Paweł RUTKOWSKI, Mariusz KASTEK, Henryk Madura, Tomasz SOSNOWSKI
MILITARY UNIVERSITY OF TECHNOLOGY, INSTITUTE OF OPTOELECTRONICS
2 Gen. S. Kaliskiego St., 00-908 Warsaw, Poland

Multi-function analysis of hyperspectral data

Abstract

Paper is about a new method of detection and identification of gases using an infrared imaging Fourier-transform spectrometer. It's focused on using a multi-function toolbox to get the best results possible. New interface introduces a chain of operations that allows the user to set a sequence of functions for the data analysis. It's focused on combining methods of detection like using a sequence of filters for gases detections. Also new functions can be added by any user.

Keywords: hyperspectral detection, infrared imaging, spectroradiometer.

1. Introduction

Industry has a big need for a remote detection of chemical substances. That include purposes of military use, monitoring or diagnostics. Many products have been made, providing various degree of detection methods and chemical compound identification.

Infrared devices used in chemical substances detections are usually engineered to have a spectral resolution matched to the absorption band of compounds that are to be detected. Such devices can be separated into two different categories. First are infrared cameras equipped with a filter designed to the required spectral resolution. Second are based on the Fourier spectroscopy (Fourier Transform Infrared Spectroscopy FTIR), but they are not common due to the big cost.

Nonetheless, FTIR's are the best instruments to provide a reliable estimates of quantities data. They were first introduced as imaging Fourier-transform spectrometer (IFTS) by Spisz [1]. Many scientists use the non-imaging FTS to remotely detect gas fumes [2] or optically thin plumes [3]. Some use different approach performing optical subtraction [4] or maximizing the use of a priori information.

The paper introduces a new interface to the IFTS plumes detection. First it explains the process of hyperspectral data acquisition to establish a scientific background. Later the work of the interface is explained. It's core, the function chain, and also available options. At the end of the paper, experimental results are presented to demonstrate the possibilities of the new software. Methods of hyperspectral data obtained using Telops HyperCam were described with details in previous references [3, 5, 6], this article focuses on data analysis and visualization.

2. Imaging Fourier Transform Spectroradiometer

Telops Inc. imaging Fourier-transform spectrometer (IFTS) was chosen for the experiment. It's a Hyper-Cam LWIR using 320×256 pixel Mercury Cadmium Telluride (MCT) focal plane arrays (FPA) with a 6º × 5º FOV. Stirling cooling system provides low noise during image acquisition. The IFTS gather spectral information by using FTIR (Fourier Transform Infrared Radiometry), which is well known method based on interference technique dedicated to gas spectroscopy. By using Michelson interferometer to mix an incoming signal with itself at several discrete time delays operator achieves result as a form of time domain waveform, named interferogram, which is related to power spectrum of the scene through the Fourier transformation. Interferogram for each single pixels of the image are then created by imaging the interefometer's output onto focal plane array and gathering data for each discrete time deferment. FTIR sensor has great advantage. High resolution and the platform motion is not creating any misalignment of different color images. However, there is a disadvantage too. Unit produces a slower frame rate compared to filter based systems. This is due to fact that twice as many points are taken for the identical number of spectral points. Luckily FTIR LWIR sensor offers sufficient frame rate for tracking gases in the atmosphere [6].

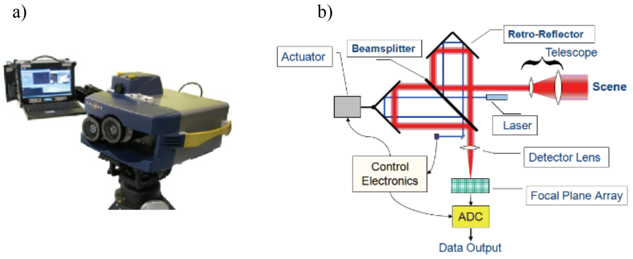

Fig. 1. a) The infrared imaging Fourier-transform spectrometer (IFTS) HyperCam, b) block diagram of imaging Fourier-transform spectroradiometer

Data of the collected measurement can be achieved within the range of 0.25 cm^{-1} to 150 cm^{-1} of the spectral resolution or between 830 cm^{-1} (12 µm) and 1290 cm^{-1} (7.75 µm) @ frame rate of 0.2 Hz. The data from visible camera boresighted with IR sensor was taken additionally to the IR data collected.

Fig. 1. presents image of the Hyper-CAM LWIR. The unit is supervised by industrial computer. Data is collected to RAID drive to provide data integrity [7].

3. Hyperspectral data analysis method

New software purpose is to let the user choose a function or a sequence of functions for his hyperspectral analysis to make looking for and identifying chemical substances as easy as possible. The key element, of multi-function analysis is the new interface, designed to make calculations and visualizations along the way, as presented in Fig 2. Program has been written in the Matlab software.

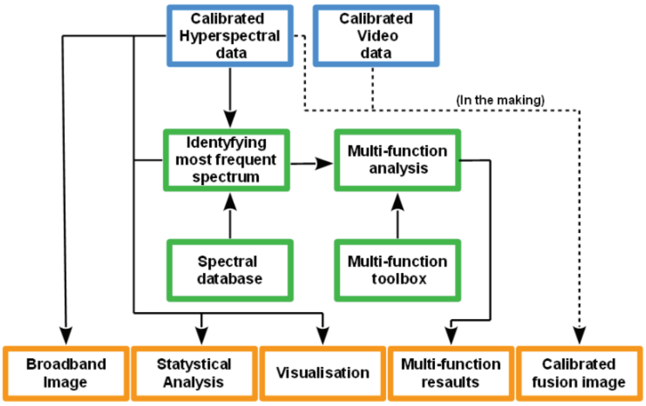

Fig. 2. Box diagram of multi-function analysis program

By stocking all of the radiation from one measurement into one image, a broadband image is created. A radiation map that can be exported and with more calculations, changed into a thermogram. Statistical analysis of the data can be made, e.g. calculating minimum, maximum or standard deviation of the image.

In the next step, the most frequent substances in the data are identified. Principal components transform (PCT) function is used for that purpose. PCT is a feature space transformation designed to remove the high spectral redundancy in multispectral and hyperspectral image bands with high correlation due to material spectral correlation, topography and sensor band overlap. Few of the most common substances detected are visualized along with their signatures.

Most crucial element of the interface is the function chain, presented in a Fig. 3. At first program reads function files. They were not implemented into the program so that the user can choose functions that he wants in his menu or even write new ones! Each function is placed alphabetically in the programs menu for the user to choose from. Calculations can be made in any order. After creating such a function chain and adding parameters (like a chemical signature to look for) the calculations can proceed.

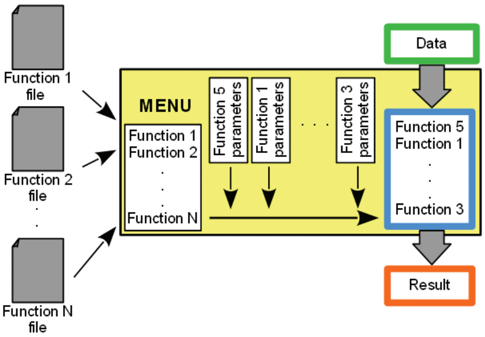

Fig. 3. Function chain schematic

Functions are treated as objects and program is a compilator of these objects. Each object has a unified data entry and exit so that every element is compatible with another, even if the numbers of parameters are different. Some functions need a chemical signature as a reference to what they are supposed to look for. Program treats signature files as a function parameter so that the compatibility is maintained. Experimental data are passed through the function chain. If one of the functions modify the data, the next function will receive the changed data, not the original data. In other words, functions don't read the original data but they pass it along and modify if necessary. If the first function is a filter, then every other function will receive filtered data.

Few functions are available in the current software version. They come from the Free Software Foundation and are easily downloadable. The once included in the program are:

- Adaptive cosin/coherent estimator (ACE) algorithm This is a simple extension of the Matched Filter where we compute the filters value, and then normalize by the length of $\widetilde{x}$.
- Adaptive matched subspace detector (AMSD) algorithm. It works through matched subspace detectors, they generalize matched filter detectors by allowing the signal to lie in a multidimensional subspace.
- Constrained energy minimization (CEM). This function uses a finite impulse response (FIR) filter to pass through the desired target while minimizing its output energy resulting from a background other than the desired targets.
- Uncostrained least squares abudance estimation (UCLS). When all the endmember information (i.e., the number of endmembers and their spectral signatures) are known, abundances can be estimated via the least squares solution. If the two abundance constraints are ignored, abundance estimation is to find α such that the pixel reconstruction error is minimized.

All of the calculations are presented at the same time in different windows so that they can be compared. Not only with themselves but also with the previous results like density map.

If our goal is to detect small amounts of gas plumes, they may not be found by the PCT transform as it is designed to look for the most frequent sources. It is just one of the tools at programs disposal. If the looked-for signature is known to the researcher then the functions mentioned above will find it in the data. Also limiting the entry data to the region of interest (where out object should be) will make it easier for the PCT transform to locate the gas as one of the most popular substances.

A new option will be added by making a calibration of the Hypercam detector and the CCD camera data, data can be transferred between both detectors. Such a method will make identifying a chemical substance source even easier by showing the regions of interest on a visual photo. Calibration will be possible after calculating intrinsic parameters and geometrical relationship between the detectors. Such calibrated data will open doors to new possibilities like a fusion image between a visual photo and a hyper data or placing data on an experiment object.

4. Example data

The working system was applied in an experiment. Data presented in this section were acquired from a plane flying over an urbanized area. Experiments photo shows mainly ground, roads and buildings.

Function chain in the program consisted only of adaptive cosin/coherent estimator algorithm (ACE). Quartz was the substance chosen to be looked for. It's spectrum with a very specific peak around 8.6 μm has been shown in Fig 4. It is the window from the program.

Fig. 4. Theoretical quartz signature shown by the program

Program was set to look for 5 most common spectral characteristics in the image. The analysis has been made for the wavelengths between 8 and 11 μm. Quartz has been identified as a third most frequent substance in the data. Fig. 5 presents its density map in the image, along with the spectrum that program identified. Very characteristic peak in the area of 8.6 μm (Fig. 4) is clearly visible in Fig. 5b as a result of analysis. Fig 5b is a spectral characteristic graph for one of the pixels.

In the next step, a fusion image has been created (Fig. 6d) by displaying a density map data (Fig. 6b) that were over a specific (user-chosen) threshold onto a broadband image (Fig. 6a). Black and white color scale has been chosen for the broadband image so that the overlapping density data is clear.

All the results are generated in a user-friendly interface as presented in Fig. 7. With a few simple clicks, all the results are created automatically. Because there are many different windows generated at the same, they do not appear automatically. The display section is manually operated by the researcher.

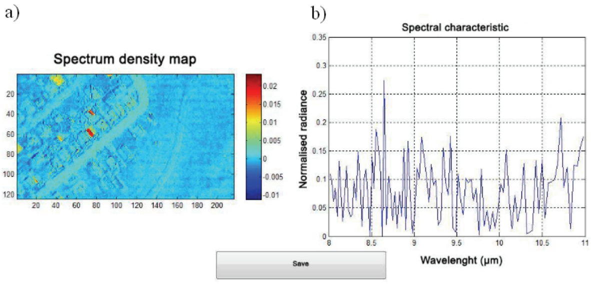

Fig. 5. Window form the program showing a) density map, and b) corresponding spectral characteristic. User has identified the characteristic as the quartz signature

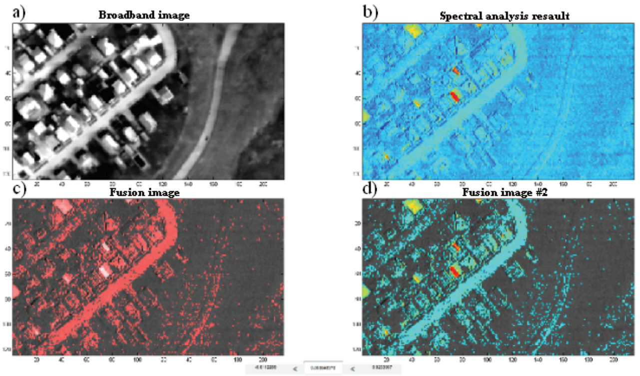

Fig. 6. a) Broadband image, b) Quartz density map, c), d) fusions of broadband image and quartz density map (with different color scales)

After the data analysis is done, project can be saved with all chosen parameters. When new data will come along, project can be loaded so that the analysis will be recurrent. Results can be easily compared as the calculations were identical and parameters did not change.

ACE
ACE

data
Typical_HSI_Airborne1_VLW.sc.mat

wavelenghts frequencies
Wavelength_micro_Typical_HSI_Airborne1_VLW.sc.mat

number of spectrums to look for
5

range
from 8 to 11

☑ entry data
☑ data analysis
☑ looked for spectrums
☑ lista operations
☑ statistic

Fig. 7. Interface presentation

5. Conclusions

In the paper a new method of hyperspectral data analysis have been presented, combining many functions in order to get the best results possible.

Multi-function analysis gives new advantages in the chemical signature detection process. Even low amounts of gas can be detected, identified and analyzed.

It has been designed to be the ultimate analysis tool for any hyperspectral researcher. With the possibility of writing new functions and editing parameters the possibilities are endless. Each calculation (like a filter) can be placed in a specific order in the events chain to get the best results.

Analyzed data are visualized in images, like broadband image, spectrum density map, fusion image and other, that makes presenting data much easier. In the future software will be significantly upgraded and new options added. Also the multi-function analysis will be put to a test with gas plumes detection.

6. References

[1] Harig R., Matz G.: Toxic Cloud Imaging by Infrared Spectrometry: A Scanning FTIR System for Identification and Visualization. Field Analytical Chemistry and Technology, 5(1-2), 75-90, (2001).

[2] Griffin M. K., Kerekes J. P., Farrar K. E., Burke H.-H. K.: Characterization of Gaseous Effluents from Modeling of LWIR Hyperspectral Measurements, Proc. of SPIE, 4381, 360-369, (2001).

[3] Tremblay P., Savary S., Rolland M., Villemaire A., Chamberland M., Farley V.: Standoff gas identification and quantification from turbulent stack plumes with an imaging Fourier-transform spectrometer. Proc. of SPIE, 7673, 76730H, (2010).

[4] Spisz T.S., Murphy P.K., Carter C.C., Carr A.K., Vallières A., Chamberland M.: Field test results of standoff chemical detection using the FIRST. Proc. of SPIE, 6554, 655408, (2007).

[5] Farley V., Chamberland M., Lagueux P. et all: Vallières A., Villemaire A., Giroux J.: Chemical agent detection and identification with a hy-perspectral imaging infrared sensor. Proc. SPIE, 6661,66610L, 2007.

[6] Kastek M., Piątkowski T., Trzaskawka P.: Infrared imaging Fourier transform spectrometer as the stand–off gas detection systems, Metrol. and Measurement Systems, Vol. XVIII, No. 4, pp. 607-620, (2011).

[7] Kastek M., Piątkowski T., Dulski R., Chamberland M., Lagueux P., Farley V.: Hyperspectral Imaging Infrared Sensor Used for Chemical Agent Detection and Identification. Sym. on Phot. and Opto. SOPO 2012, art. no. 6270545 (2012).

Received: 10.10.2016 *Paper reviewed* *Accepted: 05.01.2017*

Paweł RUTKOWSKI, MSc

He received MSc degree in physics specialization optoelectronics from Warsaw University of Technology. Currently he is working on a PhD degree in Department of Infrared Technology and Thermovision at Institute of Optoelectronics MUT. His work involves developing new algorithms analysis of multispectral and hyperspectral data for detection objects in short and long infrared.

e-mail: pawel.rutkowski@wat.edu.pl

Mariusz KASTEK, PhD

He received MSc and PhD degree in electronics specialization optoelectronics from Military University of Technology (MUT). He works on many projects supporting by Polish Ministry of Science focus on developing infrared cameras. He works on developing new algorithms analysis of multispectral and hyperspectral data for detection objects in short and long infrared. Presently he is working as an assistant professor in Department of Infrared Technology and Thermovision at Institute of Optoelectronics MUT.

e-mail: mariusz.kastek@wat.edu.pl

Prof. Henryk MADURA

A specialist in the field of optoelectronics, infrared and thermal imaging technology. He graduated from the Faculty of Electronics WAT (1976). PhD degree received in 1983, a post-doctoral degree in 1999. In 1991-1997 Deputy Commander of the Institute of Optoelectronics. He has published over 270 articles and conference papers. Author and co-author of 19 deployments and 14 patents. Since 2000 Professor of the Military Technical Academy. Since, 2015 full professor.

e-mail: henryk.madura@wat.edu.pl

Tomasz SOSNOWSKI, PhD

Tomasz Sosnowski retrieved master's degree in Electronics at Military University of Technology in 1993. Since 1996 is employed in Military University of Technology. Received PhD degree in 2003 at Military University of Technology. His technical research is mainly about digital signal analysis, thermal image processing and application of programmable digital devices and microprocessors in infrared technology for signal processing. He is an author of over 50 publications.

e-mail: tomasz.sosnowski@wat.edu.pl