wireless sensor network from the control layer to the mobile robot and vice versa.

This component processes sensors data, transforms them from analog to digital and sends the data to the server through the Wi-Fi interface module. The maximally allowed concentrations of the toxic gases are declared in the microcontroller. If they are exceeded the microcontroller generates an audio alarm.

The mobile robot acts as a sensor node that permanently monitors the concentration of toxic gases, temperature and humidity in the underground mines. Fig. 2 shows the mobile robot and the sensors that are constituent hardware part of the system.

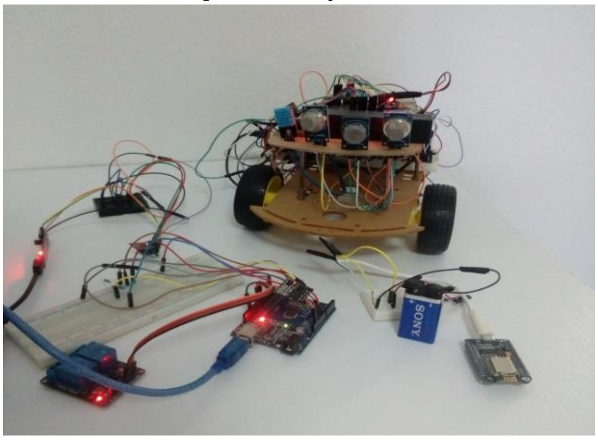

Figure 2: Mobile robot, sensor node and central node

B. Control layer

This section provides an overview of the mobile application that controls the mobile robot with commands transmitted over the wireless sensor network. The interface is shown in Fig. 3.

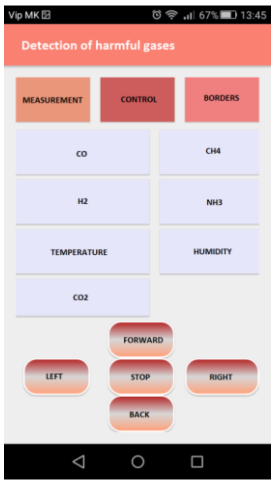

Figure 3: The interface of the mobile application

Through the mobile application, concentrations of toxic gases obtained from the sensor installed on the mobile robot or from the sensors located in the tunnels of the mine can be examined. The motion functions of the mobile robot are controlled through the control panel and the allowed actions are left, right, forward, back, and stop. Different types of gases being measured and their current concentrations are displayed on the screen shown in Fig.3, while the maximally allowed gas concentrations are displayed on the additional screen.

When the maximally allowed concentration is exceeded, there is an alarm lamp and vibration of the corresponding gas button that appears on the control interface. In the software, the color that is displayed changes according to the change of the gas concentration of the data obtained from the respective sensors, this is followed by vibration. Different warning phases (yellow, orange, red, etc.) are set depending on the status of the sensors.

The mobile application has the following features:

• Receives real-time information with sensor parameters,

• Data is displayed on the mobile application (display of data from the mobile robot and from various sensors located in the mine tunnels),

• Provides a graphical display of all data recorded by sensors in the form of tables,

• Gives a warning at six levels based on the maximally allowed concentration of each parameter,

• Signals with color and vibration based on the maximally allowed value of the individual sensor measurements.

C. *Communication layer*

This section gives an overview of the operation and transmission of data through the wireless sensor network. Wireless devices have two main functions: (1) data collection, (2) data transport.

Sensor nodes are key elements of a smart environment to protect the health and safety of miners during work and in emergency situations. They are used to provide communication and to obtain data about the concentration of toxic gases with the aim to alert the miners to preserve their health and to provide safety at work.

In this work we designed and tested inexpensive and easy to use platform for developing a wireless sensor network with ESP8266 module. The ESP8266 module is a full Wi-Fi chip with TCP/IP capability. This board has an integrated microcontroller unit.

TABLE I.
PRICES OF SOME TRANCEIVERS, ETHERNET AND WI-FI MODULE

module	price
ESP8266-01	$5
Ethernet Shield for Arduino	$60
Zigbee	$25
Wi-Fi Shield Sparkfun	$40
Wi-Fi Shield for Arduino	$80
Huzzah Wi-Fi shield by Adafruit	$40
ESP8266-12	$7

Among the main advantages of this module is its price. One module costs less than $5. Table 1 shows a comparison of prices with other Ethernet and Wi-Fi modules ranging from $30 to $60.

In WSN various transceivers are used, for example, NRF24L01 +, Zigbee that are connected to the central system that transmits data over the Internet. This leads to additional hardware and increased costs. ESP8266 can be directly connected to the Internet without the need for any additional hardware thus reducing connection problems.

The WSN in the proposed system is implemented using ESP8266 modules. The network is divided into subnetworks consisting from several ESP8266 modules. The central node has ESP8266 module attached to Arduino Uno board. The modules in the subnetworks are organized in some kind of combination between mesh and star topology and are used as access points.

Figure 4 shows a smart environment in the mine that can provide interactivity in the working environment of the mine. Each ESP8266 is programmed to read the received data from the endpoint sensors and connect to the nearest access point. After that the module sends the received data to another access point. Each mediator ESP8266 listens and receives the data, and then sends them to the next intermediary until the central node is reached. The central node is configured to be the main node for data transmission, responsible for receiving, transmitting and processing the data from the closest access points. After receiving the data it then sends them to the cloud in a database. Also, the central ESP8266 downloads the control data from the mobile application that is transmitted to the nodes where the mobile robot is located.

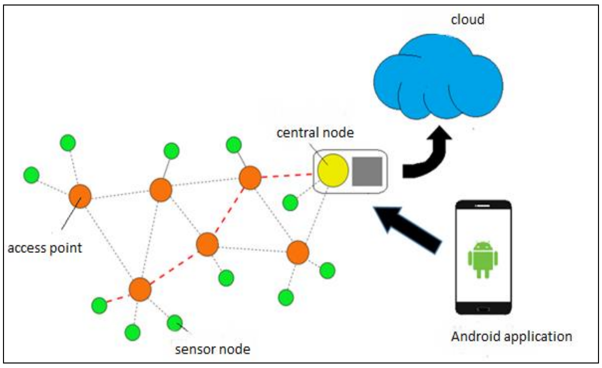

Figure 4: Implementation of WSN with ESP8266 modules

D. *Storage area and information analysis*

Storage and data integration are achieved through the cloud computing platform. The received data from different areas is transmitted via the wireless sensor network and stored in the database.

By storing the received data on the cloud, the control team has access to all information received from the working environment. Remote monitoring enables access and management from any place. In cloud systems, there are no restrictions on the number of data being stored, and maintenance costs are reduced.

III. Experimental Results

The system is used for data collection, transfer, storage and analysis. The tests in this project are done with a Huawei mobile phone with Android OS version 5.1, AWS and a mobile robot consisting of a microprocessor (Arduino), two 5V motors, sensors for detecting concentration of CO, CO_2, CH_4, H_2 and NH_3, DH11 sensor for measuring temperature and humidity and ESP8266 module.

Toxic gases in selected area are permanently monitored by the sensor nodes. Figure 5 shows the received data of the mobile application in real time, showing a variation in the gas concentration.

Figure 5. Stored output data from the sensor

When interpreting data related to an event, such as a fire or an explosion, the explosiveness of the atmosphere is monitored and should be calculated and compared with maximally allowed values, which are graphically displayed as in Figure 6.

Figure 6: Visual representation of the data when allowed concentration is exceeded

When analyzing data from sensors, other parameters that can affect the explosiveness of the atmosphere should be taken into account. Therefore, not only the level of toxic gases is monitored, but also the temperature and humidity of the air.

The mobile sensor system is used to measure the concentration of the toxic gases generated during the explosion in the surface mine Strmosh AD Non-Metallic Mines in Probishtip to obtain real-time data. The main activity in Strmosh mine is exploitation and processing of non-metallic mineral products: quartzite, opalized tuff and zeolite.

The explosion was carried out using an ammonium nitrate type of explosive. The mobile robot was positioned at a distance of 100 meters during the explosion. The results obtained are shown in Figure 7. It should be noted that during the measurement there was wind.

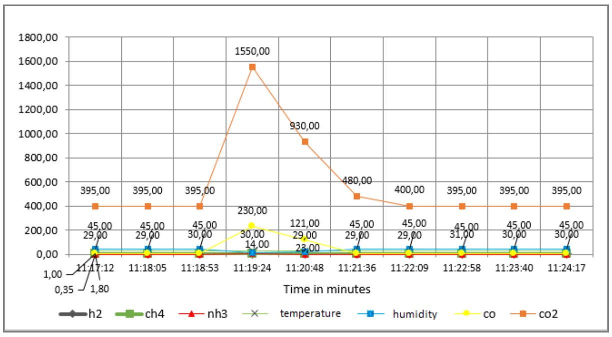

Figure 7: Monitoring values of toxic gases over time during the explosion in surface mine Strmosh. Black curve shows H_2 values, orange curve shows CH_4 values, red curve shows NH_3 values, green curve shows temperature value, blue curve shows humidity values, yellow curve shows CO values and brown curve shows CO_2 value

IV. Conclusion

The system accurately measures the concentration of several toxic gases (CO, CO2, CH4, H2, NH3) and other environmental parameters such as temperature and humidity. Data is transmitted through a wireless sensor network, making the system applicable where wired communication is a problem. The sensor system is portable and it can easily be moved from one place to another. We expect that the data collected during the exploiting phase of the system will contribute to better protection of the miners.

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