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Semiconductor gas sensors for mobile robot navigation

Streszczenie. *Praca przedstawia próbę rozwiązania problemu nawigacji robota mobilnego wzdłuż ścieżki znaczonej substancją chemiczną. Tego rodzaju nawigacja wymaga krótkiego czasu reakcji sensorów gazu na zmiany koncentracji substancji użytej, jako znacznika. W celu poprawy tego parametru dla komercyjnych sensorów opracowano specjalny system pobierania próby z mechanicznym wymuszeniem przepływu gazu przez obudowę sensora. Przedstawiono wyniki eksperymentów pokazujące znaczną poprawę parametrów dynamicznych sensora.*

Abstract*. This work deals with the problem of mobile robot navigation along a chemical track. Such navigation requires short response time of gas sensors to concentration changes of the chemical substance. In order to improve this parameter in the commercial gas sensor, dedicated probe sampling system with mechanical enforcing of the gas flow through the sensor housing was developed. The results of experiments showing significant improvement in dynamic parameters of the modified sensor are presented.* ***(Zastosowanie czujników chemicznych w nawigacji robota mobilnego)***

Słowa kluczowe: śledzenie ścieżki zapachowej, półprzewodnikowe czujniki gazów, nawigacja, robot mobilny.
Keywords: odor path tracking, semiconductor gas sensor, navigation, mobile robot.

Introduction

To move effectively in its environment a mobile robot should have a plan of the movement and should know its current position. When building the robots we often try to ape nature. In the nature most animals find their way around in environment based on smell.

The paper presents the concept of using odor sensors for mobile robot navigation. The navigation task consists in planning the path of movement and then controlling its realization. The planning stage can be supported by human-operator when the path tracking control must be performed independently by the robot controller. For this purpose, a robot could recognize the sequentially passed environment objects, using vision sensors or laser scanner. Unfortunately this approach requires a large computational effort to process sequentially collected images. It increases the cost and size of the control system and, consequently, reduces this type of solution to special applications – such as space exploration or military operations.

Another approach, extensively used in industrial solutions, is marking in the environment an easily observable path that can be followed by robot. Painted lines or cables powered by high frequency alternating current are usually used for this purpose. This type of robots moving along the wires or lines is called AGV (Automated Guided Vehicle). Disadvantage of this navigation method is its low flexibility - to change the route one should remove the old lines and paint the new ones.

Volatile chemical compounds give new capabilities in this field. The lines marked in this way vaporize after the robot completes its work – similarly like the pheromones paths created by insects [1].

To detect and to follow chemical trails the suitable gas sensors must be used. As possible for use in robotics quartz microbalance sensors [1, 2], conducting polymer sensors [3, 4], miniaturized photo ionization detector (miniPID) [5, 6] and semiconductor gas sensors were considered. There was also an interesting attempt of using biological sensor using living moth antennae [7]. It is difficult to determine which kind of sensor is the best for mobile robot [8, 9], but semiconductor gas sensor are certainly the cheapest and most readily available.

In the case of commercially available semiconductor gas sensors, the basic problem in considered applications is their slow reaction for the changes of concentrations of the active chemical (especially long relaxation time), which significantly limits the speed of the movement along the tracked path.

The paper presents the examination of selected chemical sensors and experiments with their modification, as well as the construction of the sensor system for chemical path tracking based on the modified sensors.

Problems related to the use of gas sensors for the navigation

In industrial applications the most important parameter of chemical sensors is the accuracy of measurement of gas concentration. On the contrary, in mobile robotics applications the key parameters for sensors analyzing the robot environment are [10]:

- sensitivity to tested chemical,
- detection threshold, and
- time of reaction to changes of gas concentration.

Also the work conditions (a moving robot) differ essentially from those typically found in industrial sensor systems. The nature of chemical substances propagation in the air causes very unstable response. In addition the intensity of emission decreases in time, as the trail dries by evaporation. These are the reasons why the concentration and emission of tracked gas may change in time and space in a way difficult to predict.

However, in mobile robot navigation, detailed knowledge about gas concentration and emission rate is not really necessary. The only purpose is the detection of chemical path placement as precisely and quickly as possible.

The first problem which appears here is the sensitivity of commercially available sensors. People can smell some substances (for example trimethylamine) with concentrations threshold below 1 ppb [11]. Wild animals have much higher abilities. Unfortunately currently available technology cannot provide comparably sensitive sensors. The first choice solution is to prepare strong enough artificial chemical paths. This approach however is difficult to perform and uncomfortable. In presented research the surface made of paper (80 g/m^2) soaked by ethyl alcohol was being used as a source of odor.

The second problem is the low detection rate of chemical concentrations changes of available sensors. The low detection speed limits significantly the robot motion speed along the path, complicating its mission or even making it impossible to achieve. Moreover, sensors for robotics applications should have additionally small size and weight, and high mechanical robustness.

The solution of the presented problems was obtained by careful selection of commercially available sensors and their modification.

Experimental test-bed

An analysis of available gas sensors performed according to features described above led to selection of

TGS 2201 device manufactured by Figaro (Fig. 1). It contains two sensitive elements based on SnO_2 thick film layer, with various dopants, placed on the same substrate. According to the data sheet, one sensing element is designed to detect diesel vapors and the second one to detect gasoline vapors. It is commonly known however that this kind of sensors is cross sensitive to many chemicals.

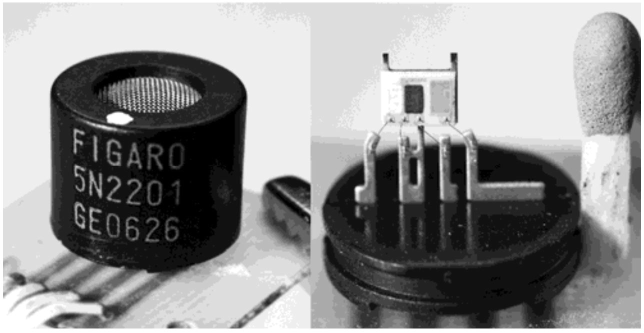
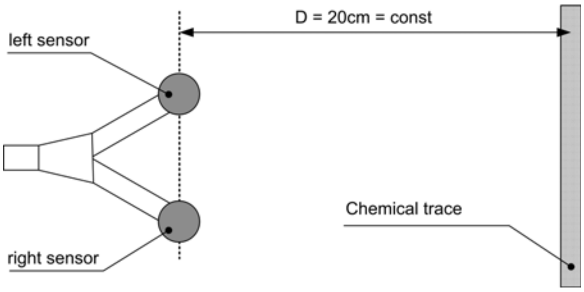


Fig. 1. TGS 2201 sensor with and without housing.

a)



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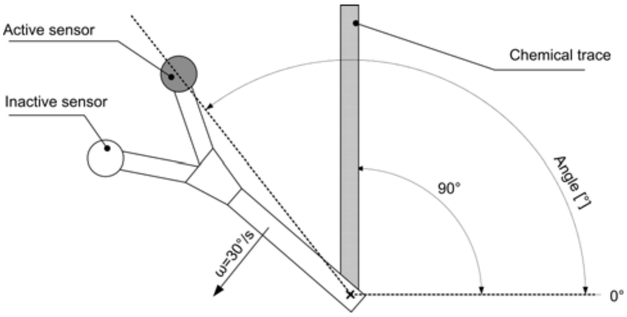


Fig. 2. Experimental test-bed schematic. (a) Sensor head placed orthogonally to smell source line, with constant distance 20 cm. (b) Sensor head rotating and crossing the smell source line.

Basic measuring setup suggested by the manufacturer [12] was applied. Sensor was connected to constant voltage V_H = 7 V. Four adjustable potentiometers were used as load resistors for each sensor/channel. For ambient air the responses, i.e. voltages measured on reference resistors were 2 V for each circuit (voltage divider). ATmega32u4 microcontroller with integrated 10-bit ADC was used to collect data and transmit it to a PC computer. The results were analyzed in MATLAB environment.

To adapt the sensor output voltage (2–7 V) to the range appropriate for the ADC (0-5 V) an rail to rail operational amplifier was utilized. The amplifier was preceded by low-pass filter to avoid high frequency noise and aliasing. Sampling frequency was 500 Hz per channel. This was high enough to digital signal processing because the useful signal has a much lower frequency (max 20 Hz). Moving average was finally employed.

The experimental setup was designed as simply and as small as possible, because we need to use the same system on small size, battery-operated mobile robot. System has two stabilized power supplies: 5 V for digital circuit and 7 V for sensor heaters and analog circuit. Source of power for linear stabilizers is small Li-Polymer accumulator.

Sensors characteristics were determined in a way specific for target application (mobile robot active sensors system). Two sensors were mounted on a rotating arm on moving platform (Fig. 2). Thanks to this, precisely controlled movement and rotation were possible.

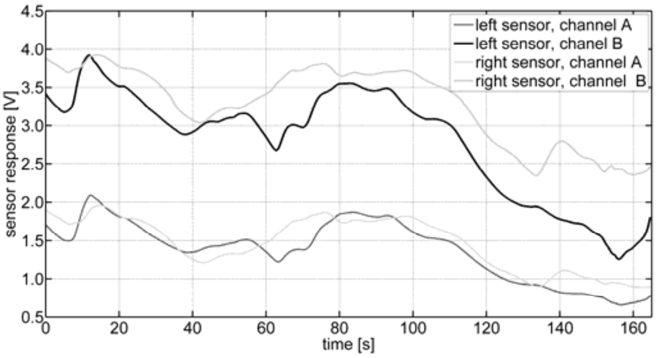
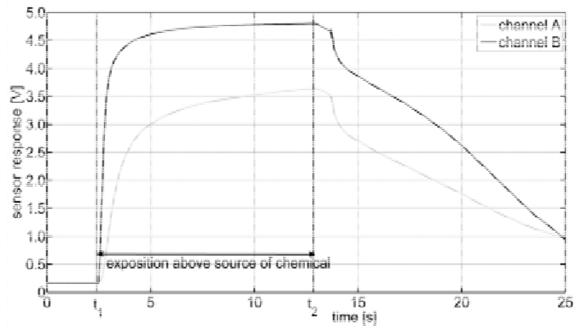


Fig. 3. Response of TGS 2201 sensor for ethanol vaporizing in open space. Constant distance 20 cm.

a)



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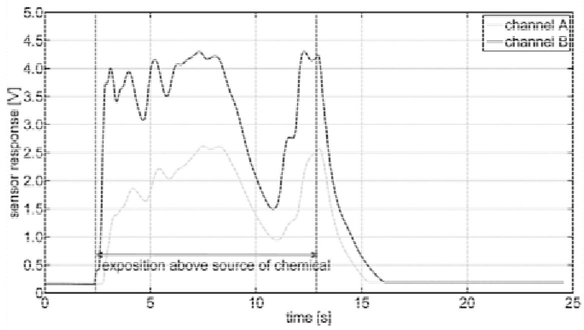


Fig. 4. Step response of TGS 2201 sensor for sudden exposition to ethanol. Original sensor (a) and sensor with housing removed (b).

Figure 3 shows the sensor response in experiment carried out according to the figure 2a. Sensor head stay motionless, orthogonally to an odor source line, with constant distance equal to 20 cm. As we see the response is very unstable in time (varies from 30 to 80% of the range). This is probably caused by air random movements.

Step response of the sensor was shown in the Figure 4a. At time t_1 sensor is moved just above the source of chemical. At time t_2 the source is removed. As we see in graph a response is not symmetric. The refresh time is long, and amounts over a dozen seconds. This is caused by gas trapped inside of sensor housing.

Figure 4b shows the same experiment but with housing cap removed. It revealed that sensor without housing is very unstable, but this modification improved dynamic of the response significantly. This instability is probably caused by thermal movement of air, so controlling the air flow around sensing element is necessary.

Probe sampling system

According to the research presented in the section above, the mechanical forcing of the gas flow around the active element (sensible film) is necessary to reduce the inertia of the sensor.

First idea of sampling system was suction of air with constant flow rate through the sensor housing. But this way may result in transport of the odor from a distance by airflow and may blur the chemical path image. To avoid this problem an air curtain system [2] was adapted. Diagram of developed solution is shown in Figure 5. A small fan (25 x 25 mm^2) is used to force the airflow. The stream is directed downwards, and part of it returns and passes through the perforated sensor housing. The rest of stream is being released to the sides, forming an air curtain blocking molecules from large distances preventing reaching the sensor.

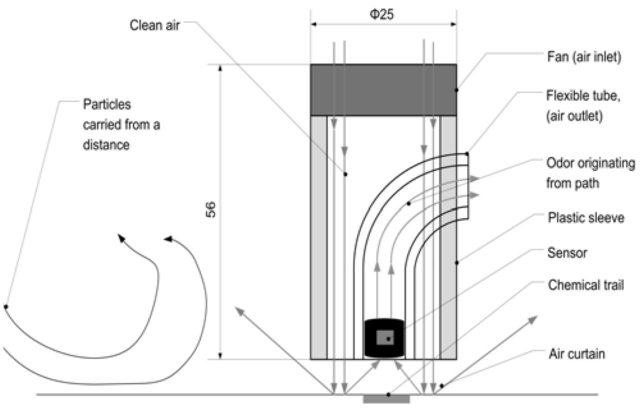


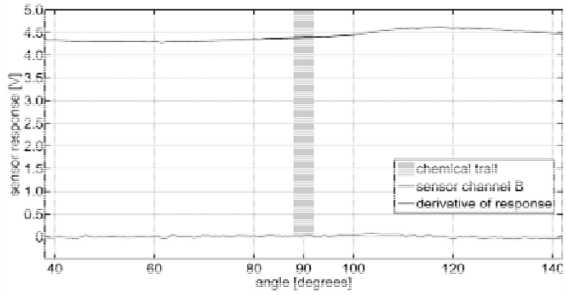
Fig.5. Schematic of sensor housing modification.

The whole system is the cylinder with the diameter of 25 mm and the height of 56 mm. Inner tube has diameter slightly wider then diameter of sensor housing (15 mm) and thickness bellow 1 mm. The dimension of outer plastic sleeve was selected according to the fan dimensions, and has outer diameter of 25 mm and thickness 2 mm. Inner tube is held in axial position with three spacers. This creates a 3 mm width cylindrical gap. Outer sleeve and inner tube end on the same level over the ground. Clean air deriving from the gap creates an air curtain and encloses sensor. Odor particle cannot reach the sensing element until active sensor system is located directly above the chemical trail.

An advantage of the elaborated active sensor was shown in the pictures 6 and 7. Sensor is placed on an arm moving with constant rotational speed equal 30^{O}/s (sensor scans surroundings) (Fig. 2b). Chemical trail is marked as a narrow line (about 7 mm), and should be detect at 90^{O}.

When we use original sensor (or if the fan is turn off) we obtain characteristic as in Figure 6a. Sensor response is very weak and clearly shifted. When fan is working, reaction is strong, and shift is very small. Simply detector based on comparing values of signal derivative can be applied to determine location of the source of volatile organic compound (in this case ethyl alcohol).

a)



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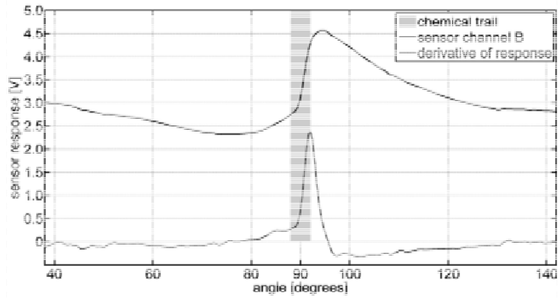
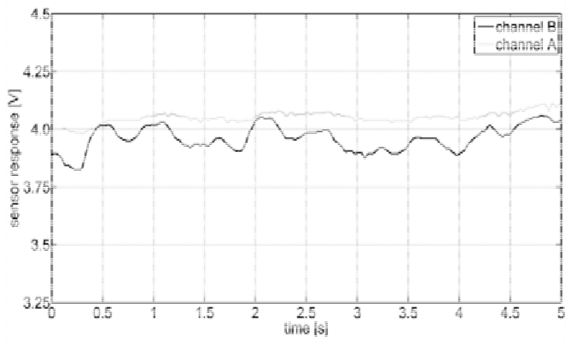


Fig. 6 Response of modified TGS 2201 sensor for alcohol. Measurements performed for sensor head crossing the smell source line with constant rotational speed. Fan turned off (a) and on (b).

a)



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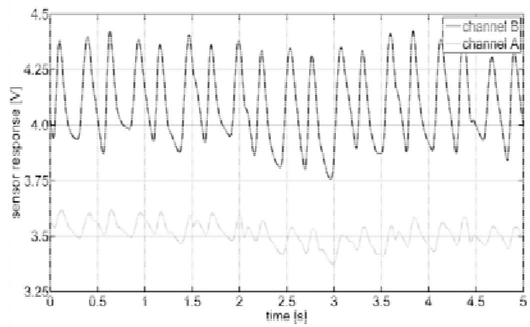

Fig. 7. Response of modified TGS 2201 sensor for alcohol. Measurements performed for sensor head oscillating above and crossing the smell source line with frequency of 4 Hz. Fan turned off (a) and on (b).

Figure 7 shows ability to distinguish a single pulse in a pulse series. Sensor crosses over the path 4 times per second. When fan is off, distinction between single crossings is impossible. With use of modified sensor the distinction is easy, and no crossing is missing.

This modified sensor is suitable and ready for use in mobile robot tracking odor path.

Practical results – application on mobile robot

The set of four TGS2201 sensors was used to develop sensing unit for mobile robot. Two of them modified in the manner described above were placed on a rotating arm, called a robot “nose”. The aim of the nose is to detect the position of the trail in relation to the longitudinal robot axis to determine the curvature of the path. The calculated value is passed to the motion controller to control the speed of robot wheels. Two other sensors play an auxiliary role and allow the correction of orientation error of the robot.

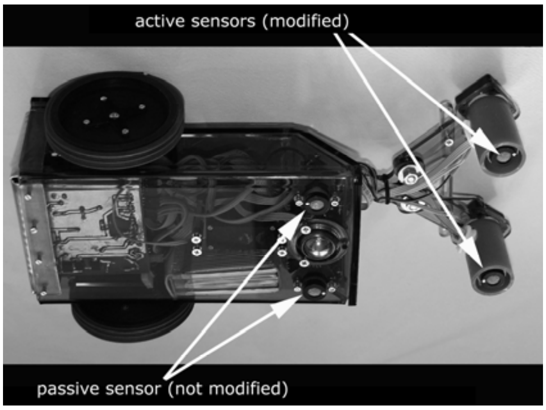

Fig.8. Mobile robot with developed sensor system (the bottom view).

The results of experiments carried out with developed mobile robot equipped with elaborated odor sensor system were shown in Figure 9. The black line represents the path marked with ethyl alcohol. The white line shows the real trajectory of the robot registered by the video camera (three rides along the path). It was created by bright LED diode placed in the center of the robot. Path tracking speed was up to 10 cm/s. The loss of the track and falling out from the right path may be seen in the bottom right corner. It may be also seen however that the robot can return to the correct track, with the appropriate corrective maneuvers.

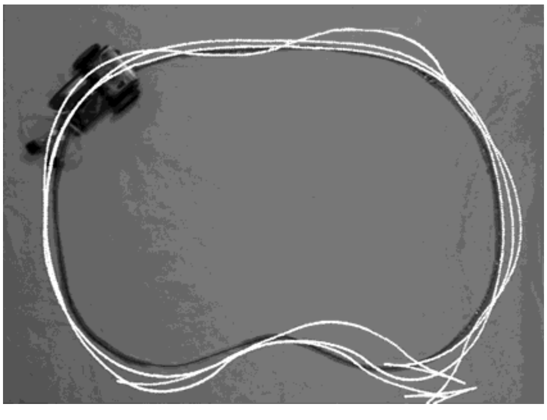

Fig. 9. Trajectory of mobile robot tracking the odor path.

Conclusions

The modification of the chemical sensor TGS2201, to adapt it to the navigation requirements was carried out. The essence of modification consisted in forcing a controlled gas flow around the sensor active element (gas sensitive film). The result is the significantly better dynamic performance. Based on these modified sensors the active sensory system that allows guiding the robot along the odor path was developed. The conducted experiments showed that the developed system provides sufficient information for proper odor navigation.

Presented approach encourages further work. Next objectives are:

- search for other options to modify the gas sensor to achieve higher sensitivity,
- experiments with sensory systems organized in the other way,
- search for other volatile substances which ensure certain properties of chemical trace,
- development of sensory system able to distinguish between separate, created concurrently tracks (various chemicals), so that the robot could decide which goal to pursue, (which path to move),
- development of a sensor system capable of evaluation of the concentration gradient in three dimensional space (“odor compass”) [13, 14],
- development of a sensor system providing active localization of sources of gas emission dedicated for emergency and monitoring systems [15, 16].

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