Infrared Gas Imaging and Quantification Camera for LDAR Applications

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ABSTRACT

A new technology developed for remote imaging and quantification of gases has been developed using state-of-the-art diffractive optics and image processing algorithms. This technology was developed and patented by Pacific Advanced Technology for the US Defense Department[1]. The technology has been applied to remote gas leak imaging and quantification for the oil, gas, chemical and power industry. Gas Imaging Technology (GIT) has been granted the world wide exclusive license to market the Sherlock® for this purpose. This paper describes the Sherlock camera, theory of operations, and applications for environmental monitoring with major emphasis on LDAR applications.

The Sherlock has been field tested at numerous oil, gas, and chemical facilities in the US, Canada and the EU. Sherlock has demonstrated that it can see gaseous hydrocarbon leaks at rates as low as 5 ccm and measure concentrations of fugitive gases as low as a few thousand ppm. Recently tests performed in the Val d'Agri Oil Centre at Viggiano (PZ) Italy compared Sherlock's ability to quantify methane gas leaks with a conventional FID device. The Viggiano facility is one of the newest oil and gas plants of the Exploration & Production Division of ENI SpA. The quantification demonstration was supported by ENI Technology in Italy, with the assistance of Energy Laser Srl of Italy.

INTRODUCTION

The Sherlock is a small, hand held, battery operated imaging infrared spectrometer. It is Sherlock's spectral imaging capability that enables the measurement of gas concentrations. The computation uses standard Beer's Law calculation in the same manner as an FTIR instrument.

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[1] IMSS, Image Multi-spectral Sensing) US Patent 5,479,258 and 5,867,264, 6,680,778

The Sherlock infrared imaging spectrometer is unique is that it combines multiple functions in a single instrument; an infrared camera, computer, video data recording capability, data logger, imaging spectrometer and real time image processing are all included in a single hand-held battery operated instrument (shown in Figure 1). The Sherlock also includes standard I/O ports for Ethernet, USB, and Firewire and can be integrated into any local area network for remote operation, such as required by facilities for continuous monitoring of safety applications.

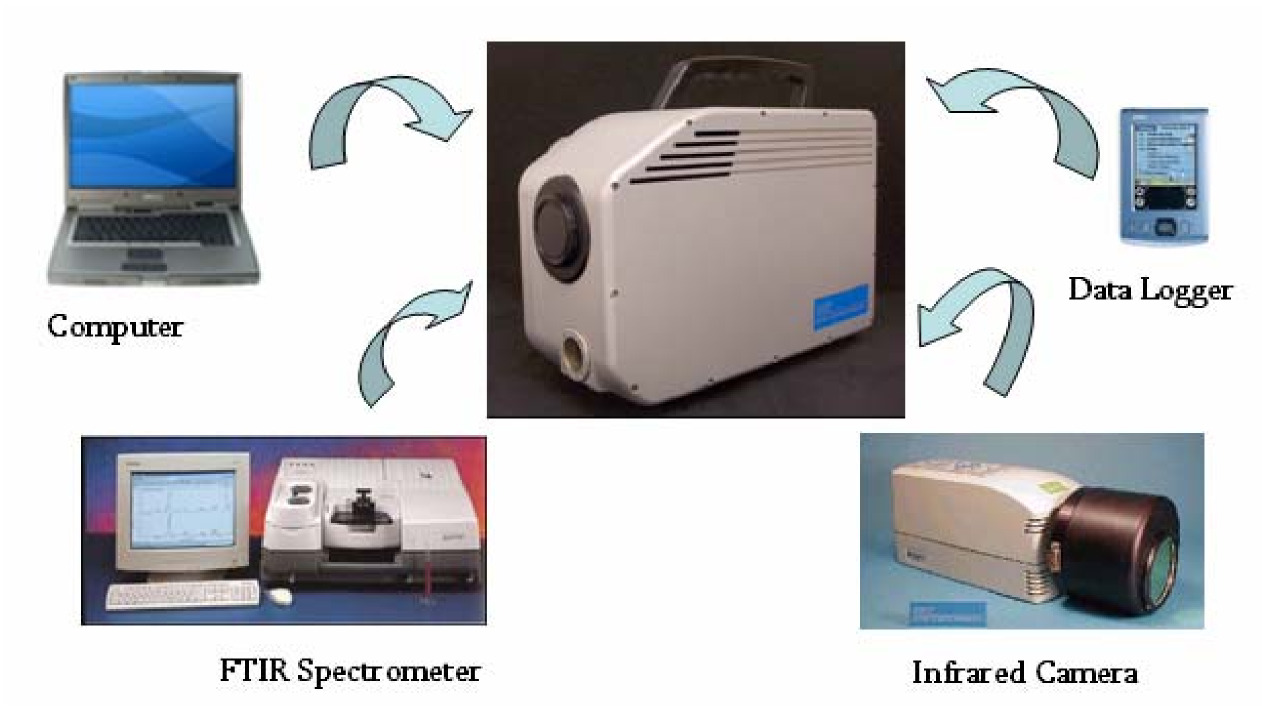


Figure 1. Block Diagram for the Sherlock Spectral Imaging Camera.

Using the embedded Power PC, data and video clips of the data received during a standard LDAR survey can be logged and stored in the Sherlock. After returning to the control room, data can be transferred over the Ethernet for further data analysis or achieving.

Sherlock's imaging spectrometer is based on the Image Multi-spectral Sensor (IMSS) technology developed and patented by Pacific Advanced Technology. Although originally developed as a gas leak detection camera for imaging various hydrocarbon leaks, the Sherlock imaging spectrometer may be used for many other applications as well. Such applications would include flare analysis, continuous surveillance, safety and emission monitoring.

This paper describes the fundamental principal behind IMSS and the operation of the Sherlock camera, including applications and examples of the Sherlock's performance for imaging and quantification of fugitive leaks.

THE IMSS PRINCIPLE

The Image Multi-Spectral Sensing (IMSS) was developed under a Small Business Innovative Research (SBIR) contract to the Air Force Space Division in 1992. Since that time numerous contracts from the US Navy, US Army, BMDO and Department of Energy (DoE) have supported the further development of the technology for use in instruments for defense related applications.

The IMSS is based on the principal of diffractive optics to disperse light. As such, it is a combination of a diffractive imaging spectrometer and an adaptive tunable filter. Using a single lens, IMSS performs both imaging and dispersion. The IMSS has a high throughput with a spectral resolution on the order of 6 wavenumbers. Its noise equivalent spectral response NESR has been measured at 6×10^{-7} w/cm^2- µm-sr.

The basic concept of IMSS is shown in Figure 2, comparing it with a monochrometer. A conventional monochrometer has an entrance and exit slit and a dispersive element such as a prism or grading. Light coming through the entrance slit is dispersed onto the plane of the exit slit and the exit slit is scanned through the dispersed light. The IMSS uses a diffractive optical element to disperse the light along the optical axis of an imaging system. The lens performs both imaging and dispersion functions. The infrared image is divided into narrow bands that are imaged sequentially in time. IMSS is a very high throughput system because it uses both the light gathering capability of the lens, and the dispersive power of a diffractive optic.

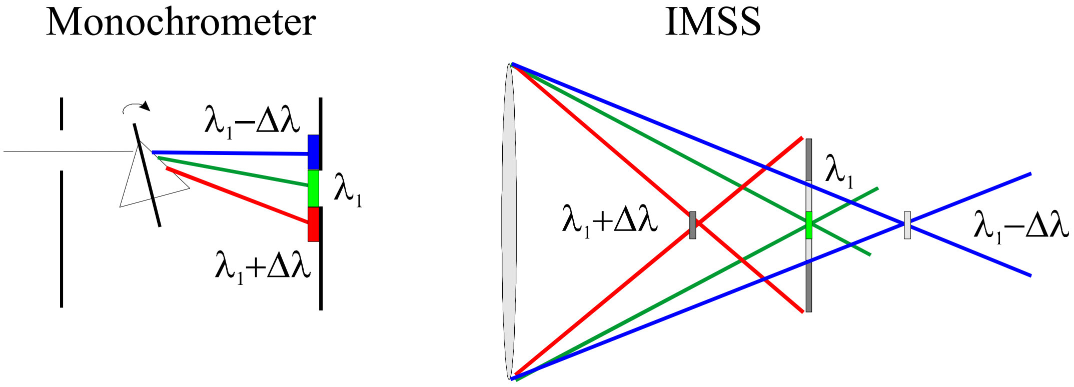


Figure 2. Basic principle of the IMSS.

IMSS operates in a staring mode, as opposed to spatial scanning as conventional dispersive imaging spectrometers require. This allows it to be portable and ideal for applications that require a small, light weight, robust instrument such as the Sherlock.

The band sequential images of the Sherlock camera are shown in Figure 3. Each frame of the camera is a spectral color and subsequent frames can be different colors if the IMSS lens is scanned along the optical axis. Or, subsequent frames can be the same color if the lens is not translated along the optical axis as shown in Figure 3. In this manner the Sherlock imaging spectrometer is adaptive and can collect only those spectral bands of interest, or can dwell at a single spectral band indefinitely. This adaptability makes Sherlock ideal for gas leak detection, as opposed to other spectral techniques that require the collection of all spectral bands such as conventional dispersive instruments and FTIR spectrometers. For gas leak detection certain spectral regions are of greater interest than others. As a result, there is no need to collect more than the necessary number of spectral bands, thus saving time, money, and necessary processing power.

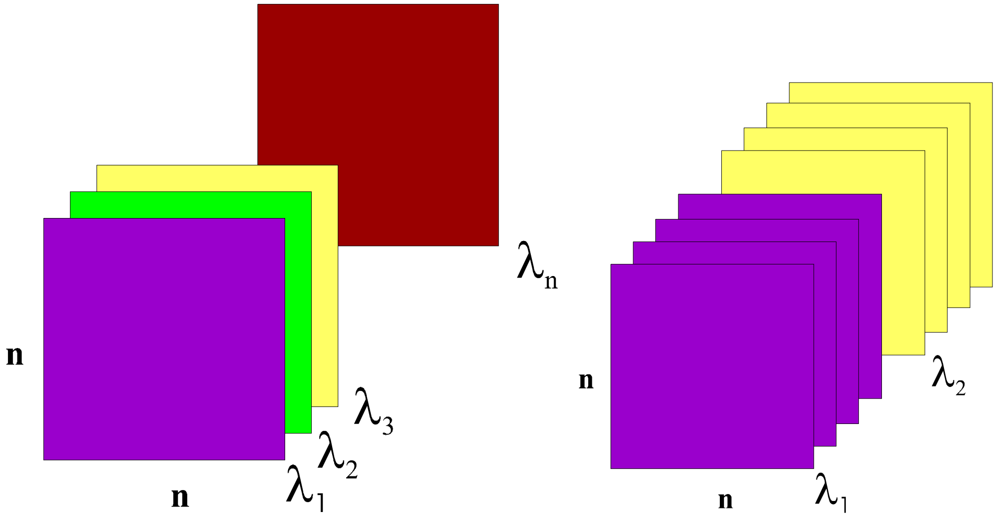


Figure 3. IMSS collects band sequential data which can be operated in a spectral scanning mode as shown on the left or collect only those spectral bands of interest as shown on the right.

APPLICATIONS FOR SHERLOCK

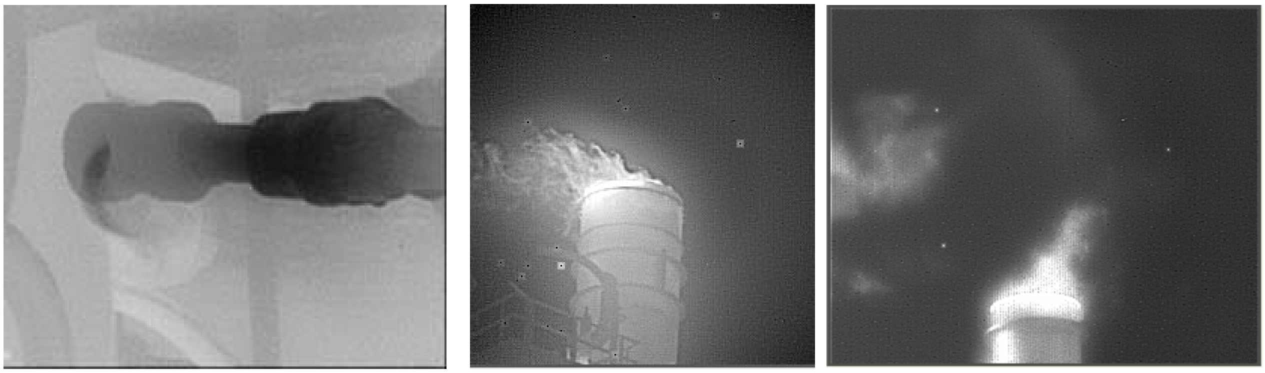
There are numerous applications for the Sherlock infrared spectral imaging camera for gas imaging and analysis in the oil, gas and chemical industry such as detecting and quantifying fugitive gas leaks, safety and risk mitigation, flare analysis monitoring, measuring emission rates from stacks and quantifying greenhouse gases such as methane, carbon dioxide and sulfur hexafluoride. The IMSS technology, the heart of Sherlock, has been demonstrated for many of these applications as presented in previous papers [1], [2], [3], [4] and [5].

Figure 4. Sherlock shown with an operator monitoring a process in a chemical processing plant.

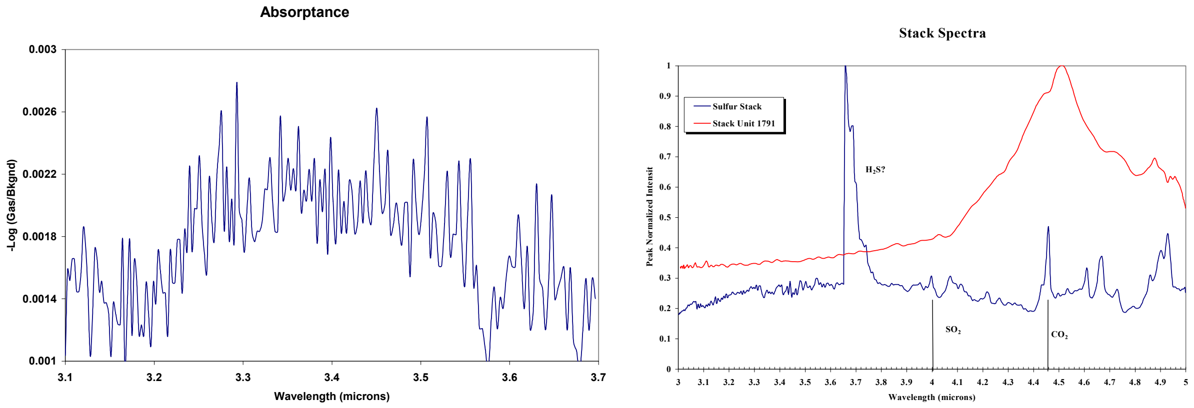
Sherlock is shown in Figure 4 monitoring fugitive leaks at a gas processing plant. Sherlock has been used at oil, gas and chemical processing plants in the US, Canada and Europe, and has been tested under various environmental conditions including very hot and humid conditions in Louisiana and Texas in the summer, cold and dry conditions in Colorado in the winter, very cold wet and foggy conditions in the Netherlands in the winter, and a damp and mild environment on the north east coast of England in the fall.

Under all of these conditions, Sherlock demonstrated the ability to detect and image gas leaks of various types: hydrocarbons, many different chemicals such as acetone, methyl-chloride, sulfur compounds, and greenhouse gases such as carbon dioxide, methane and sulfur hexafluoride.

Shown in Figure 5 are three infrared spectral images taken with the Sherlock at different plants. A small fugitive leak of isobutene is shown on the left, stack emissions in the center, and residual gases from an enclosed flare on the right. By selecting a pixel in the image, and monitoring it's intensity as a function of wavelength, a spectra of the gas can be measured. An example of spectra that Sherlock has colleted is also shown in Figure 6. From these, spectra species and quantification analysis can be performed.



Sherlock spectral images of fugitive emission, stack gases and enclosed flare residual gases.



a) b)

Figure 6. Spectra a) fugitive gas leak, b) an efficient burning stack as compared to a very inefficiently burning sulfur stack.

FIELD TRIALS AND QUANTIFICATION

Testing was performed at the Val d'Agri Oil Centre at Viggiano (PZ) Italy**.** This is one of the newest oil and gas plant of the Exploration & Production Division of the ENI SpA**.**

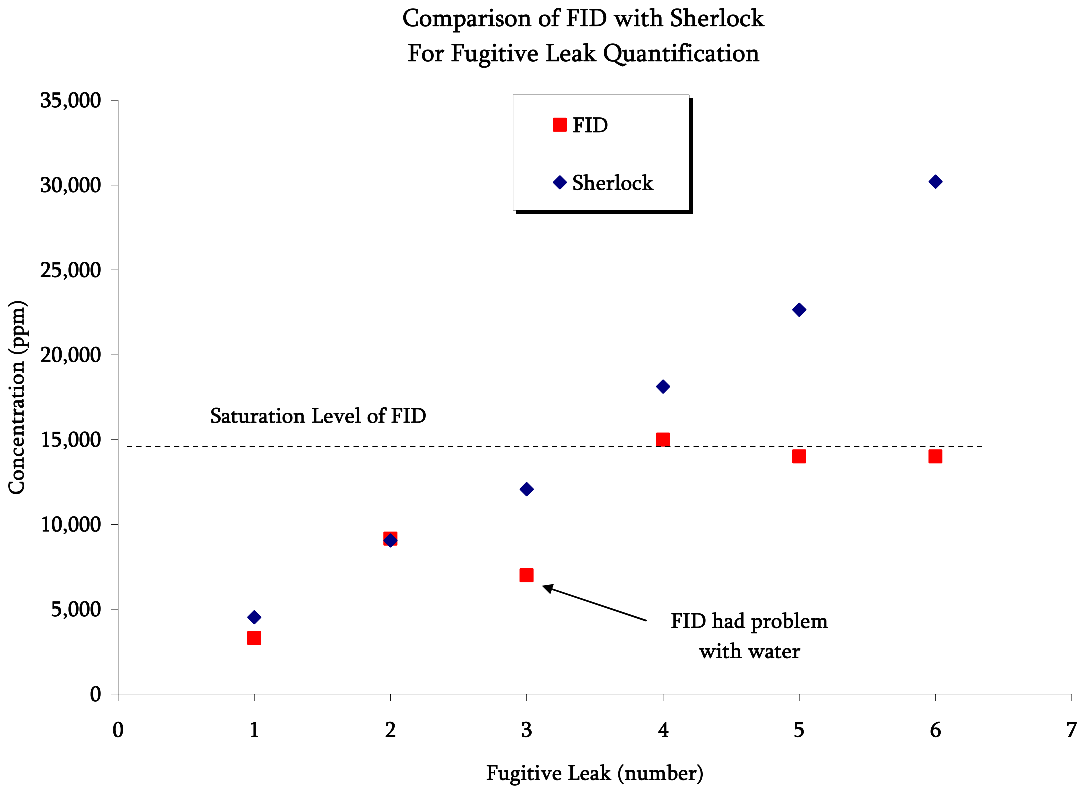
A portable flame ionization detector which is explosion proof (MicroFid PhotoVAC) and meets the safety requirement and the specifications included in the EPA method 21, was used for comparison purposes. Very few components were leaking (mainly valves and flanges) so not all potential leaking components as described in the EPA method could be tested in this field trial. The measured concentration values using the Sherlock as compared with the FID are shown in table 1.

Table 1. Comparison of concentration measurements as measured using the FID and the Sherlock camera..

Scan Number	FID (ppm)	Sherlock (ppm)	S/N	Notes
scan 66	3,300	4,530	1.15	
scan 9	9,155	9,060	1.23	
scan 63	7,000	12,079	4.10	FID had problem with water
scan 1	15,000	18,119	4.92	FID saturated
scan 67	14,000	22,649	4.08	FID saturated
scan 65	14,000	30,198	1.64	FID saturated
scan05	n/a	400,771	2.31	Ethelyneglycol Pressure Relief Valve Leak @ 500 m

A plot of the data in Figure 7 shows very good correlation for the data points where the FID could be compared with the measured values from the Sherlock. The Sherlock was able to measure concentrations above the value at which the FID device saturates. On the one data point, the FID indicated a much lower concentration than measured by the Sherlock. This was when the FID had difficulties due to rain that was falling during the testing period.

The purpose for performing the comparison between the concentration measurements using the FID and the Sherlock was to gain a better understanding of the Sherlock's ability to quantify fugitive leaks in a plant environment. Using the FID measurement as compared to the Sherlock is only a qualitative evaluation. To better understand the Sherlock's quantification of fugitive leaks a more rigorous test employing bagging techniques would give a better indication of the accuracy. In the future the authors hope to perform a more quantitative testing program. However, even with this simplistic approach the comparison of the Sherlock's concentration measurements and the FID showed good correlation.



F*igure 7. Correlation between the concentration measurements made by the FID device as compared to that measured using the Sherlock.*

The concentration of a fugitive leak as measured by the Sherlock was determined using a standard Beer's law approach as shown in equation 1. The Sherlock is an imaging spectrometer, therefore can accurately measure the spectral signal from the gas and the background in the same spectral-image data cube. The intensity of this signal is a function of wavelength. With proper calibration gives the concentration of the gas. The path length is determined by the image of the gas (pixel footprint at the gas and the number of pixels). The assumption is that the gas is symmetric. The log of the ratio of the signal from the gas and the background is equal to the product of the absorption coefficient of the gas, the path length of the gas and the concentration.

$$-\log\left(\frac{I_{gas}}{I_{background}}\right) = \alpha Lc \qquad \text{Eq. 1}$$

Calibration was performed using both methane and butane gas. The procedure for calibration using standard gas cells is diagrammed in Figure 8. Nitrogen was used in the control cell. The length of the cell and the concentration was known. From this, the absorption coefficient for various gases is computed.

Figure 8. Standard setup for concentration calibration of the Sherlock camera using standard gas cells.

CONCLUSION

An infrared spectral imaging battery operated camera, useful for gas imaging, quantification and analysis was developed by Pacific Advanced Technology. An exclusive world wide license has been granted to Gas Imaging Technology for the use of Sherlock in the oil, gas, chemical and power industry. The Sherlock has been extensively tested by industry, and EPA/API sponsored laboratory testing at BP Naperville in the spring of 2005. As a result of this testing, Sherlock demonstrated that it has the sensitivity to be used as an optical imaging instrument for the alternate work practice to Method 21. Sherlock has demonstrated that it can see hydrocarbon leak rates as low as 5 ccm, and measured concentrations of fugitive gases in the field as low as a few thousand ppm.

The Sherlock is an autonomous system with an embedded Power PC computer, and real time image processing implemented in FPGA's. It can be controlled over an ethernet link from remote locations throughout the world. The architecture of the camera is such that easy upgrades can be made by changes in software for various and differing applications such as fugitive leak imaging and quantification, remote monitoring of flare, stacks and continuous monitoring of plants for detection of leaks that can be a safety hazard to plant operations.

Through both laboratory and field testing Sherlock has shown that it has the sensitivity to be applied to fugitive leak detection, imaging and quantifications. Field test at the ENI SpA production facility in southern Italy demonstrated the quantification capability of the Sherlock. When the results of the concentrations measurements made by Sherlock were compared to measurements of the same leaking component with an FID device, reasonable correlation was demonstrated. However, to better understand the accuracy of the Sherlock's quantification, further testing is required. It is anticipated that future field trials will be performed along with bagging techniques to better understand the accuracy of the Sherlock measurements.

ACKNOWLEDGEMENTS

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References:

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