

Sherlock SF6 gas imaging and analysis video camera as tested at PG&E facilities in California

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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 Department¹. The technology has been applied to remote gas leak imaging and quantification for the oil, gas, chemical and power industries. Gas Imaging Technology, LLC (GIT) has been granted the world wide exclusive license to market the Sherlock® for this purpose. This paper describes the Sherlock® imaging spectrometer, theory of operations, and applications in the power industry to find sulfurhexafluoride (SF6) gas leaks from circuit breakers and gas insulated switch gear (GIS).

The Sherlock® has been field tested at numerous oil, gas, and chemical facilities in the US, Canada and the EU. The Sherlock® SF6 model has demonstrated that it can see gaseous leaks at rates as low as 1 ml/min or 7 lbs./year. Recently, tests were performed at power substations at PG&E facilities in California. These tests are on-going and the results are not ready to be included in this paper but will be presented at the EPRI substation Equipment Diagnostics Conference XV. This paper will describe the Sherlock SF6 system and how it works.

INTRODUCTION

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

The Sherlock® infrared imaging spectrometer is unique in 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 and USB, and can be integrated into any local area network for remote operation, such as required by facilities for continuous monitoring of safety applications.

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

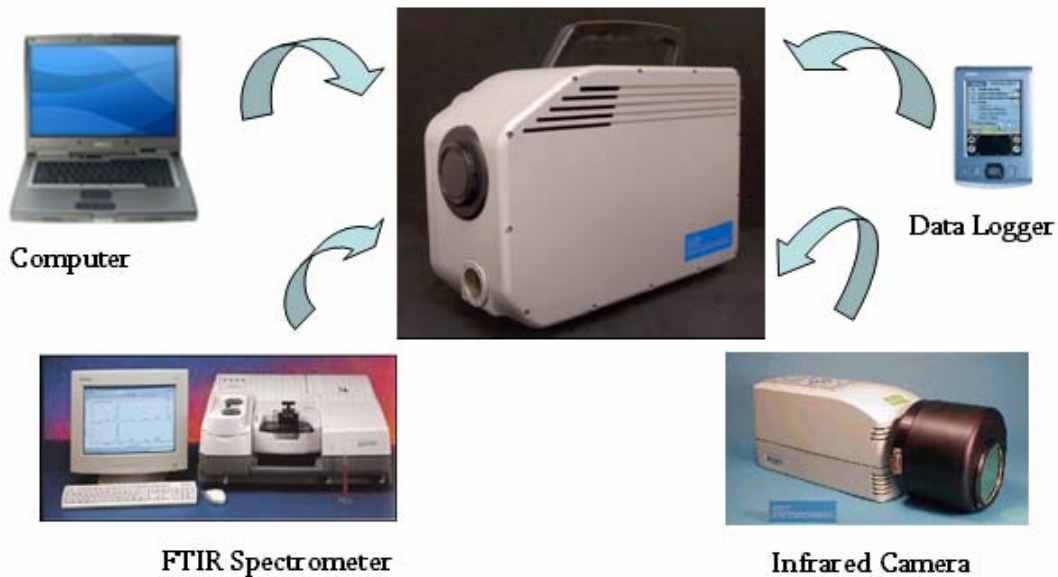


Figure 1. Block Diagram for the Sherlock Spectral Imaging Camera.

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

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 gas 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 principle behind IMSS and the operation of the Sherlock® system, including applications and examples of the Sherlock's performance for imaging and quantification of gas 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 further development of the technology for use in instruments for defense related applications.

The IMSS technology is based on the principle 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 $6 \times 10^{-7} \text{ w/cm}^2\text{-}\mu\text{m-sr}$.

The basic concept of IMSS is shown in Figure 2, compared with a monochromator. A conventional monochromator has an entrance and exit slit and a dispersive element such as a prism or grating. 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.

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, lightweight, robust instrument such as the Sherlock®.

The sequential band images of the Sherlock® spectrometer 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

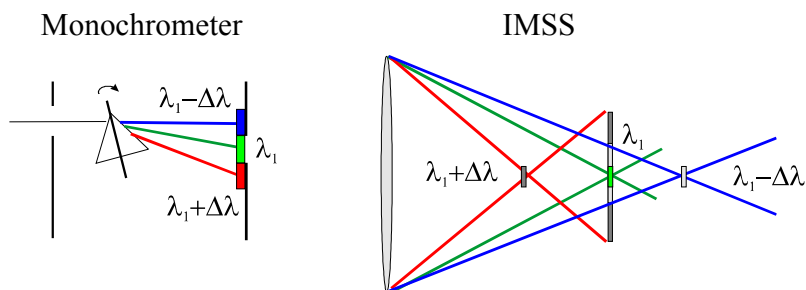


Figure 2. Basic principle of the IMSS.

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.

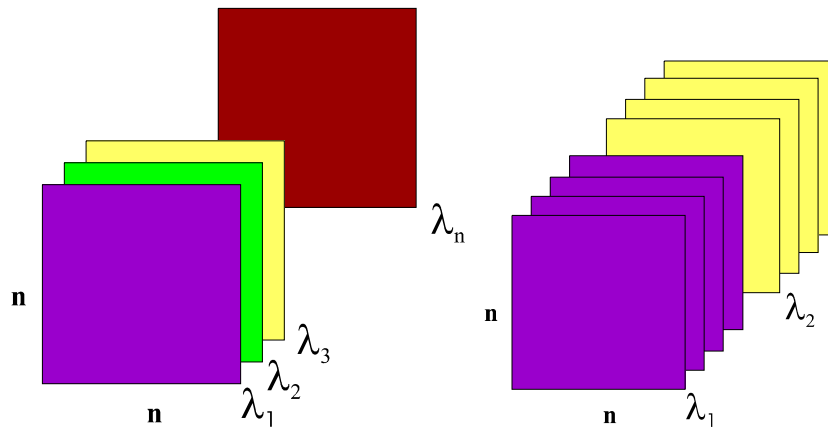


Figure 3. IMSS collects band sequential data which can be operated in a spectral scanning mode as shown on the left or collect only those spectral bands of interest as shown on the right.

APPLICATIONS FOR SHERLOCK®

There are numerous applications for the Sherlock® infrared imaging spectrometer for gas imaging and analysis in the, power, oil, gas and chemical industries. Some specific applications are the finding and visualization of SF6 gas leaks from circuit breakers and (GIS). The IMSS technology, the heart of Sherlock®, has been demonstrated many times for various applications as presented in previous papers [1], [2], [3], [4] and [5].

Sherlock® is shown in Figure 4 monitoring SF6 gas leaks at a PG&E substation in California. 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.



Figure 4. Sherlock shown with an operator looking for leaks at a substation.

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 is an infrared spectral image taken with the Sherlock® at a power substation. The SF6 gas has been image enhanced and colorized in red to accentuate it's presence. This was done post processing. The data was collected in the frame grabber embedded in the Sherlock®

SF6 and processed using the GIT proprietary HyPAT software to detect the gas in the image and color it red.

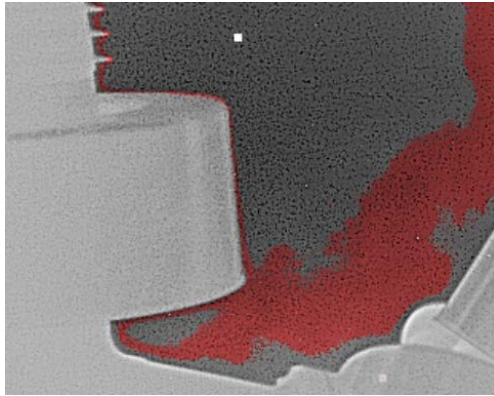


Figure 5. Image processed Sherlock spectral image showing a SF6 gas, colored red, behind a circuit breaker.

CONCLUSION

An infrared spectral imaging battery operated system, useful for gas imaging, quantification and analysis was developed by Pacific Advanced Technology and licensed to Gas Imaging Technology, LLC for applications in the Power Industry. The Sherlock® has been extensively tested in the oil, gas and chemical industry and most recently it has been undergoing testing by the power industry. As a result of this testing, Sherlock® SF6 has demonstrated that it has the sensitivity to detect SF6 gas leaks as low as 7 pounds per year.

The Sherlock® is an autonomous system with an embedded Power PC computer, and real time image processing implemented in FPGAs. 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.

Currently, GIT and PG&E are working together to better understand the performance of the Sherlock® SF6 in finding sulfurhexafluoride gas leaks in power substations in California. SF6 is a greenhouse gas as well as an expensive resource. As good stewards of the environment, the power industry is interested in finding such leaks early and minimize the amount of the gas that leaks into the environment. Also, the early detection of a gas leak in a circuit breaker or (GIS) is an indication of a pending problem and can allow for controlled equipment repair scheduling.

ACKNOWLEDGEMENTS

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