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UNIVERSAL SENSOR FOR USE IN DANGEROUS ROAD TUNNEL

UNIVERZÁLNY SNÍMAČ PRE POUŽITIE V NÁROČNOM PROSTREDÍ DOPRAVNÉHO TUNELA

Abstract

This article deals with the problems of detection of dangerous substances in the road tunnel during an accident and proposes-design and construction of a mobile sensor system for online detection. Gases are measured by specific detectors of the MQ series. The D1 mini Pro development board with WiFi chip integration was chosen as the control unit. The universal sensor was designed especially for firefighters intervening during an accident in road tunnels. The measured data are sent and saved into the external database, from which they are then presented on the website. The website is then viewed on-line firefighters who intervene in the tunnel during an accident.

Abstrakt

Tento článok sa zoberá problematikou detekcie nebezpečných látok v náročnom prostredí dopravného tunela počas nehody, návrhom a konštruovaním senzorického systému. Jednotlivé plyny sa merajú špecifickými detektormi rady MQ. Ako riadiaca jednota bola zvolená vývojová doska D1 mini Pro s integrovaním WiFi čipom. Následne prepojením jednotlivých komponentov a umiestnením do puzdra vznikol univerzálny snímač, pre zasahujúcich hasičov počas nehody v cestnom tunely. Namerané dáta sú odosielané a úkladné do externej databázy, z ktorej sú následne vhodne prezentované na webovej stránke. Webová stránka je určená pre hasičov, ktorí zasahujú v tuneli počas nehody.

Keywords

tunnel, gas detection, dangerous substances, MQ sensors, universal sensor

1 INTRODUCTION

Slovakia is a mountainous country, so the tunnels are especially important for infrastructure development. For transport networks, such as railways, but also roads or highways, it is necessary to streamline transport across mountain ranges through tunnels. This mainly saves time and transport costs, especially the fuel consumption. However, reliable tunnel security is required for the smooth running of the road. Several sensors, detectors, a comprehensive ventilation system and variable traffic signs are needed to ensure the smoothness and safety of traffic in the tunnel. In the event of an accident, it is necessary to know what kind of gases and liquids have leaked out from the vehicles and which dangers will the firefighters be exposed to, while intervening in the tunnel accident [10].

A road tunnel is a linear ground object with a longitudinal slope of less than 5° and an excavation area greater than or equal to 16 m2 (standard STN 73 7501), above which is a layer of rock or embankment. A distinction is made between single-pipe, double-pipe and multi-pipe tunnels [2]. Each tunnel has technical equipment consisting of a sensor system (including opacity and flow rate sensors,

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dangerous gas detectors and a camera system) and actuators (such as ventilation and variable traffic signs).

Today's fire brigades intervening in the tunnels have equipment that is adapted to work in extreme environments. As an example, modern firefighting vehicles can operate in a non-breathable, high-risk, high-temperature environment and are able to provide enough fresh air for firefighters and for the vehicle itself [9]. The vehicle has various sensors for detecting substances in the environment. Using the measured values, it informs the intervening firefighters, what kind of danger they should expect. However, the Slovak Republic has only a limited number of these vehicles. One is located in Bratislava and the other is located in Mengusovce [4].

The fire brigade with a specialized vehicle will take a long time to reach the desired location. Therefore, the idea of a universal sensor was created, which could provide important information to the firefighters in the tunnels without the need for special technology. This universal sensor can be carried in any vehicle. It does not have to be exactly one, but they can be many of them, where in the case of using more universal sensors, a sensor network will be created from the tunnel portal to the traffic accident.

Later in this article we will discuss the components, software and methods, which were applied to create the universal sensor.

2 COMPONENTS

Components that are compatible with the Arduino or Raspberry Pi platform were used for the project. The aim was to build the smallest possible device with the lowest price, as it is assumed that the universal sensor will be destroyed during the intervention.

The development board D1 mini Pro version 1.1.0 (hereinafter referred to as D1mP) from WEMOS with the WiFi chip ESP8266EX was chosen as the control unit. The board contains the necessary input and output pins, dimensions, has sufficient computational power and supports communication via WiFi.

Four Li-ion cells in parallel with the nominal voltage of 3.6 V and the nominal capacity of 3000 mAh were chosen for the D1mP power supply. The D1mP requires a nominal supply voltage of 5 V for its function. Therefore, a step-up inverter XZX-887Y was connected to the batteries. For the correct operation of the inverter, it is necessary to keep the battery voltage in the range of 3.2 V to 4.2 V. The circuit also has protection against overcharging and discharging the battery as well as a short-circuit protection.

Gas sensors from the MQ series were selected and installed into the universal sensor. They were chosen due to their small size, low energy consumption, price and ease of work with them. The sensors have both analog and digital (binary) output. One of the significant advantages is the adjustment of the sensor sensitivity. Detection is based on a change in the resistance of the sensing material that occurs when the chemoresistor comes into contact with a gas. Sensors MQ-2 (smoke concentration sensing), MQ-6 (LPG, propane, butane concentration sensing), MQ-9 (CO concentration sensing) and MQ-137 for sensing NH3 and C2H6O were installed.

NTC 3950 thermistors with a temperature range from -40°C to 300°C were selected for temperature sensing. They are characterized by high sensitivity and fast response. The nominal resistance value at 25°C is 100 kΩ. To correctly evaluate the data from the sensor, the thermistor was connected in a resistance divider, where the nominal value of the resistance is 100 kΩ. For more accurate temperature measurement, there are 4 heat sensors on the universal sensor.

The D1mP has only one analog input. The universal sensor contains 4 temperature sensors and 4 gas sensors, so it was necessary to use an analog multiplexer. A 16-channel analog multipexor CD74HC4067 was used for the universal sensor.

The last part of the universal sensor is the case (Figure 1 and Figure 2). The case consists of two parts, two hemispheres (Figure 1), so that it can be easily opened during the maintenance and calibration. The case was designed in Autodesk Fusion 360 software and printed by 3D printer.

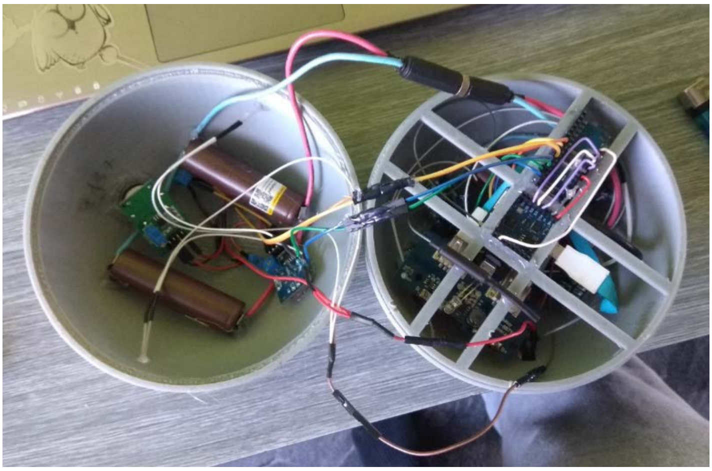

Figure. 1 Universal sensor model (open)

Figure. 2 Universal sensor model (closed)

For a better idea of how the individual components are connected, a block diagram is shown in Figure 3.

All sensors are connected to a multiplexer, which is controlled by the D1mP control unit. It controls the switching of individual inputs and gets values from sensors. These are processed and then sent to the database (more about processing in the Software section). The D1mP is powered by an inverter to which the batteries are connected.

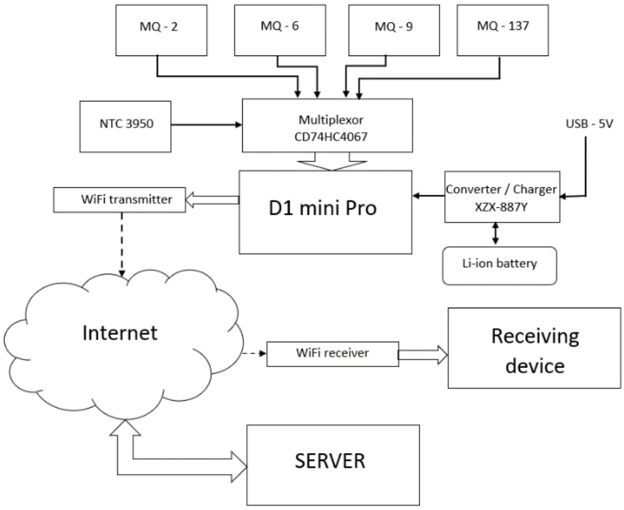

Figure. 3 Block diagram

3 SOFTWARE

The C ++ programming language using the Wiring framework in the Arduino IDE program was used for D1mP programming. The functional description can be seen in the Figure 4.

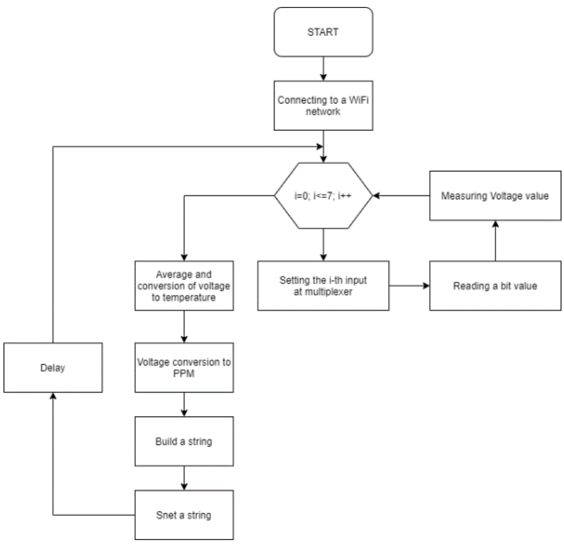

Figure. 4 Flowchart

At the beginning of the cycle, D1mP connects to a WiFi network that has Internet access. After a successful connection, the control microcomputer gradually checks the analog outputs of the individual sensors via an analog multiplexer. The obtained values are written in a one-dimensional array. These values are converted to voltage using equation (1) and the values in the array are overwritten.

$$U\ [V] = \text{value}\ [LSB] \cdot \frac{5\ [V]}{1023\ [LSB]} \tag{1}$$

Subsequently, an average is calculated from the first four values, these values represent data from heat sensors, and the average resistance Rt is calculated according to equation (2), and the temperature is calculated using equation (3) (based on the NTC 3950 thermistor characteristic).

$$R_t\ [k\Omega] = \frac{U\ [V] \cdot 100\ [k\Omega]}{5\ [V] - U\ [V]} \tag{2}$$

$$t\ [°C] = 200{,}22 \cdot e^{-0{,}0075 \cdot R_t\ [k\Omega]} \tag{3}$$

The remaining values are obtained from the gas sensors. First, the output resistance of the given sensor R_S is recalculated using equation (4), R_0 is the value of the resistance of the sensor when no gas affects it.

$$R_S\ [k\Omega] = \frac{R_0\ [k\Omega] \cdot U[V]}{5\ [V] - U[V]} \tag{4}$$

Subsequently, the sensors resistance values are converted specifically to the concentration of the toxic gas in ppm (parts per million).

Equation (5) was used to calculate the smoke concentration (relation derived from the characteristics of the selected gas sensor [5]).

$$\text{Smoke}\ [ppm] = -2689{,}2 \cdot \frac{R_S\ [k\Omega]}{R_0\ [k\Omega]} + 2125 \tag{5}$$

Similarly, equation (6) was used to calculate the LPG concentration (relation derived from the characteristics of the given gas sensor [6]).

$$\text{LPG}\ [ppm] = -3000 \cdot \frac{R_S\ [k\Omega]}{R_0\ [k\Omega]} + 3100 \tag{6}$$

The CO concentration is calculated by equation (7) (relation derived from the characteristic of the given gas sensor [7]) and the NH3 concentration by equation (8) (relation derived from the characteristic of the given gas sensor [8]).

$$\text{CO}\ [ppm] = -2222{,}2 \cdot \frac{R_S\ [k\Omega]}{R_0\ [k\Omega]} + 1867{,}8 \tag{7}$$

$$NH_3\ [ppm] = -16740{,}2 \cdot \frac{R_S\ [k\Omega]}{R_0\ [k\Omega]} + 18670{,}8 \tag{8}$$

Subsequently, a data-string with data is created and sent via the Wifi network to the database. The database is stored on external servers. A website has been set up on these servers, on which it is possible to view and monitor individual data how they change over time, as well as to search data in history. The site is designed to be responsive. A responsive website ensures that the site is shown optimally on different types of devices. This means that they display well not only on a classic computer, but also on a laptop, mobile phone or tablet. The responsive website recognizes which device it is currently displaying and the width of its display, and then adjusts its content accordingly in order to maintain readability. We have decided to use this feature mainly for two reasons. The first is due to the variability of devices on today's market. The second reason is that field firefighters can use small tablets to gather information and then monitor it. On the other hand, the fire brigade in which is the intervention firefighter manager, mainly they use laptops and desktops.

4 PRACTICAL MEASUREMENT

Individual sensors (temperature sensor, smoke detection, LPG, CO and NH3) were connected with D1mP and subsequently tested in laboratory conditions. We have monitored the rise time of the sensors after switching on, the recovery time of the sensors after the measurement. All measurements are recorded in Tab 1. After the universal sensor was completed, measurements were performed on the overall universal sensor, where all selected substances were measured at once. Measurements of the concentration of dangerous gases were performed on the exhaust gases on the petrol and diesel engines and also on the petrol engine with LPG combustion (Figure. 5).

Tab 1. Measured values

Sensor	MQ-2	MQ-6	MQ-9	MQ-137	NTC 3950
Rise time [s]	110	30	40	300	10
Recovery time [s]	30	50	40	10	30
Max value [ppm]	1501,03	2754,34	1285,64	2874,05	97,13°C

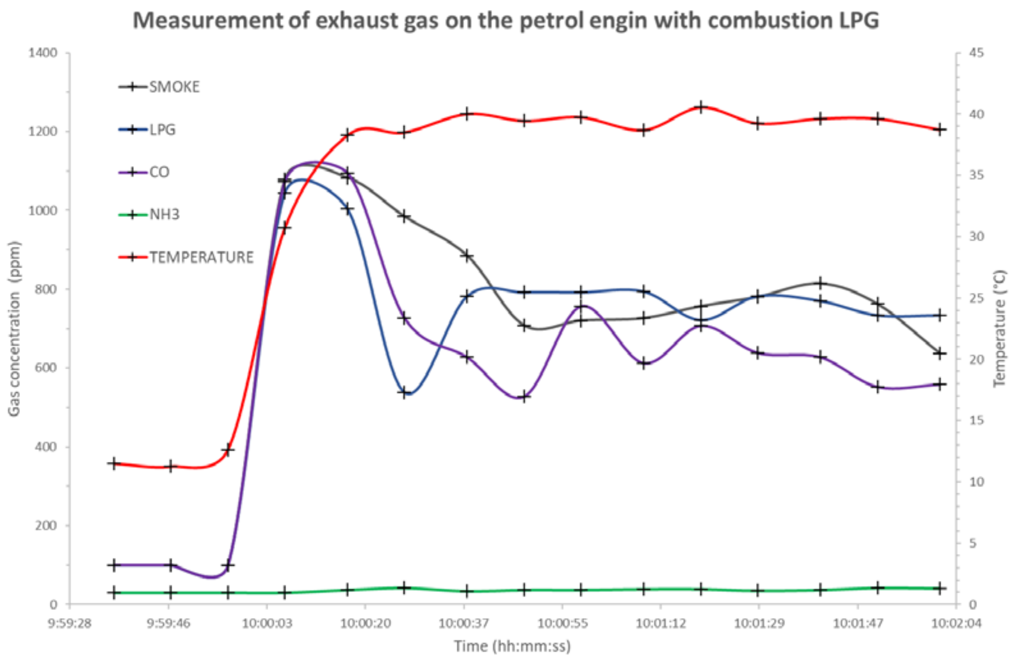

Figure. 5 Exhaust measurement on an LPG engine

5 PROCEDURE OD SENSOR APPLICATION

1. Imagine a model situation in a tunnel. A truck with a tanker with an unknown substance entered the tunnel. In the tunnel will be wheel-defect on the truck. As a result, the tank truck overturns and an accident in the tunnel and one tunnel tube is blocked.
2. The dispatcher has to perform all necessary actions and then call the fire brigade. After the firefighters arrive at the accident, the firefighters do not know what substance can be there [11].
3. They will then use our project
4. The fire truck must connect to the Internet via a WiFi router, which is installed in fire truck
5. Then, the firefighter choses one universal sensor. It turns it on and waits for a connections to the router. Next, firefighter check the connection on his portable display device (tablet)
6. The firefighter has to switch on the sensor equipment of the universal sensor. After this step, the firefighter must place the universal sensor as close as possible to the accident.
7. Assume that the universal sensor lands as close as possible to the accident site. The firefighter monitors all measured quantities on his equipment. After displaying the individual values, it can determine exactly what kind of substance it is, what its concentration is, whether there is a fire in the tunnel, and how close the universal sensor is to the accident sites
8. We continue with the model situation and image this situation. The universal sensor measures the temperature rise above 200°C, which indicates that there is a fire in the tunnel. Also, one of the sensors measured the increased smoke concentration. Another of the sensors measured the increased concentration of ammonia
9. The firefighter reads this information and evaluates what equipment is needed to intervene now
10. Then they know that there is a fire in the tunnel, and it is partially smoky. Ammonia, which is toxic, also escapes from the unknown tank, so special equipment is needed and intervention as soon as possible

6 CONCLUSIONS

The aim of the article was to describe and explain the construction, principle of operation, processing and transmission of the information within a universal sensor for detection of dangerous gases to during the intervention of firefighters. In the design, there was an emphasis on small size, easy handling and low cost. Since it is assumed that the universal sensor will be destroyed during the intervention, it is necessary that the intervening units be equipped with a more that on these sensors. If several sensors are used during the intervention, it is possible to create a sensor network that will inform the intervening firefighters about the current situation in a larger section of the tunnel. As a result, this sensor can help to speed up the intervention and improve the firefighters' safety during a tunnel accident, minimizing casualties and damages.

Currently, the sensor is equipped with four gas sensors, but it is possible to install other sensors to it, which would expand the measurement capabilities of the universal sensor (e.g. radiation sensor, NO sensor, etc.).

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