Improved Gas Detection Algorithm for FTIR-Based Hyperspectral Imaging System Using Normalized Matched Filter

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***Abstract*— A Hyperspectral Imaging System (HIS) can be used to detect a harmful gaseous plume from a long distance. Each pixel in the HIS can obtain a radiance spectrum. The hazardous gaseous plume has a unique pattern expressed in the radiance spectrum. A Normalized Matched Filter (NMF) is an algorithm extracting the absorption pattern from the radiance spectrum. We propose to apply a NMF algorithm into the brightness temperature spectrum in order to detect chemical warfare agents (CWAs). Simulation results demonstrate that the proposed algorithm significantly improves the detection performance.**

Keywords- Gas detection, Hyperspectral Image.

I. Introduction

Passive remote sensing using a Hyperspectral Imaging System (HIS) based on Fourier Transform InfraRed (FTIR) spectrometers is known as a key technology to detect hazardous gases in the atmosphere. The HIS, which consists of an FTIR spectrometer and a focal plane array detector, can provide not only spectral information but also spatial information. Each pixel in the HIS can obtain the radiance spectrum for the corresponding field of view (FOV) from a standoff distance.

Generally, the hazardous gaseous plume present in the atmosphere has a specific radiance spectrum pattern. The spectrum measured by the HIS is a combined spectrum of the gaseous plume and the background. The presence of the gaseous plume can be determined by extracting the absorption pattern of the target gas from the radiance spectrum measured by the HIS instrument [1]. A Normalized Matched Filter (NMF) can be used to extract the absorption pattern from the measured radiance spectrum and detecting the gaseous plume [2].

In this paper, we propose an algorithm that transforms the measured radiance spectrum into brightness temperature and adapts the NMF to the brightness temperature spectrum. Since in the brightness temperature domain, the background spectrum is constant, it is easier to extract the target pattern.

The rest of this paper is organized as follows. Section II describes transforming a radiance spectrum into a brightness temperature spectrum. Section III addresses the proposed normalized matched filter. Section IV presents the experimental results. The acknowledgement and conclusions close the article.

II. Brightness Temperature Spectrum

The measured spectrum for each pixel obtained from the HIS equipment is the radiance spectrum. The envelopes of radiance spectra are different according to the temperature of the gaseous plume and the background. The radiance spectrum generally does not have constant baseline. It is difficult to extract the pattern of gases from the radiance spectrum by these reasons. On the other hand, the brightness temperature spectrum of the background is nearly constant in the range of 925 – 1440 cm^{-1} where most Chemical Warfare Agents absorb [1]. For these reasons, we transform the radiance spectrum into the brightness temperature spectrum $T_{meas}(v)$ using Plank's function, as follows:

$$T_{meas}(v) = \frac{hcv}{\ln\left(\frac{2hc^2v^3}{L_{meas}(v)}+1\right)k}, \quad (1)$$

where h is Plank's constant, c is the speed of light, k is Boltzmann's constant, v is the wavenumber, and $L_{meas}(v)$ is the measured spectral radiance for the wavenumber.

III. Normalized Matched Filter

Let H_0 and H_1 denote the absence and presence of a target gas, respectively. The measured brightness temperature spectrum $\mathbf{x}$ is described as the following two hypotheses:

$$\mathbf{x} = \begin{cases} \mathbf{v}, & H_0, \\ \mathbf{s}g + \mathbf{v}, & H_1, \end{cases} \quad (2)$$

where $\mathbf{s}$ is the target gaseous absorption spectrum, $\mathbf{v}$ is the background clutter, i.e., $\mathbf{v} \sim N(\mathbf{m}_b, \mathbf{C}_b)$ and g is the amount of a gas. $\mathbf{m}_b$ and $\mathbf{C}_b$ are denoted as mean and covariance of background clutter. Using the Generalized

Likelihood Ratio Test (GLRT) approach [2], we obtain the NMF detector

$$T_{NMF} = \frac{\left(\tilde{\mathbf{s}}^T \tilde{\mathbf{x}}\right)^2}{\left(\tilde{\mathbf{s}}^T \tilde{\mathbf{s}}\right)\left(\tilde{\mathbf{x}}^T \tilde{\mathbf{x}}\right)} \underset{H_1}{\overset{H_0}{\gtrless}} \lambda \tag{3}$$

where $\tilde{\mathbf{s}} = \mathbf{C}_b^{-1/2}(\mathbf{s} - \mathbf{m}_b)$ and $\tilde{\mathbf{x}} = \mathbf{C}_b^{-1/2}\left(\mathbf{x} - \mathbf{m}_b\right)$. If T_{NMF} is larger than a detection threshold λ, the decision is H_1, otherwise it is H_0.

IV. SIMULATION RESULT

The data used for the experiments were obtained with a FTIR passive remote-sensing equipment, HI-90 by Bruker Optics. It can provide a datacube with a spectral resolution of 4 cm^{-1} in the spectral range of 900 ~ 1260 cm^{-1} and a spatial resolution of 128×128 pixels at a high frame rate.

Figure 1 shows radiance spectra (a) and the brightness temperature spectra (b) of each pixel of the hyperspectral image at the background and a sulfur hexafluoride (SF_6) gaseous plume filled in a gas cell. The figure shows that a particular absorption pattern of SF_6 at a spectral range near 950 cm^{-1}. the absorption pattern appears more prominently in the brightness temperature spectrum than in the radiance spectrum.

We compare our proposed algorithm with the conventional gas detection algorithm, which uses the NMF to the radiance spectrum. Figure 2 depicts the Receiver Operating Characteristic (ROC) curve, which presents the detection performance of the algorithm. The proposed algorithm has better performance than the conventional algorithm because the brightness temperature spectrum is better than the radiance spectrum for finding the absorption pattern of a gas by applying the NMF.

Figure 3 shows the detection results of the proposed algorithm and the conventional algorithm. We set the detection thresholds λ of two algorithms so that the probability of false alarm P_{fa} is 0.005.

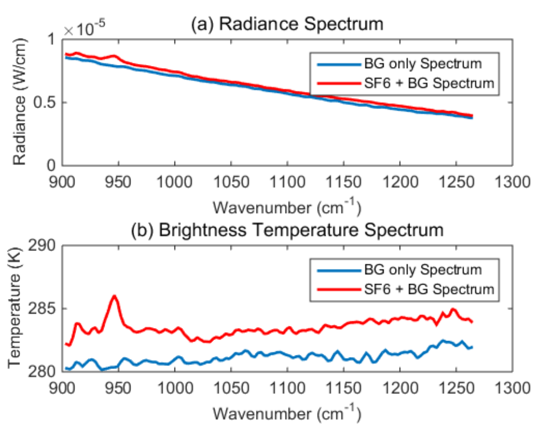

Figure 1. Radiance spectra (a) and brightness temperature spectra (b) of a gas plume and the background

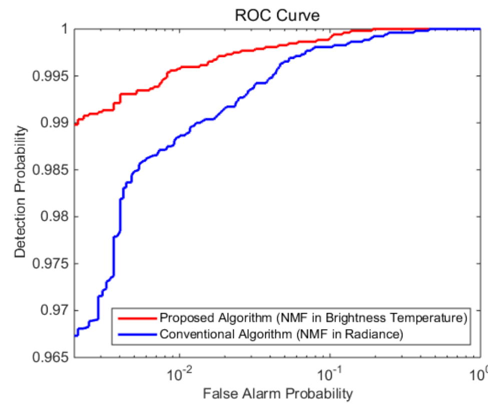

Figure 2. ROC curve of proposed algorithm and conventional algorithm

In case that the proposed algorithm detects gas at the pixel, the green color is mapped. In case that the both algorithms detect gas at the pixel, it is expressed in red color. We can see that the NMF in the brightness temperature spectrum is better than the NMF in the radiance spectrum.

V. CONCLUSIONS

We proposed a hazardous-gaseous plume detection algorithm for the FTIR-based HIS. First, the measured radiance spectra are transformed into the brightness temperature spectrum using Plank's function. Gas detection is performed by applying the NMF to the brightness temperature spectrum. The proposed algorithm outperforms the existing algorithm which applies the NMF to the radiance spectrum.

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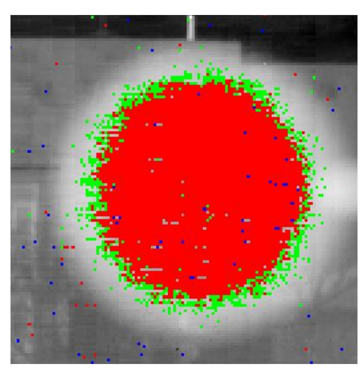

Figure 3. Detection results of the proposed algorithm