Chemical Source Localization Using Electronic Nose Sensors

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Abstract

The goal of this project is to develop a closed-loop system to estimate the location of an odor source, using a chemical sensor array mounted on a robotic platform capable of moving in 2D. We model our electronic nose sensors' responses to different concentrations of ethyl alcohol, and we apply the Nelder-Mead method to iteratively converge on the location of the odor. We tested our chemical source localization approach for different scenarios using simulations in MATLAB. Our end goal is implementing our model on an actual robot, by programming a microcontroller and interfacing it with the robot's sensors. When the sensors are exposed to an odor, the program will estimate the concentration and the Nelder-Mead method will guide the robot towards the source.

Background

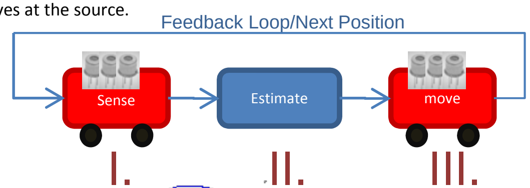
Electronic sensing technology is a developing field of study that has greatly advanced over the last decade. Currently, most research focuses on classifying odors within a limited odor set. Also of interest is detecting and distinguishing specific odors and the particular compounds within each odor. There has been some use of electronic noses in building safety and quality control.

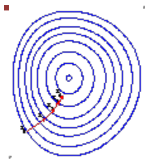
Applications

The designed GUI and experimental setup can be used as a starting point for future research exploring chemical array signal processing applications, such as specific compound detection, chemical source localization, and medical diagnosis.

Experimental Setup & Methods Used

The overall experiment consists of three main parts: **I.** modeling, **II.** simulation, and **III.** integrating our methods into a feedback loop system that will detect the location of an odor source. The sensors are theoretically mounted on a robot and begin at a position close enough to the odor such that the concentration is still detectable. The sensors will respond to the odor and we will estimate the concentration from their responses using a model of the sensors' voltage responses to concentrations. The Nelder-Mead method will then direct the motion of the robot. This cycle continues at each new position until the system arrives at the source.

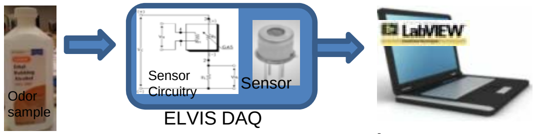




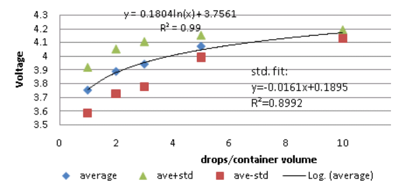
Theoretical model displaying gradual movement of robot towards an odor source

I. Sensor Response Modeling

The sensor responses to ethyl alcohol were modeled based on experimentally acquired sensor voltage vs. odor concentration data. A sensor array was exposed to specific amounts of ethyl alcohol and the voltage responses were recorded with a LabView GUI. Responses were for concentrations of 1, 2, 3, 5, 10 drops in a neutral chamber volume of 14,400 drops (739.34 mL) at sensor heater voltages of 3 and 5 volts. The variance in the response was also modeled.



Sensor Response Vs. Concentration

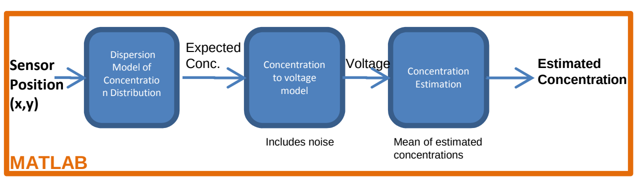


Steps in Odor Data Collection

1,2,3,5 or 10 drops of alcohol are dripped onto a piece of paper inside the odor chamber. This chamber exposes the sensors to the odor in an isolated environment. It is then covered and the LabView program collects sensor data. Each run lasts 2 minutes and limits the amount of time the heater is on. This expedites data collection and prevents sensor overheating. Sensor data was recorded 5 times for each concentration at heater voltages of 3 volts and 5 volts. The voltage responses were averaged and plotted along with the standard deviation. The standard deviation models the noise in the system. The noise may be due to sensor output or sensor input.

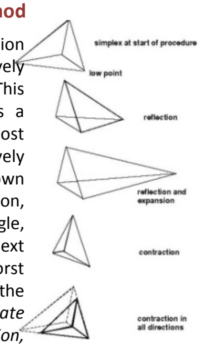
II. Concentration Estimation Simulation

We simulate the performance of our method by implementing a MATLAB program that takes in an initial sensor position, x_0, and estimates the concentration at that position. It assumes that odor concentration disperses in a simple Gaussian fashion [1]. This concentration is then inputted into our experimentally modeled concentration vs. voltage relationships, (from Part I.) including noise, to output a voltage. Using this voltage, the estimated concentration is then found by back-solving the voltage model.



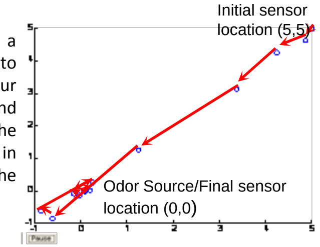
III. Convergence Using the Nelder-Mead Method

The Nelder-Mead method uses the concentration estimation algorithm (from Part II.) and iteratively moves the robot towards the odor source. This method, also known as the amoeba method, is a nonlinear optimization technique [2]. Like most optimization techniques, this method iteratively converges to a locally minimal value of a known function from a given starting point. For each iteration, the Nelder-Mead method creates a simplex, or triangle, of test points. Each point is tested and the next iteration's simplex is updated to replace the worst point in the current simplex. For each iteration, the following actions take place: *1)Order 2)Calculate 3)Reflection*. One of the these actions *Expansion, Contraction, Reduction* takes place depending on the quality of the new/reflected test point.



Results

This diagram is the result of a simulation of our system converging to the odor source. It shows that if our sensors begin at position x_0=(5,5) and the odor source is at x_s=(0,0), the robot will move towards the source in an iterative fashion according to the Nelder-Mead method.



Discussion

The above simulation is not an accurate representation of what would happen if our system is actually implemented. For simplicity, we assume that odor dispersion follows a Gaussian model [1]; actual odor dispersion is more complicated. Secondly, there is significant variance in our model. The variance may be due to the sensors and accompanying circuitry or due to the inconsistency of source odor concentration in our experiments. If it is mostly due to the former, using a larger array of sensors may help decrease the variance. Also, using newer and more sensitive sensors may increase accuracy. We could also gather more experimental data to better model our sensor responses and administer the alcohol under more controlled circumstances. This would give up insight in to whether the noise was due to experimental inconsistencies or sensor properties.

Future Research

We hope to mount the sensors, along with their appropriate circuitry, onto a robotic platform. We want to test our concentration estimation algorithm and see if the Nelder-Mead method is appropriate for odor localization.

References

[1] Mathews, John H., and Kurtis K. Fink. *Numerical Methods Using MATLAB*. Print.

[2] Chastain, John P., and Francis J. Wolak. "Application of A Gaussian Plume Model of Odor Dispersion To Select A Site For Livestock Facilities." Web. http://www.kniaz.net/software/rosnm.aspx