Corridor Gas-Leak **Localization** Using a Mobile Robot with **a** PID Sensor

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Abstract: The use of an autonomous mobile robot to locate gas-leaks and air quality monitoring in indoor environments are promising tasks that will avoid risky human operations. However, these are challenging tasks due to the chaotic gas profile propagation originated by uncontrolled air flows. This paper proposes the localization of an acetone gas-leak in a 44 m-length indoor corridor with a mobile robot equipped with a PID sensor. This paper assesses the influence of the mobile robot velocity and the relative height of the PID sensor in the profile of the measurements. The results show weak influence of the robot velocity and strong influence of the relative height of the PID sensor. An estimate of the gas-leak location is also performed by computing the center of mass of the highest gas concentrations.

Keywords: gas source detection, mobile robot, PID sensor, LIDAR sensor, SLAM.

1. INTRODUCTION

Detecting critical air conditions, particularly when it is a risk for human health, is an important application challenge for a mobile robot. The electronic noses (e-noses) are proved to be suitable systems to address this problem¹⁻⁴ but the estimate of the gas leak source is still a very difficult task because of the chaotic gas profile propagation⁵ that is affected by parameters such as wind, pressure, humidity and temperature⁶. There are some papers in the literature that proposes the use of a gas sensor or e-nose attached to a mobile robot (fig. 1) to implement different exploratory alternatives in order to estimate a gas-leak source⁷⁻⁹. For example, in Lilienthal et al.¹⁰ the practical operation of a mobile equipped with a tin metal oxide (MOX) gas sensors odour sensing system was investigated in an indoor environment without a constant airflow. In this case, the conclusion was that the performance of the mobile robot odour system could be significantly enhanced by driving the robot with a constant speed in order to generate the air turbulence required by the MOX sensors.

In a similar direction, this paper proposes the use of a mobile robot equipped with a gas sensor to locate a gas-leak source in an indoor unknown corridor. The new contributions are the assessment of the influence of the robot velocity and the absolute height of the gas sensor air-sampling point in the profile of the measurements obtained.

2. MATERIALS

This section describes the materials used in this work: mobile robot, experimentation scenario and gas-leak source.

2.1. Experimentation scenario

In this paper, the hypothesis is that there is a gas-leak source in one office or laboratory of the second floor of the Polytechnic School of University of Lleida (see Fig. 2). The general assumptions are that all the doors of the floor are closed and that the gas-leak diffuses up to

the corridor. Figure 2 shows a map of the experimentation scenario, the corridor area (44 m length) is highlighted in light red color; the focus of the gas leak source is represented by the red dot; the black line summarizes the expected exploratory trajectory; the black dot is a reference point close to the main stairs ($x = 46$ m) and the white dot close to the emergency stairs ($x = 6$ m). In this case, one side of the corridor is almost plain and the other has a saw shape.

2.2. Gas-leak source

In this paper, the effect of a gas-leak source is simulated by using an acetone evaporator that has a cylinder (200 mm height and 90 mm wide) lifted 10 mm from the floor with a fan in the upper part to generate a forced vertical air flux that throws the gas up (Fig. 3). This system evaporates in average 32 ml/h of acetone and was switched on 15 minutes before starting any experiment.

2.3. Mobile robot

Figure 1 shows the mobile robot used in this paper which is a polyvalent research instrument that carries a wind sensor (WindSonic), a light detection and ranging (LIDAR: UTM-30LX) laser sensor, a photo ionization detector (PID: ppbRAE 3000), and a frontal stereo camera (Minoru 3D). The PID was configured to detect acetone. The mobile robot is controlled with an onboard computer which includes an Intel Core2 @1.66Hz processor, 1Gbyte of RAM, and Windows XP. The mobile robot can operate autonomously by performing real-time SLAM¹¹ and is able to sample its relative position, the wind velocity and direction, and the gas concentration at 1Hz (the PID sensor limits this sampling rate).

3. EXPERIMENTS AND RESULTS

In this paper, the exploratory mobile robot is placed at the beginning of an unknown corridor with their frontal part oriented to the end (Fig. 2-black dot). The mobile robot starts the

exploration of the corridor by using the onboard LIDAR for real time SLAM¹¹. The internal path planning algorithm is then configured to analyze the map of the corridor and drive the mobile robot to the end while avoiding obstacles and following a trajectory very close to the left wall (at approximately 50 cm). When the path planning algorithm detects that the mobile robot has arrived to the end of the corridor the robot is returned to the starting point while navigating also close to its left wall.

Three different experiments were carried out in this paper to assess the influence of the velocity of the mobile robot, the influence of the gas sensor height, and also to locate the gas-leak source.

3.1. Effect of the mobile robot velocity

In this experiment the mobile robot was configured to use the plain wall of the corridor as a reference in order to define a straight trajectory up to the end of the corridor. Two measurements were performed: the first in January 2013 and the second in May 2013. In both cases the air flow in the corridor was weak; less than 0.07 m/s and without a predominant direction. During both experiments different mobile robot velocities were tested. The velocity of 0 m/s means that the robot goes forward 1 m and stops to measure the gas concentration and wind intensity and direction.

Figures 4 and 5 show the typical profile of the gas concentrations measured. The results show big differences between both measurements. During the measurements performed in January (Fig. 4) the gas profile used to have a peak close to the gas leak source (distance lower than 0.5 m) and this peak is sharper at lower mobile robot velocities. Alternatively, during the experiments performed in May (Fig. 5) the gas profile used to reach the maximum concentration near the ending exploratory point (close to the emergency stairs), suggesting an underlying air displacement in the corridor which was probably caused by natural convection.

The case of velocity 0 m/s reveals better the location of the gas leak source whereas the case of velocity 0.6 m/s measures the highest acetone concentration around the gas leak source.

3.2. Effect of the PID height

In this experiment, performed in May 2013, the mobile robot was configured to follow a straight trajectory up to the end of the corridor. The robot velocity was fixed at 0.6 m/s and the height of the PID was changed from 1 cm to 150 cm in steps of 30 cm. Figure 6 shows the profile of the gas concentration measured. The peak of the profile was very close to the gas leak source when the PID sensor was at 60 cm. In general, the peak of the acetone concentration was closed to the gas-leak peak when the PID sensor was placed at intermediate heights (60 cm). The largest acetone concentrations were measured when the sensor was placed at 60 cm or higher, probably because the air flow forced by the evaporator system (see Fig. 3) accumulates acetone at higher heights.

3.3. Gas-leak location

This last experiment consisted in the simulation of a gas-leak emergency condition and was performed in May 2013. In this case the mobile robot was placed just in the emergency stairs entry of the corridor. The path planning algorithm was configured to explore both sides of the corridor (return trajectory) with the mobile robot at approximately 50 cm of its right wall. The robot velocity was fixed at 0.6 m/s, and the PID sensor height at 150 cm.

Figure 7 shows the corridor map and the trajectory of the mobile robot obtained with the real-time SLAM procedure; the line depicts the mobile robot trajectory and the colored circles the absolute intensity and placement of the gas concentration measured; the location of the maximum concentration measured is labeled with an empty red square; a black edge depicts acetone concentrations higher than the 75% of the maximum concentration measured in the exploration. In this experiment the average intensity of the wind measured coincides with the

velocity of the mobile robot. The distance between the highest acetone concentration (Fig. 7-empty red square) and the gas-leak source in the map was 2.74 m. The proposed procedure for gas-leak source location is the computation of the center of mass from the higher acetone concentrations (Fig. 7-solid red square), then the distance to the gas-leak source was only 1.01 m.

4. CONCLUSIONS

This paper shows the results obtained when using a mobile robot to locate a gas-leak source in a large corridor. The mobile robot used a LIDAR and a real-time SLAM procedure for trajectory path planning and a PID sensor for gas concentration measurement. This paper assessed the influence of the mobile robot velocity and the relative height of the PID sensor in the measurements. Results showed a weak influence of the mobile robot velocity and a strong influence of the relative height of the PID sensor. This paper also proposes the location of the gas-leak source by performing a complete corridor exploration and by computing the center of mass of the highest gas concentrations measured during the exploration. The results obtained in one simulated emergency case showed that this location can be estimated with an error of 1 m in a corridor of 44 m. Future works will be focused on the assessment of the influence of other parameters such as temperature, humidity, gas density and gas propagation.

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Fig. 1. Image of the mobile robot and detail of the main sensors.

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Fig. 2. Map of the experimentation area.

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Fig. 3. Acetone evaporation system.

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Fig. 4. Acetone concentration for different mobile robot velocities. (January 2013, temperature 24.2°C, humidity 30%).

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Fig. 5. Acetone concentration for different mobile robot velocities. (May 2013, temperature 27.0°C and humidity 38%).

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Fig. 6. Acetone concentration for different sensor heights.

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Fig. 7. Corridor map, mobile robot trajectory and gas concentration obtained in the exploration.