Chemical source localization in real environments integrating chemical concentrations in a probabilistic plume mapping approach

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Keywords: chemical plume source localization, Bayesian inference, chemical concentration, mobile robots, real environments.

ABSTRACT

Chemical plume source localization algorithms can be classified either as reactive plume tracking or gas distribution mapping approaches [1-2]. Here, we focus on gas distribution mapping methods where the robot does not need to track the plume to find the source and can be used for other tasks [3]. Probabilistic mapping approaches have been previously applied to real-world data successfully; e.g., in the approach proposed by Pang and Farrell [4]. Instead of the quasi-continuous gas measurement values, this algorithm considers events (detections and non-detections) based on whether the sensor response is above or below a threshold to update recursively a source probability grid map; thus, discarding important information. We developed an extension of this event-based approach, integrating chemical concentrations directly instead of binary information. Initial results obtained in simulation were presented in [5]. In this work, both algorithms are compared using real-world data obtained from a photo-ionization detector (PID), a non-selective gas sensor, and an anemometer in real environments. We validate simulation results and demonstrate that the concentration-based approach is more accurate in terms of a higher probability at the ground truth source location, a smaller distance between the probability maximum and the source location, and a more peaked probability distribution, measured in terms of the overall entropy:

$$H = -\sum_{i=1}^{N_{cells}} P_i \cdot \log_{Ncells}(P_i) \qquad (1)$$

P_i is the probability assigned to cell i in the grid map, and N_{cells} is the total number of cells. Lower values of H correspond to a higher certainty regarding the source location.

EXPERIMENTAL DESIGN

Twenty experiments were carried out in the *Mobile Robotics and Olfaction Lab* (Örebro, Sweden) using a mobile robot mounting a PID (sampling frequency 1Hz) and an ultrasonic anemometer (sampling frequency 2Hz). The experiments were performed under forced ventilation, indoors and outdoors (Fig. 1), with and without obstacles and with one or two chemical sources at the same time. The list of source substances included: acetone, ethanol and 2-propanol. The robot was programmed to randomly explore the area, stopping for 30s at different fixed positions.

Figure 1. Examples of experiments carried out indoors (left) and outdoors (right).

RESULTS AND DISCUSSION

We show a selected representative experiment (2-propanol gas source, indoor environment, with obstacles) in this abstract due to space limitations. The instantaneous measurements from the PID and the anemometer at each point in the random trajectory of the robot are shown in Fig. 2. In both approaches tested (event-based and concentration-based) a probability map of the source location is updated with new measurements. Fig. 3 shows the probability maps at the end of the exploration, obtained with optimized parameters selected after testing 20 different values for each meta-parameter.

The probability at the ground truth source location, the distance between probability maximum and source location, and the entropy (1) over the probability maps were computed for the 12 experiments with a single source: P_{event}=0.05 ± 0.03, P_{conc}=0.07 ± 0.06, D_{event}=(1.84 ± 1.21)m, D_{conc}=(1.48 ± 1.30)m, H_{event}=0.90 ± 0.10, H_{conc}=0.86 ± 0.06. These results confirm the improved performance of the concentration-based approach.

The proposed concentration-based approach does not need a threshold to identify an odor event since it continuously updates a model of the background (interfering chemicals) for each cell (please note that a relatively large cell size of 1x1m^2 was used to have sufficient points to compute the background model). Instead, it requires estimating the source strength. However, this parameter is of direct interest to a user compared to the threshold level.

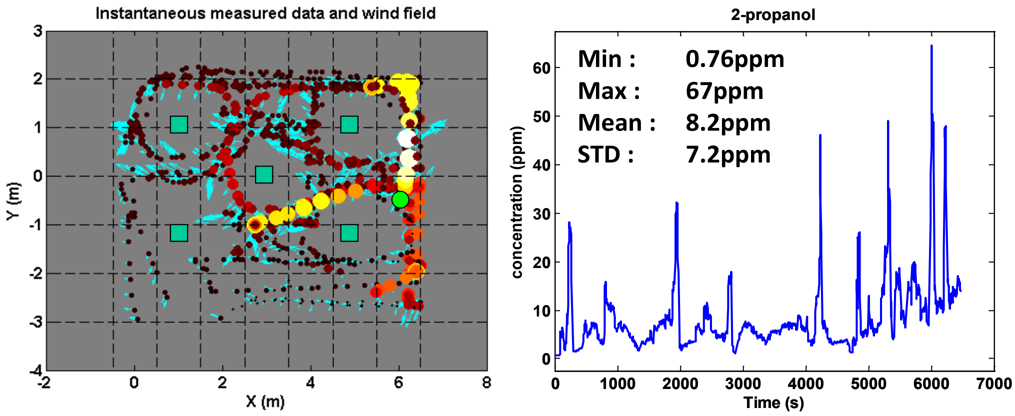

Figure 2. Left: Instantaneous concentrations measured with a photo-ionization detector (PID), shown in a specific heatmap (higher concentrations are additionally indicated by larger dots) together with measured mean wind vectors (cyan). The source is located at (6, -0.5)m, depicted using a green dot. Obstacles appear as green squares. Right: Instantaneous concentration measurements from the PID during the full experiment.

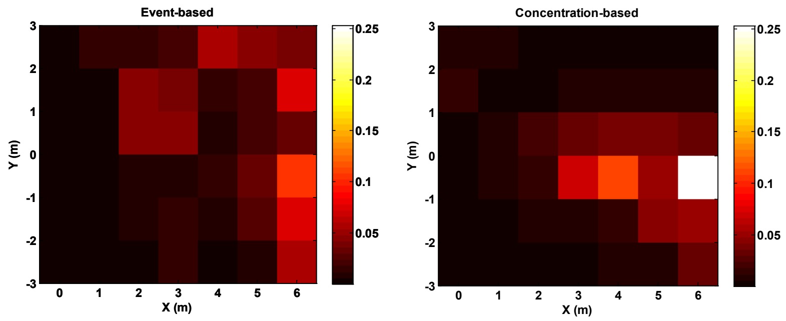

Figure 3. Final probability maps provided by the event-based (left) and concentration-based (right) approach using optimized parameters. The source is located at (6, -0.5) m.

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