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Active Sensing with Fabry-Perot Infrared Interferometers

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Abstract. In this article, we describe an active-sensing framework for infrared (IR) spectroscopy. The goal is to generate a sequence of wavelengths that best discriminates among chemicals. Unlike feature-selection strategies, the sequence is selected on-the-fly as the device acquires data. The framework models the problem as a Partially Observable Markov Decision Process (POMDP), which is solved by a greedy myopic algorithm. In previous work [1], we had applied this framework to temperature-modulated metal oxide sensor. Here, we adapt the framework to a tunable IR sensor based on Fabry-Perot interferometers (FPI). FPIs provide a low-cost alternative to traditional Fourier Transform Infrared Spectroscopy (FTIR), though at the expense of a narrower effective range and lower spectral resolution. Here, we first test whether the framework can scale up to large problems consisting 27 chemicals with 60 dimensions; our previous work on metal oxide sensors employed three chemicals and 7 dimensions. For this purpose, FPI spectra are simulated from FTIR. Then we validate the framework experimentally on 3 chemicals using a prototype instrument based on FPIs. These preliminary results are encouraging and indicate that the framework is able to solve classification problems of reasonable size.

Keywords: Fabry-Perot Filter, Infrared Spectroscopy, Active Sensing

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METHODS AND RESULTS

For simulation, we chose 27 chemicals with absorption peaks in the range of the FPI (3-4.3 μ m). Simulated FPI responses were obtained from FTIR spectra in the NIST Webbook [2]. FTIR data was down-sampled to 60 wavenumbers using linear interpolation, and then low-pass filtered to simulate the spectral resolution of the FPI. This resulted in 60 evenly-distributed wavelengths for each chemical. Correspondingly, there are $|A| = 60$ actions, each corresponding to a different wavelength. The POMDP seeks to find a minimum sequence of actions that provides good discrimination between chemicals; this balance is achieved through two sets of parameters: the cost C_{a_i} associated with taking sensing action a_i (e.g., some sensing actions may require more energy), and the cost C_{uv} of misclassifying sample from class u as belonging to class v . For the simulations here, we assumed constant sensing costs $C_{a_i} = C_a$, and a zero-one loss function for misclassification costs: $C_{uv} = 1$ if $u \neq v$; $C_{uv} = 0$ if $u = v$. To test the relative impact of sensing costs, we adjusted C_a while keeping C_{uv} fixed. Shown in FIGURE 1, when the sensing costs are low, the program produces longer sequences and, as a result, achieves higher classification rates.

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Next, we evaluated the approach on an integrated FPI detector (InfraTec LFP-3041L). The resolving power of this device is $\lambda/\Delta\lambda=60$ within an effective a range of $\lambda=1.3\mu\text{m}$ (3-4.3 μm). The detector, IR source and optical path were mounted on an optomechanic system to allow careful alignment of each component (FIGURE 2 (a)). Transmittance spectra were obtained by dividing the sensor response by reference gas (ambient air) response. FIGURE 2 (b) shows the transmittance for acetone, isopropyl alcohol, and propanol. When the active sensing framework is applied to this dataset (a total of 60 wavelengths), the system is able to correctly identify the chemicals with an average of two measurements. As an example, in the presence of acetone, the POMDP selects the sequence of actions 3.44 μm and 3.36 μm ; see FIGURE 2 (b).

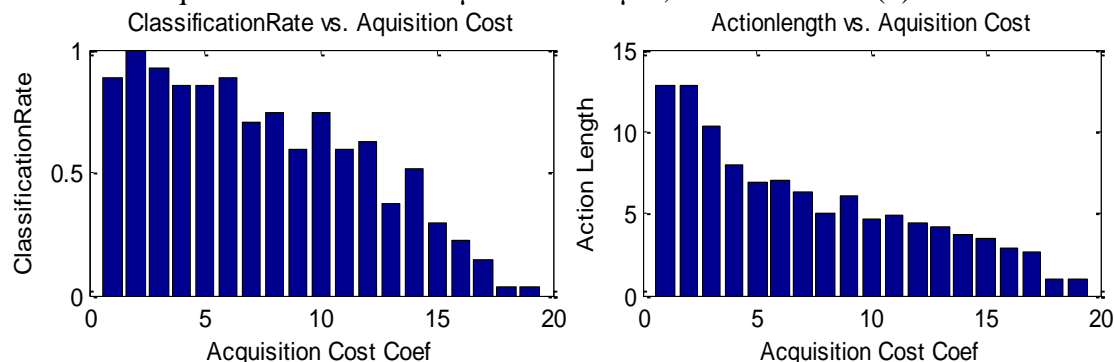


FIGURE 1. (a) As simulation shows, while sensing costs increase, the generated sequence becomes shorter, (b) and the overall classification rate drops.

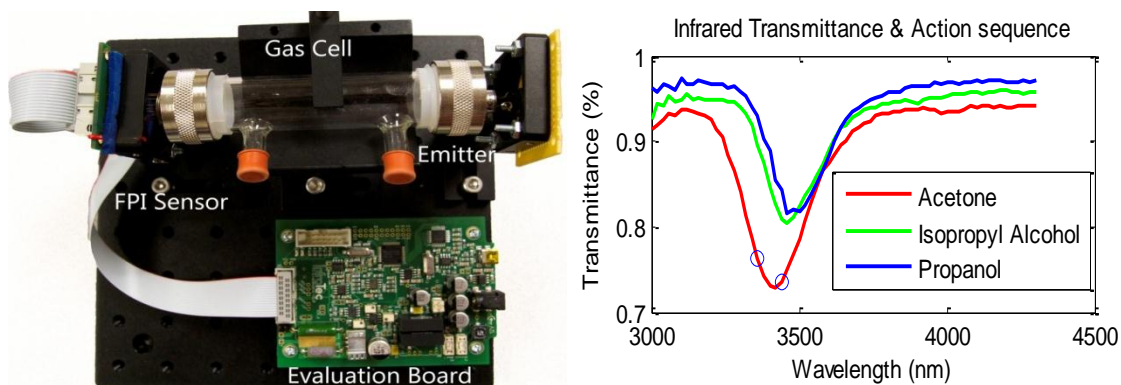


FIGURE 2. (a) Prototype tunable infrared spectroscope (b) Transmittance spectra for acetone, Isopropyl Alcohol, and propanol. In the case of acetone, only two measurements were necessary for active sensing algorithm to identify the sample.

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