Stand-off detection of alcohol in car cabins

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Abstract. The results of experiments concerning detection of alcohol vapors in car cabins using a laboratory device, which was developed and built at the Institute of Optoelectronics at the Military University of Technology, are described. The work is a continuation of the investigations presented in an earlier paper. On the basis of those results, the whole device was designed and built. Then it was investigated using a car with special system simulating a driver under the influence of alcohol. To simulate the appropriate concentration of alcohol in human blood, a special method of generation of alcohol vapor was developed. © *The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI.* [DOI: 10.1117/1.JRS.8.083627]

1 Introduction

Stand-off detection of different chemical and biological compounds with the use of a monochromatic laser beam at a wavelength fitting into the absorption spectra of these materials is described in many papers.[1–6] At the same time, many new developments in lasers that can be used in this application has been achieved in recent years.[7–12] Thus, many devices based on this technology were presented in laboratories as well as applied to civil industry, environmental protection, and military. Simultaneously, stand-off detection of alcohol in moving cars draws more and more attention of scientists as well as institutions responsible for safety on the roads,[13–16] who are aware of the fact that effective detection of drivers under the influence of alcohol would significantly reduce the number of fatal car accidents.

To address this problem, research in this field was taken up at the Institute of Optoelectronics at the Military University of Technology and a special device was designed and built. The configuration of the device was based on the work presented in Ref. 17. The idea of using such device is very simple. It should be deployed by the side of the road to monitor each car passing by. If some vapors of alcohol are detected in a car, a message with a photo of the car including its number plate is sent to a policeman who is waiting by the road several hundred meters further. Then the policeman stops the suspected car driver and checks him using conventional equipment. Sometimes it may occur that the driver is sober while passengers are not or some sort of alcohol was spilt in the car. However, despite this, the idea will surely decrease the number of cars that have to be checked by police and, at the same time, will increase efficacy of stopping drunken drivers.

In this paper, we present the results of investigations of the built device in semireal conditions. It means that the real car with special system simulating a driver under the influence of alcohol was deployed on the road while the device was placed in the laboratory. Placing the device in the laboratory made possible to monitor every part of it.

2 Experimental Setup

The investigations of the detection of alcohol in the car cabin were carried out in the setup presented in Fig. 1. The monitoring single-mode laser beam with a wavelength of 3.39 μm and

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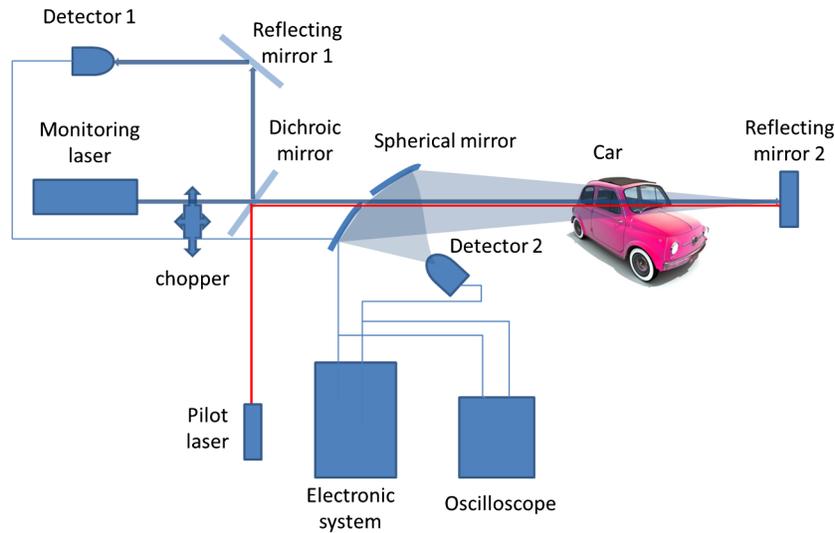*Address all correspondence to: Jarosław Młyńczak, jmlynczak@wat.edu.pl

Fig. 1 Experimental setup for detection of alcohol in cars.

power of 2 mW was directed onto a reflective mirror, which was placed on the other side of the car. The beam was also modulated by a chopper with frequency of 3.6 kHz so as to make the synchronous detection possible. It enabled the detection of signals with amplitudes much lower than the amplitude of noise. Additional laser beam of 0.6 μm wavelength was used as a pilot beam and was aligned with the monitoring beam by a dichroic mirror. The same mirror was also partially reflected for monitoring beam and the partially reflected beam was directed onto the detector 1 to monitor the power of the beam. Checking the monitoring laser beam was necessary because of the fluctuation of its power. To focus the monitoring beam returning from the car onto detector 2, a spherical mirror was used. The spherical mirror had a hole in the middle to let the emitted monitoring beam go through. The signals from the detectors were analyzed by a specially developed electronic system with appropriate signal analysis. To accurately adjust the whole system, an oscilloscope was used.

Because the monitoring beam goes through the car two times, the absorption of the beam by the alcohol vapor is increased. Additionally, the displacement of the beam by car windows was also eliminated. On the other hand, this solution caused the increase of absorption of the monitoring beam by the car windows; however, this was overcome by using cooled detectors of high sensitivity.

In a real situation, the alcohol vapor comes from the human lung, so in the experiment, this source had to be simulated. It was achieved by evaporation of water solution of alcohol of appropriate concentration and at appropriate temperature. The concentration of alcohol vapor over evaporating solution is determined by Raoult's law.[18] On the basis of this law, the molecular pressure of alcohol vapor over its solution is described by the following equation:

$$p_A = x_A \cdot p_{nA}, \tag{1}$$

where x_A is the mole fraction of alcohol in the solution and p_{nA} is the molecular pressure of saturated alcohol vapor at given temperature.

When mixing alcohol of volume V_a with water of volume V_w, mole fraction of alcohol in the solution is given by the following equation:

$$x_A = \frac{N_a}{N_w} = \frac{m_a}{M_a} \cdot \frac{M_w}{m_w} = \frac{M_w}{M_a} \cdot \frac{m_a}{m_w} = \frac{M_w}{M_a} \cdot \frac{\rho_a}{\rho_w} \cdot \frac{V_a}{V_w}, \tag{2}$$

where N_a is the amount of moles of alcohol in solution, N_w is the amount of moles of water in solution, M_a is the molecular weight of alcohol, m_a is the weight of alcohol, M_w is the molecular weight of water, m_w is the weight of water, ρ_a is the density of alcohol, and ρ_w is the density of water.

Inserting appropriate values from physical arrays,[19] mole fraction of alcohol can be written as

$$x_A = \frac{18}{46} \cdot \frac{0.79}{1} \cdot \frac{V_a}{V_w} = 0.3091 \cdot \frac{V_a}{V_w}, \tag{3}$$

$$x_A \approx 0.31 \cdot \frac{V_a}{V_w} = 0.31 \cdot C_a, \tag{4}$$

where

$$C_a \equiv \frac{V_a}{V_w}. \tag{5}$$

The molecular pressure of saturated alcohol vapor p_{nA} depends on temperature. In Fig. 2, the molecular pressure of saturated alcohol vapor was presented as a function of temperature.[19]

When human beings have the concentration of alcohol in their blood equal to 0.2‰, the concentration of alcohol in the exhaled air is equal to 0.1 mg/dcm³, which in turn is equal to 50 ppm ($C = 5 \cdot 10^{-5}$).[20] Knowing that normal atmospheric pressure with all vapors is equal to 1013.25 hPa $\equiv$ 760 Tr, the molecular pressure of alcohol vapor in such air can be described by the following equation:

$$p_A = 760 \cdot 5 \cdot 10^{-5} \text{ Tr} = 3.8 \cdot 10^{-2} \text{ Tr}. \tag{6}$$

At the temperature of 25°C, the molecular pressure of saturated alcohol vapor is equal to 59 Tr (Fig. 2). Such pressure will be over the solution of mole fraction equal to x_A.

Taking into consideration Eq. (1) it can be written

$$3.8 \cdot 10^{-2} \text{ Tr} = x_A \cdot 59 \text{ Tr}. \tag{7}$$

Thus,

$$x_A = 6.4 \cdot 10^{-4}. \tag{8}$$

Inserting Eq. (8) into Eq. (4),

$$0.31 \cdot \frac{V_a}{V_w} = 6.4 \cdot 10^{-4}. \tag{9}$$

Thus,

$$\frac{V_a}{V_w} \equiv C_a = 2.06 \cdot 10^{-3} \approx 2 \cdot 10^{-3}. \tag{10}$$

Concluding this derivation, it can be stated that on evaporation of the water solution of alcohol of concentration $C_a = 2 \cdot 10^{-3}$, the obtained concentration of alcohol vapor in the air is equal to the concentration in the air exhaled by a human being who has a concentration of alcohol in
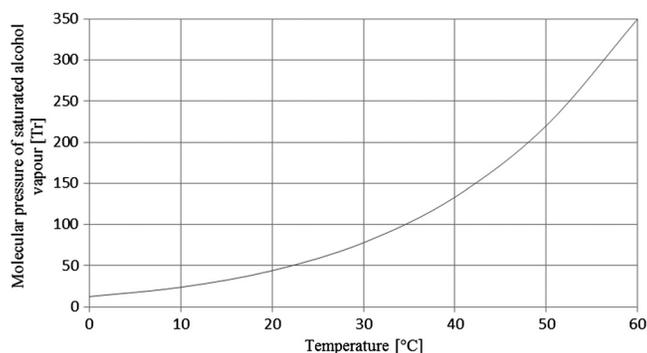

Fig. 2 Molecular pressure of saturated alcohol vapor as a function of temperature.

their blood equal to 0.2‰. Thus, one can obtain a specific concentration of alcohol vapor in the air by evaporating the water solution of alcohol of known concentration and at known temperature.

3 Experiment

The investigated device was deployed in the laboratory close to the open window so as to have the right position to monitor the car that was placed in the path of the monitoring 3.39 μm laser beam. The side windows of the car were closed. On the other side of the car, the reflecting mirror was placed so as to redirect the laser beam in the opposite direction. The configuration of the car and the mirror is presented in Fig. 3.

During the experiments, the water solutions of alcohol of concentration between $C_a = 0$ and $C_a = 2 \cdot 10^{-3}$ were evaporated. These correspond to concentration of alcohol in human blood between 0 and 3‰. The measurements were made on the plume of evaporation of alcohol simulating the plume of the air exhaled by the driver. The transmission of this vapor was measured by the device. The results of the investigations are presented in Table 1 as well as in Fig. 4.

Fig. 3 Configuration of the car and the reflecting mirror.

Table 1 Relation between the concentration of alcohol in human blood and the transmission of alcohol vapor in the air exhaled by this human being measured by the device.

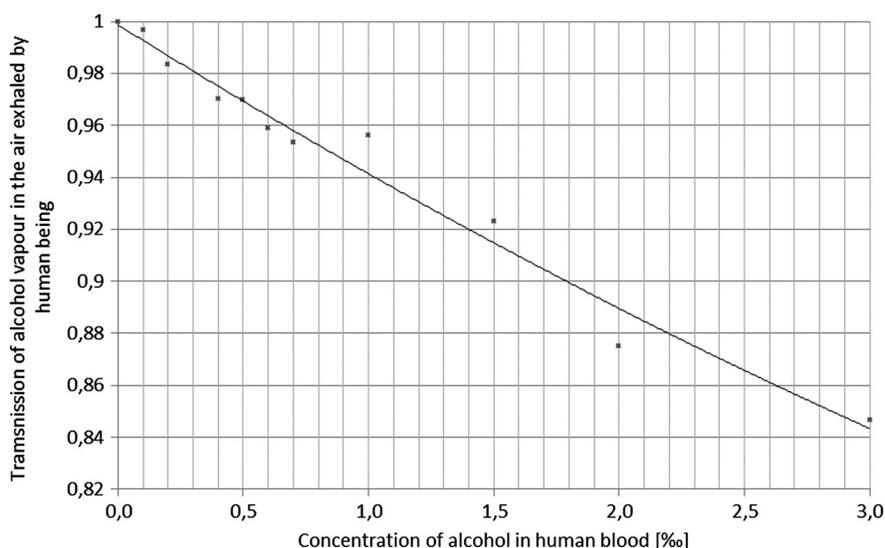| Concentration of alcohol in human blood [‰]	Transmission of alcohol vapor in the air exhaled by human being
0.0	1.0000
0.1	0.9967
0.2	0.9836
0.4	0.9701
0.5	0.9699
0.6	0.9588
0.7	0.9534
1.0	0.9562
1.5	0.9232
2.0	0.8751
3.0	0.8466

Fig. 4 Transmission of alcohol vapor in the air exhaled by a human being in function of concentration of alcohol in blood.

4 Conclusion

The results of the investigations presented in this paper show that the developed device works properly. It is able to detect alcohol vapor in a car in which a human being with a concentration of alcohol in blood of at least 0.1‰ is present. Moreover, in real situation, when a person has a concentration of alcohol in blood of 0.1‰, one can expect even higher concentration of alcohol vapor in the exhaled air because the temperature of human's lung is ~37°C, which is much higher than in our experiments (25°C). Additionally, even though the transmission of car windows at the wavelength of 3.39 μm is very low and the monitoring beam goes through two windows two times, the power is still high enough to detect the alcohol vapor at such low concentrations.

From the practical point of view, there seem to be some countermeasures, such as driving with windows open, solar screens on the side windows, etc., that can be applied by drivers to deceive the system. However, such situations are very easily detected by the system, which sends this information to the policeman indicating that the car should be checked. In case of driving with air-conditioning or fans on, the results of measurements will surely be distorted, but it depends on the speed of moving air, which usually is very low and, thus, its impact on the measurements is slight. All the possible countermeasures are very important and have to be investigated, which will be done during the next stages of the ongoing project.

As far as the commercialization of the device is concerned, the next step would be to make it more compact, robust, and customer friendly, which can be achieved with high probability.

Acknowledgments

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