A mobile robot agent for gas leak source detection

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Abstract. This paper presents an autonomous agent for gas leak source detection. The main objective of the robot is to estimate the localization of the gas leak source in an indoor environment without any human intervention. The agent implements an SLAM procedure to scan and map the indoor area. The mobile robot samples gas concentrations with a gas and a wind sensor in order to estimate the source of the gas leak. The mobile robot agent will use the information obtained from the onboard sensors in order to define an efficient scanning path. This paper describes the measurement results obtained in a long corridor with a gas leak source placed close to a wall.

Keywords: gas detection, mobile robot agent, laser sensor, self-localization.

1 Introduction

There are some accidental and harmful situations such as gas leak accidents in which humans expose their health to risky factors and situations. Currently, computers and sensor technological advances have allowed the development teleoperated robots [1] and artificial agents in order to substitute humans in risky tasks. In [2] was proposed an agent architecture for risk perception and interpretation taking into account different dimensions. Furthermore, a multi-agent system for ambient assistance based on user behavior learning was implemented and assessed [3].

On the other hand, gas leakage localization is a well-known problem in chemical robotic applications. Electronic noses are the most used devices for gas detection in many applications; nevertheless, there is a high difficulty in source leak location using these sensors due to the chaotic diffusion of the gas in the air [4]. In the bibliography there are several papers where uses autonomous mobile robot agents equipped with odor sensors as input for specific algorithms to predict the localization of gas leak sources [5, 6]. In robotics and in other autonomous systems often uses a laser sensors to detect and locate objects or obstacles with high fidelity. In [7] is described an object localization procedure using a static Light Detection and Ranging (LIDAR) sensor for mobile robot tracking and discusses the location errors found.

This paper simulates a gas leak accident in an indoor scenario in which the air is mixed with Acetone, always with low concentrations in order to keep the air breathable for humans without having any risk during the experimentation. Figure 1 presents the robot agent developed by the research group which is capable to auto-localize itself in an indoor environment capturing data with its LIDAR sensor and perform a Simultaneous Localization and Mapping procedure (SLAM). The final milestone of this work is to implement an effective robot agent which will be able to estimate the localization of the source gas leak scanning and processing the data taken from the photo ionization detector (PID) and the other sensors for each position. This paper reflects closely the processes performed by the robot agent for reaching its functional objective.

Fig. 1. Mobile robot agent developed, rBot.

2 Materials and methods

The mobile robot agent developed has the following sensors attached: a LIDAR, an anemometer, and a photo ionization detector (PID). For the experimentation is also used a gas source mechanism to simulate the gas leakage. Additionally, the procedure for simultaneous location and mapping (SLAM) is considered as a method in this work.

2.1 LIDAR sensor

The robot agent uses a Hokuyo UTM-30LX Laser (Figure 2) for mapping, self-localization and obstacle avoidance. This sensor scans the distance between the sensor and the obstacle, with a range from 0.1 to 30 m. However, in this paper, the maximum range has been limited to 4 m. Each sensor scan takes approximately 25 ms and gathers 1.081 distance points between the angles -135º to +135º where the 0º is the center of the sensor. Lectures are represented in polar coordinates and distance component has a resolution of 1mm. It is placed in front of the robot and the computed samples are sent using an USB 2.0 interface.

Fig. 2. Hokuyo UTM-30LX LIDAR sensor.

2.2 Anemometer

The robot agent is equipped with an anemometer on the top of its build for detecting the wind speed and its direction. The WindSonic model by Gill Instruments Ltd. obtains the velocity of the wind in m/s and the direction angles in degrees, both lectures at 4Hz of maximum sampler frequency. The communication with this device is performed by using a USB simulating a RS232 interface. The information obtained by this sensor will be used as an input parameter for the estimation algorithms of gas source leak localization.

2.3 Photo ionization detector (PID)

A PID ppbRAE 3000 sensor by RAE Systems is installed in the robot to detect the gas concentration in the air. This sensor can detect the concentration of different types of gases, so the device must be configured to detect acetone gas. Samples are obtained in parts per billion (ppb) with 2 seconds of response time and are sent by RS232 interface, but it can also be communicated through Bluetooth or USB interfaces. As the previous device, sample values are also used for the gas source leak localization algorithms as input parameter.

2.4 Mobile robot agent

A Hewlett-Packard laptop Intel Core2 Duo @1.66GHz, 1GB of RAM, is used as the core of the mobile robot and runs with Windows XP Operating System. All the previous sensors are connected to this computer directly. In addition, a motor control board is installed and connected with the laptop through USB connection. To engage the communication, the system creates a virtual serial port, so it can be used as a standard serial interface from a terminal or any command sending script. Using the motor encoders, the robot agent can perform discrete movements. For example: go straight 1m, or turn left 40º. The laptop and the other robot devices are powered with two external batteries of 95 W/h. The control program initializes all the communication interfaces used in the mobile robot and then executes the proposed mobile robot agent implementation.

2.5 Gas leak source

A mechanism has been built in order to simulate a gas leak source (Figure 3). In this case some Acetone is placed in the bottom of the vertical plastic pipe which has a fan on the top. So, this mechanism extracts the air out and evaporates the acetone at 32 ml/h in average.

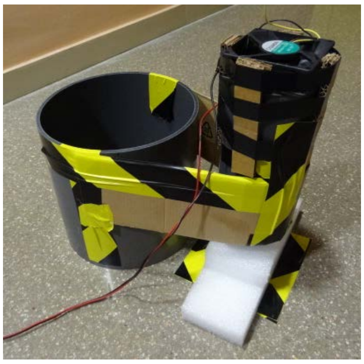

Fig. 3. Acetone evaporator mechanism.

2.6 SLAM

The robot self-localization procedure requires an SLAM methodology to estimate the displacement offset in real-time. The odometry [8] obtained from the encoder of the motion motors is also available as a comparative reference. The SLAM method consists on comparing laser scans in real-time. This comparison is based on the template matching method between the reference data obtained with the LIDAR (explored map) and the new acquired data by the laser. The comparison returns a position offset (Δx, Δy) and a relative rotation angle (φ), so, the map would be built while the mobile robot is exploring the area. The explored map is represented as a two-dimensional boolean matrix.

3 Agent methodology

The proposal of this paper is the development of a fully autonomous agent that will obtain data from the environment in order to develop the planned tasks. The agent will also decide if the final objective has been completed and provide the localization of the gas leak source). Figure 4 shows different steps included in the agent methodology.

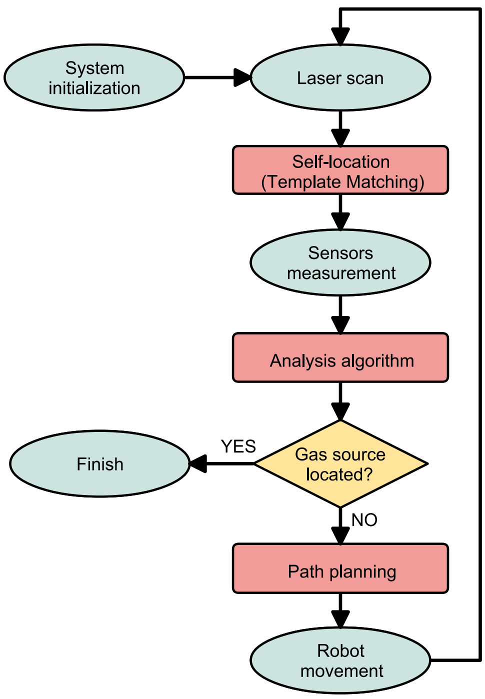

Fig. 4. Robot Agent behavior diagram.

In the first step, the robot initializes and checks all the devices and sensors connected physically to it. At this point, the agent performs the first laser scan and stores it as the initial reference map, thus, there is no self-location process executed. Then, the agent tries to detect reference elements such as straight walls from the initial reference map in order to guide the initial displacement mobile robot and initiate a complete exploration of the area in front of the mobile robot. The mobile robot agent proposes an exploratory path planning depending on the information extracted on the reference map. For instance, in small spaces fully covered in the initial reference map (the LIDAR scan provides information of up to 40 m) the robot will perform a right wall exploration until arriving to the starting position. Otherwise, in larger areas, the robot can perform a wall-to-wall zig-zag exploration and it can be configured to perform random path planning exploration in order to compare its effectiveness against the zig-zag displacement. The mobile robot also used the LIDAR information to avoid unexpected obstacles.

In the next iterations the mobile robot agent obtains scan data from the LIDAR and performs the self-location procedure. The new gathered data is compared with the reference map and the displacement is processed in a heavy template matching procedure implemented in C-code for speed optimization. Simultaneously, the agent completes gas, wind and odometry measurement. The information obtained with the sensors is used to update a localization map that is also used to compute the estimate of the gas leak source. In this paper the hypothesis is that the gas source position estimate will be more accurate as the information of the exploration is more complete.

4 Results

The experimental part of this paper was carried out at the second floor of the Polytechnic School of the University of Lleida. This area has a large and tight corridor of approximately 40m long, so the robot will have the opportunity to explore it by following its right-side wall. The evaporation mechanism was placed near the wall of the corridor at a centric localization to simulate a gas leak accident. The mobile robot performs a complete exploration of the corridor by measuring gas concentration and relative position. In this experiment, the gas leak source is estimated as the center of mass (centroid) of such information. Figure 5 shows the map of the corridor obtained with the SLAM procedure and the gas concentration represented as colored circles (the yellow circle represents the true gas leak source). The mobile robot agent implemented samples gas concentration at approximately 1 Hz with a relative maximum displacement of 0.6 m/s. The mobile robot agent updates a gas leak source estimate by computing the centroid of all the available gas concentrations until detecting that the unknown area was completely explored. The error obtained in the final gas leak source position estimate was always lower than 1 m.

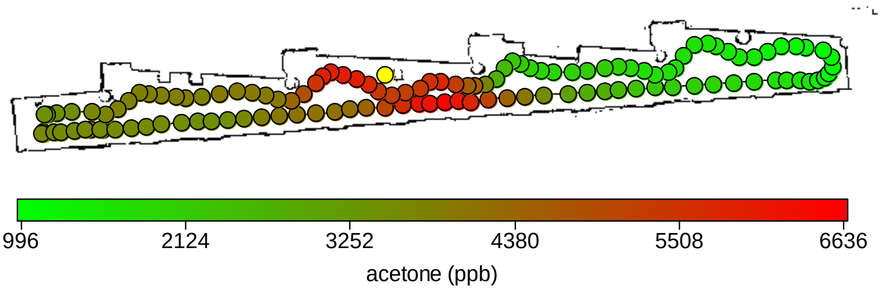

Fig. 5. Corridor map obtained with the SLAM procedure, relative position of the gas concentrations (colored circles) and position of the gas leak source (yellow circle).

5 Conclusion

This paper proposes the implementation of a mobile robot agent for gas leak source detection in human-risky indoor conditions. The mobile robot carries several sensors in order to analyze and recognize the environment and measure gas concentration in the air. The objective of the agent is estimate the location of a unique gas leak source. The mobile robot agent is designed to explore an unknown area by using a SLAM procedure while sampling gas concentration and air displacement in order to provide a gas leak source position estimate performed by computing the centroid of the gas concentration values. Results showed that the proposed mobile robot agent estimate the gas leak source position with an approximated error of 1m. Future works will be focused on improving the gas detection procedure by mixing the information of the displacement of the air provided with the onboard wind sensor and the gas concentration measured [9].

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