APPLICATION NOTE

TELOPS

Remote Quantification of Greenhouse Gas Emissions from a Power Plant

Abstract

New regulations about greenhouse gas emissions force governmental and environmental organizations around the world to look for efficient monitoring tools in order to manage their contribution to global warming. Monitoring and, above all, quantification of the amount of released carbon dioxide (CO_2) and other greenhouse gases in the environment from industries may present a challenge due to the technical difficulties associated with sampling or site access. The Telops Hyper-Cam, an infrared hyperspectral imager, offers the possibility to detect, identify and quantify greenhouse gases generated by industrial facilities. This paper demonstrates how standofff quantification of greenhouse gas emissions can be accurately achieved using a combination of high resolution hyperspectral imaging and signal processing algorithms.

Figure 1: Fossil fuel power station

Introduction

The increasing presence of greenhouse gases such as carbon dioxide (CO_2) and nitrous oxide (N_2O) raise major concerns worldwide due to their potential effect on global warming. As a global environmental effort, most countries try to reduce their greenhouse gas emissions. In such context, the need for a monitoring tool capable of efficient identification and quantification of these emissions is mandatory.

The main entropic contribution of CO_2 into the atmosphere comes from power stations, such as fossil fuel power plants (Figure 1). Coal combustion, as for most fossil fuels, generates CO_2 and water vapor (H_2O) as well as nitrogen oxides (NO_x) and sulfur oxides (SO_x) as by-products. The overall amount of generated product depends on several parameters such as the fuel grade and the efficiency of the burning technology. Therefore, versatile tools are needed for the quantification of the gas emissions. Not all gas exhausts are equipped with continuous monitoring emission systems (CEMS). In addition, values reported by these devices are not always accurate due to interference in the complex gas mixture of smokestacks. Direct sampling of the emission gases may present itself as a complex and costly task as most of these structures are out of reach. Remote sensing presents a distinct advantage in this case as well as an excellent alternative verification method, since remote sensing techniques do not require any sampling system.

Fourier transform infrared spectroscopy (FTIR) is a sensitive technique used for the detection and identification of greenhouse gases such as CO_2 and N_2O. Telops Hyper-Cam is a remote sensor, based on FTIR technology, capable of both identification and quantification of various chemical species in complex gas mixtures. The usefulness of Telops Hyper-Cam sensor as a monitoring tool in industrial environment is illustrated in this paper, whereas monitoring of gas emissions from an operating fossil fuel power plant is successfully carried out.

Figure 2: The Telops Hyper-Cam

Experimental Information

The Telops Hyper-Cam

The Telops Hyper-Cam (Figure 2) is a lightweight and compact hyperspectral imaging instrument using Fourier Transfer Infrared (FTIR) technology. It provides a unique combination of spatial, spectral and temporal resolution for a complete characterization of the substances being monitored. Its high performance and efficiency as a standoff chemical agent detector has been proven through numerous field campaigns.

The Hyper-Cam Long-Wave features a Focal Plane Array (FPA) detector containing 320×256 pixels over a basic 6.4°×5.1° field of view. The spectral resolution is user-selectable between 0.25 and 150 cm^{-1} over the 8.0 to 11.8 μm spectral range. The Hyper-Cam offers a high sensitivity for each pixel of the scene under observation, and its lightweight makes it ideal for field operation.

The Hyper-Cam was designed from the ground up so the control and the data acquisition are specifically optimized. The sensor is capable of generating calibrated data (Fourier transformed and radiometrically calibrated) in real-time at the highest data rate available.

Remote Quantification

Benefiting from the rich amount of information provided by the Hyper-Cam, Telops developed a suite of gas identification and quantification algorithms suitable for distant smokestack emissions monitoring (Figure 3). Turbulence, induced by unsteady and/or uneven gas streams, as well as the fluctuating winds create artifacts which prevent straightforward quantification from hyperspectral images. Telops has developed quantification algorithms to overcome these scene variations, ensuring a valid calculation of the emissions by gas plumes.[1]

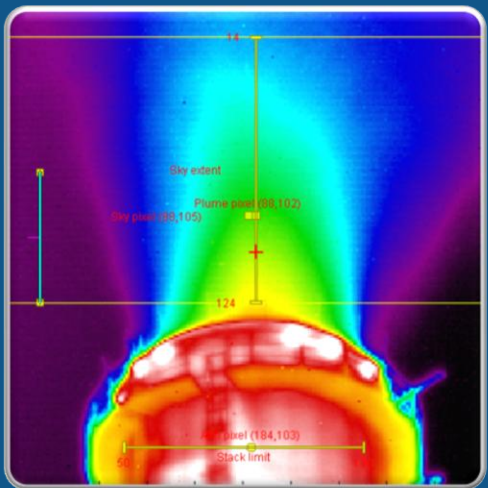

Figure 3: Broadband infrared image of a fossil fuel power station as measured by Telops Hyper-Cam

Results & Discussion

As an illustration of Telops Hyper-Cam capability to monitor greenhouse gas emissions from industrial power plants, CO_2 and H_2O mass flow rates were inferred from hyperspectral images recorded at a fossil fuel power station in Mumbai, India.

Figure 4: Visible image of fossil fuel power station chimney from the sensor recording location

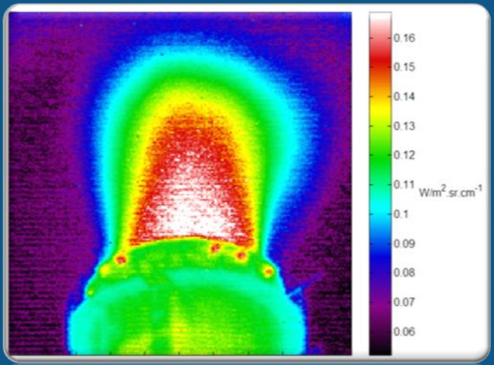

Figure 5: Hyperspectral image at 1054 cm^{-1} of fossil fuel power station chimney

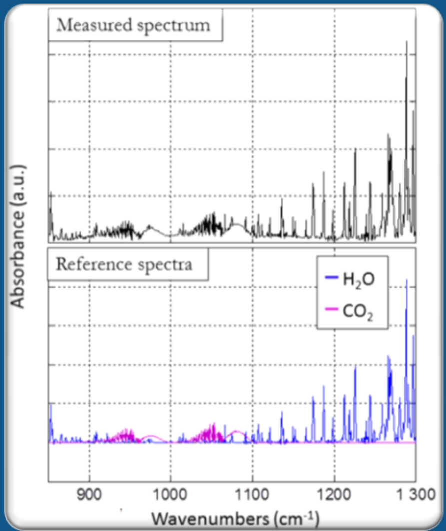

Figure 6: Measured spectrum of a typical pixel located in gas emissions (top) and reference spectra (bottom)

Hyperspectral Imaging

Figure 4 shows a visible image of the monitored power station chimney as seen from the sensor's recording point, located 200 meters away from the target. The corresponding hyperspectral image is shown in Figure 5. The spectrum of a typical pixel located above the chimney's exit is shown in Figure 6 (top). As it can be observed in Figure 6, the emission gases contains mostly H_2O and CO_2, a conclusion which can be drawn right away from a quick comparison with individual reference spectrum represented in Figure 6 (bottom). The current hyperspectral image was captured at 1054 cm^{-1}, a spectral region associated with CO_2. Contrast is therefore representative of the amount of CO_2 in the scene. In more complex situations, an automated compound library match, built into the gas algorithm suite developed by Telops, ensures complete identification of all components in gas emissions. Detection of chemical species is based on prior identification from their unique infrared signature. This unique feature illustrates the versatility of hyperspectral imaging as this procedure is applicable to a wide variety of systems including power stations using different technologies or types of fuel.

Density Profiles

For proper standoff gas quantification, several physical parameters must be taken into account. The distance from the target can be readily determined using a commercial rangefinder device. Other atmospheric parameters like the ambient temperature and the relative humidity index are readily recorded by internal sensors located in the Hyper-Cam itself. Combined with the hyperspectral data, the quantification algorithm is used to determine a transverse slice profile as shown in Figure 7. Density profiles are therefore determined for each identified component and the results are shown in Table 1.

	Column density	
	ppm.m	% error
H_2O	2 300 000	14
CO_2	2 400 000	11

Table 1: Column density

Detections of other gases such as NO_x and SO_x, usually associated with fossil fuel combustion, can also be achieved with the Long Wave version of the Hyper-Cam as these species are infrared active. N_2O is a well-known greenhouse gas while nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and sulfur trioxide (SO_3) are major contributors to the formation of acid rains. In the current situation, no significant amount of these gases have been detected in the coal power station gas emissions. However, the minimum column density detection limit of these species was estimated for this specific case and the results are shown in Table 2.

	Column density (ppm.m)
NO_2	≤ 19 000
N_2O	≤ 390
SO_2	≤ 860
SO_3	≤ 130 000

Table 2: Detection limits for NO_x and SO_x in the present situation

A complete picture of the different chemical species in gas emissions also allows one to judge the efficiency of an industrial process. The relatively low values reported in Table 2 suggest that combustion in the monitored chimney of the monitored power station is efficient and that the fuel contains relatively low amounts of sulfur and nitrogen.

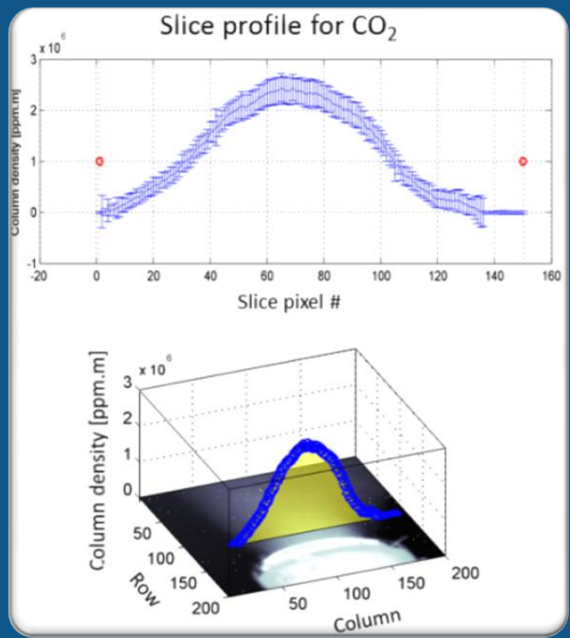

Figure 7: Density profile of CO_2 exiting the chimney

<u>Mass flow rates</u>

The simultaneous spatial and temporal resolution provided by Telops Hyper-Cam supplies unmatched information about dynamic phenomena like gas streams. Figure 8 shows the gas emission velocity map[2] of the monitored fossil fuel power station chimney. Each arrow represents the local velocity for selected pixels. An effective gas flow rate of 5.4 meter/second was determined in this case. The combination of column density and velocity map allows for the determination of an effective mass flow rate for each species as reported in Table 3.

	Mass flow rate (kg/s)
H_2O	39 ±6
CO_2	102 ±15

Table 3: Mass flow rate of gas emissions

Quantitative information about greenhouse gas emissions is then provided from a distant recording site in a safe and non-invasive way.

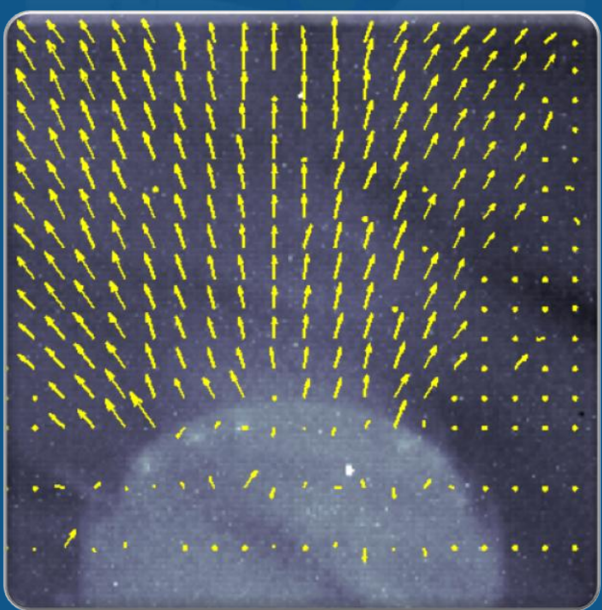

Figure 8: Velocity map of gas emissions from fossil fuel power station chimney

Conclusion

Remote quantification and identification of greenhouse gas emissions using the Telops Hyper-Cam offers unmatched benefits as it allows monitoring in a quick, safe, and non-invasive way. Real-time detection and identification in gas emissions also enables detection of numerous chemical species of interest. Hyperspectral images recorded and analyzed with processing tools developed by Telops demonstrate the strength of a Hyper-Cam system for industrial applications.

References

1 Pierre Tremblay et al., Standoff gas indentification and quantification from turbulent stack plumes with an imaging Fourier-transformed spectrometer, Proc. of SPIE, 7673, 76730H.

2 Patent pending.