Hand held hyperspectral imager for chemical/biological and environmental applications

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ABSTRACT

A small, hand held, battery operated imaging infrared spectrometer, Sherlock, has been developed by Pacific Advanced Technology and was field tested in early 2003. The Sherlock spectral imaging camera has been designed for remote gas leak detection, however, the architecture of the camera is versatile enough that it can be applied to numerous other applications such as homeland security, chemical/biological agent detection, medical and pharmaceutical applications as well as standard research and development.

This paper describes the Sherlock camera, theory of operations, shows current applications and touches on potential future applications for the camera. The Sherlock has an embedded Power PC and performs real-time-image processing function in an embedded FPGA. The camera has a built in LCD display as well as output to a standard monitor, or NTSC display. It has several I/O ports, ethernet, firewire, RS232 and thus can be easily controlled from a remote location. In addition, software upgrades can be performed over the ethernet eliminating the need to send the camera back to the factory for a retrofit. Using the USB port a mouse and key board can be connected and the camera can be used in a laboratory environment as a stand alone imaging spectrometer.

1 INTRODUCTION

The Sherlock is a hand held imaging spectrometer based upon the Image Multi-spectral Sensor (IMSS) technology developed and patented by Pacific Advanced Technology.[1] The Sherlock camera is a completely autonomous instrument with an imbedded processor based on a Power PC with a Linux operating system with the ability to perform real time image processing algorithms using programmable FPGA's. The camera can be controlled remotely over an Ethernet port. A high speed FireWire interface allows high speed data transfer to remote storage media such as FireWire removable drives.

Although originally developed as a gas leak detection camera for imaging various hydrocarbon leaks from facilities such as oil refineries, gas processing plants, petrochemical and pharmaceutical plants the Sherlock is innovative and easily adaptive to many other applications where an infrared imaging spectrometer can be used. Such applications can include chemical/biological agent detection and identification, environmental monitoring applications, reconnaissance and surveillance, and numerous research applications. The light weight, small size and battery power makes it ideal to be flown on an unmanned aerial vehicle.

In this paper we will describe the fundamental principal behind IMSS, the architecture and operation of the Sherlock camera and show examples of the IMSS technology for imaging spectroscopy.

1. 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 into instruments that have performed applications such as missile warning, infrared search and track, signature collection, and environmental

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[1] US Patent 5,479,258 and 5,867,264

monitoring. The Sherlock camera has been developed with funds from the DoE, the Gas Research Institute, State of California and internal PAT IR&D funds.

The IMSS is based on the principal of diffractive optics. 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. This enables a very small, light weight, robust, and low cost imaging spectrometer. The IMSS has a high throughput with a spectral resolution on the order of 6 wavenumbers. It's noise equivalent spectral response NESR has been measured at 6 x 10^{-7} w/cm^2- μm-sr at the detector.

The basic concept of IMSS is shown in figure 1 where it is compared with a monochrometer or dispersive spectrometer.

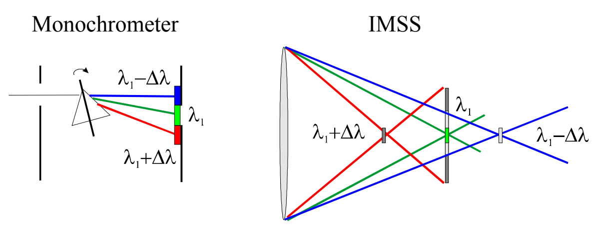

Figure 1. Basic principle of the IMSS.

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. To obtain fine spectral resolution the dispersive spectrometer must reduce the size of the entrance and exit slit and thus reduce the throughput of the instrument.

For the case of IMSS, which uses the dispersive power of a diffractive optic to disperse the light along the optical axis and the light gathering capability of the lens allows a very high throughput instrument. The fact that IMSS uses a single element to perform both imaging and through put gives it the added advantage that no other spectral imaging approach has and that is the multiplexed advantage of image and dispersion with a single element. This allows high throughput, low cost, small size and an extremely robust instrument which has very little optical alignment sensitively. The fact that IMSS operates in a staring mode means that it does not require spatial scanning and therefore can be man portable and ideal for applications that require a small, light weight, robust instrument.

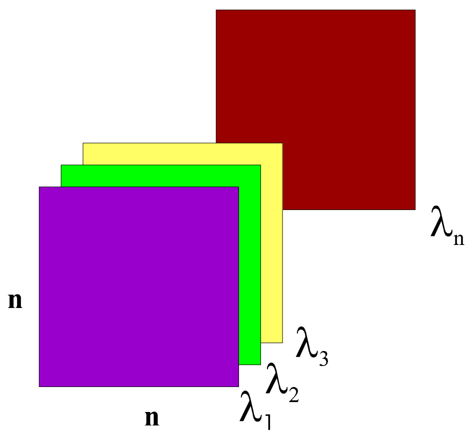

Figure 2. IMSS collects band sequential data.

The IMSS and Sherlock camera collect spectral images in a band sequential mode as shown in figure 2.

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 as shown in figure 3. In this manner the IMSS imaging spectrometer is extremely adaptive and can collect only those spectral bands of interest and can dwell at a single spectral band indefinitely. This adaptability of IMSS makes it 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 only certain

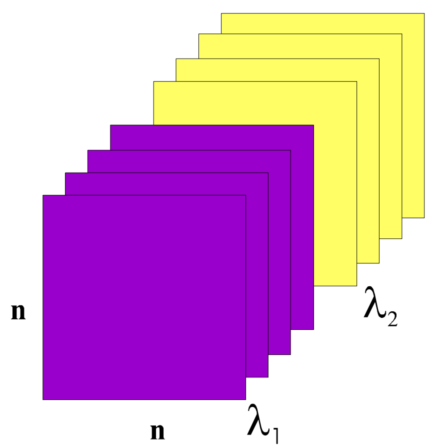

Figure 3. IMSS can collect only those spectral bands of interest if necessary.

spectral regions are of greater interest than others and thus there is no need to collect more than the necessary number of spectral bands. Thus saving time and necessary processing power. This ability allows the IMSS to easily be adapted to numerous applications where real time spectral processing is of interest.

2 APPLICATIONS FOR SHERLOCK

There are numerous applications for the Sherlock camera from defense related, homeland security, environmental monitory, medical applications and basic research. The IMSS technology has been demonstrated for many of these applications as presented in previous papers [1],[2],[3],[4].

The Sherlock has numerous applications in the petrochemical industry from detecting and identifying leaks to, flare monitoring and measuring emission rates from stacks. The precursor to the Sherlock camera, as shown in figure 4, has been taken to the field to several oil and gas processing plants and chemical plants both in the US and in the UK. It was tested under various environmental conditions from the very hot and humid environment in Louisiana in the summer to the dry and cold environment in Colorado in the winter to the damp and mild environment on the north east coast of England in the fall. Under all of these conditions the technology demonstrated the ability to detect chemical leaks of various types from methane, propane, butane, acetone, carbon monoxide, carbon dioxide as well as numerous other species.

Figure 4. IMSS on Radiance 1 infrared Camera in oil refinery.

Methane gas leaking from a pipe simulating a roof vent where shy is the background was easily detected and imaged using the Radiance 1 infrared camera coupled to the IMSS imaging spectrometer. One such picture is shown in figure 5.

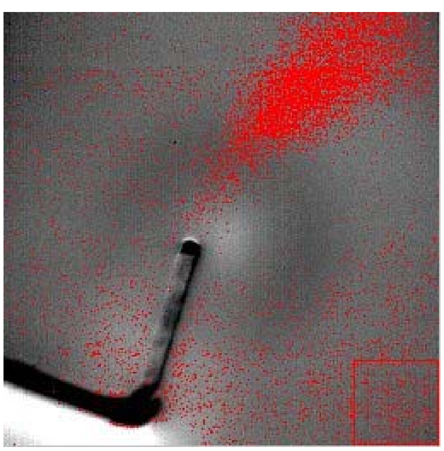

Figure 5. Methane gas leaking from simulated roof vent.

Shown in figure 6 are spectral images are six different wavelengths of a smoke stack in Louisiana in the summer on a very hot and humid day. Under these conditions finding hydrocarbon species with spectra embedded in the water lines is a particular challenge. Also this arrangement was even more challenging with the dynamic cloud background that was constantly changing. The sun was behind the camera reflecting off the clouds in the background adding to the already difficult problem. In spite of this, the IMSS was able to identify the small concentration of propane (20%) in the stack effluent as shown in red in the lower image.

In addition to applications in the petrochemical industry, the Sherlock is small enough to be mounted on an unmanned aerial vehicle for surveillance and reconnaissance applications as well as automatic target recognition. The fact that it has an embedded computer, as well as the capability to perform real time image processing, makes it a stand alone system that can easily be integrated in many of these different platforms that are already being used in the "War on Terror".

The Sherlock is ideal as a laboratory imaging spectrometer for numerous applications in the field of science, from basic research to calibration applications.

Imaging spectroscopy is just now being applied to the medical field. Most of the work to date has been in the visible, however, there are numerous applications for an infrared imaging spectrometer and that is where the Sherlock camera can be of service.

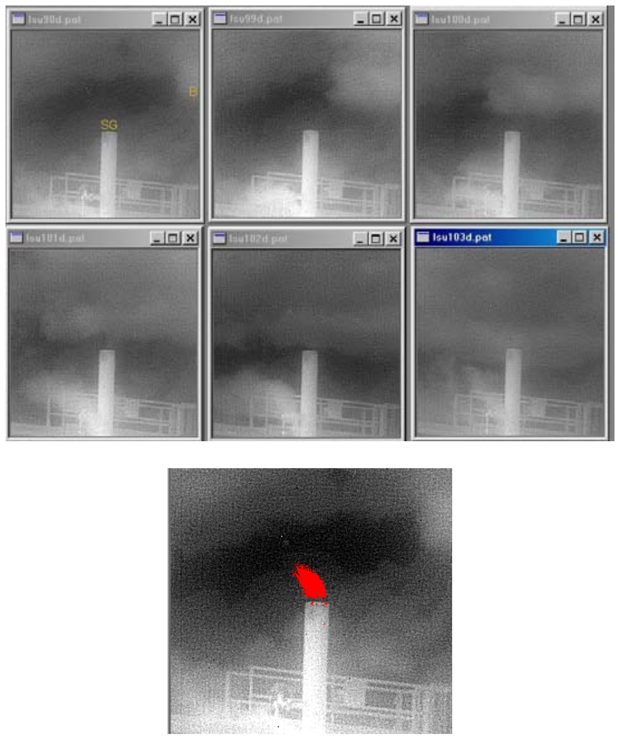

Figure 6. Smoke stack in Louisiana in the summer.

3 SHERLOCK ARCHITECTURE

The Sherlock camera combines the lens, detector, controller, computer and real time image processing in a single hand held battery operated infrared camera. The camera also has the option to overlay the gas image on a visible image due to the fact that there is a built in visible camera in the Sherlock. It is possible to perform data fusion with the infrared and visible image.

The Sherlock has been designed for gas leak detection and most of its features have been optimized for that application. However, the architecture of the camera is such that it can easily be upgraded for other applications with simple software changes with the addition of a small circuit card on the back of the LCD display and a small circuit card that holds and drives the visible camera on a chip. The Sherlock has four main circuit cards:

1) Analog front end
2) Image Processor card
3) Control Processor card

4) Motor Controller card

A block diagram of the Sherlock electronics is shown in figure 7.

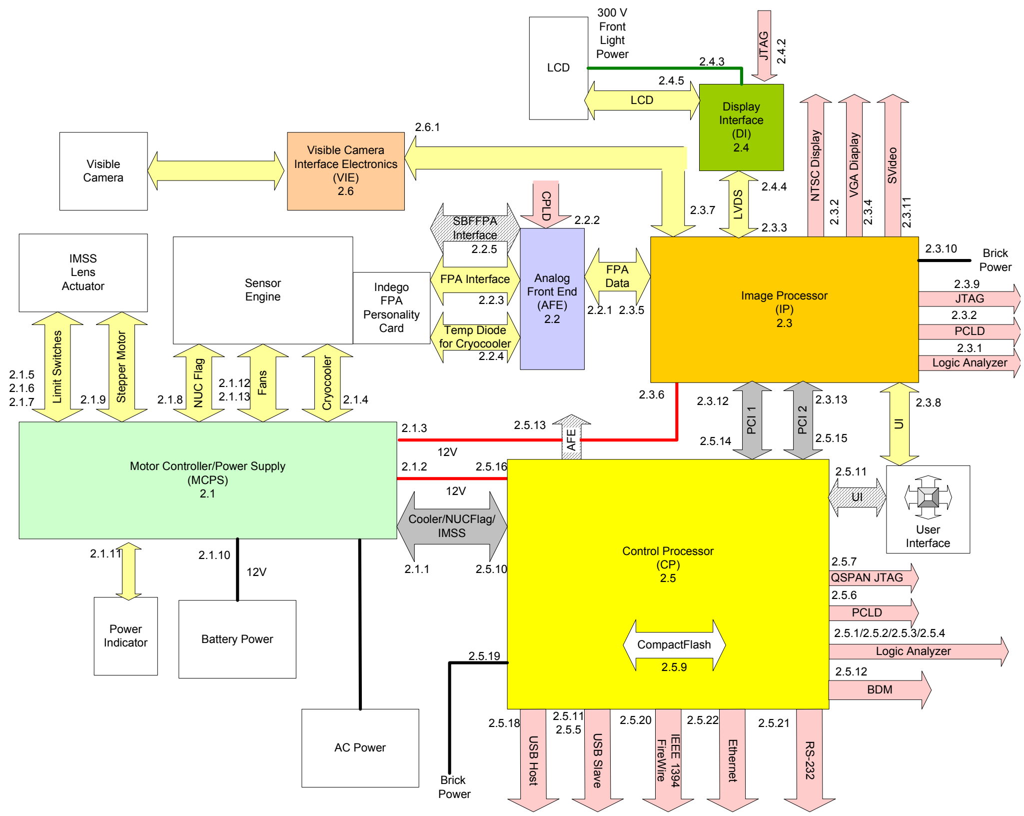

Figure 7. Block Diagram for the Sherlock Spectral Imaging Camera.

The analog front end card performs the noise sensitive operations and is mounted very close to the dewar that houses the FPA. All analog signals and conversion to a 14 bit digital signal is performed on this card.

The image processing card is the work horse of the camera. It uses a Xilinx FPGA to generate all the timing and control signals for the FPA, video display, video storage and real time image processing of the spectral images to find and false color the gas leaks.

The control processor uses a Motorola Power PC 860 processor and is the main computer for the camera. It has a CompactFlash/IBM Mini Drive card for video data storage. The operating system is Linux. The input/out ports on this card are:

1) Ethernet
2) USB
3) RS232
4) Firewire
5) User Interface (for hand held applications)

The motor controller performs all the control functions for the motors in the camera as well as control of the cryocooler for the FPA. It controls the non-uniformity correction flag for the FPA and the lens driver for the IMSS lens. It also is the interface to the power supply which can be either a battery or line power. The interface between the motor controller and the command processor is serial data strings.

The first prototype Sherlock system was field tested in early 2003. It was able to detect and image hydrocarbon leak with leak rates as low a 5 ccm. The current configuration of the Sherlock is for gas leak detection and real time image processing to display the leak in false color fused with the infrared or visible image. However, in the future other features are planned to be added. The architecture (both hardware and software) to do this has been designed into the camera and only software changes are necessary to implement different applications.

The various components in the Sherlock camera are shown in figure 8. Shown is the sensor engine supplied to PAT by Indigo Systems in Goleta California. The rest of the components have been designed and developed internally by the staff at PAT except for the visible camera on chip.

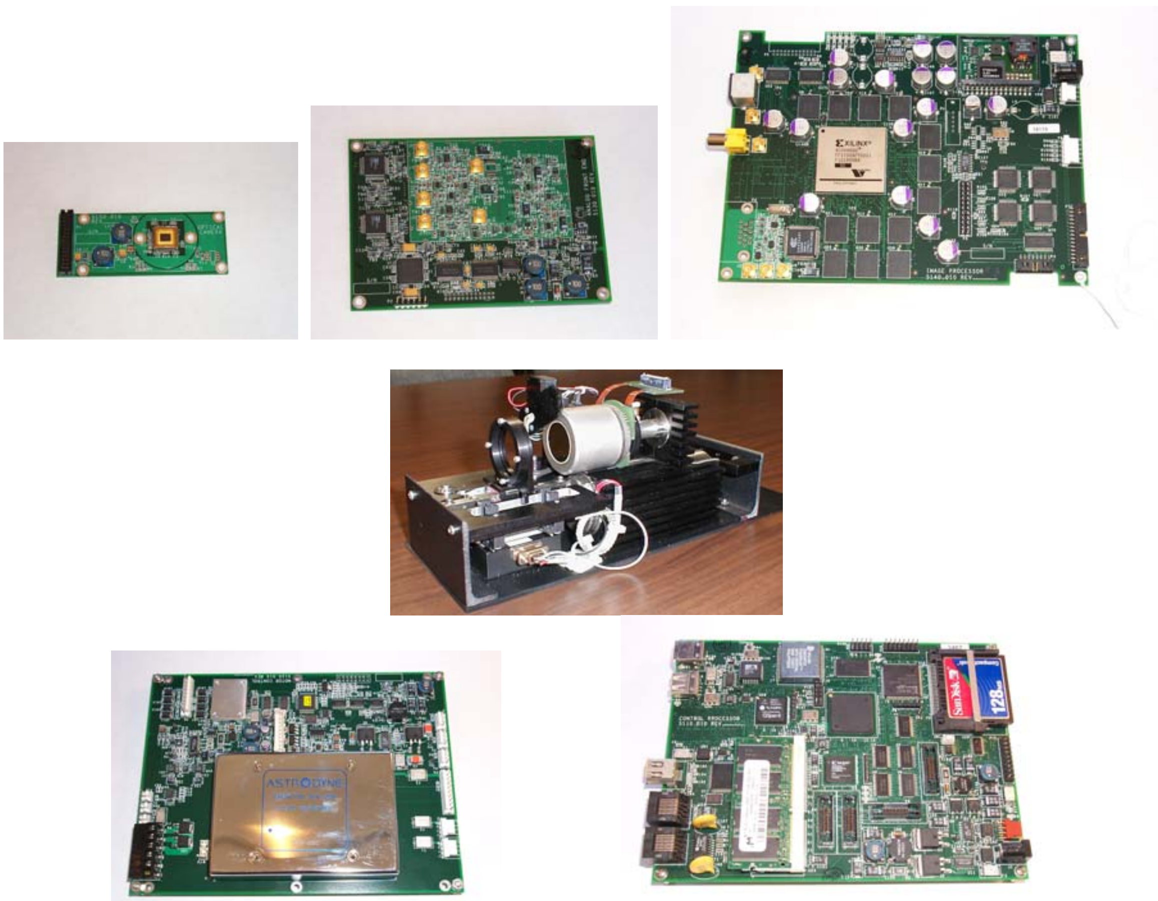

Figure 8. Sherlock Major Components.

The sensor engine is shown in the center along with the IMSS lens actuator.

The Sherlock spectral imaging camera has numerous features that have been designed into the camera.

1) **Video storage** - support up to 1Gbyte CompactFlash cards or 4 Gbyte IBM mini drive for local storage of video data.

2) **External Video Storage** - the Sherlock camera has a FireWire interface in order to support external storage and high speed transfer of video from the camera. External FireWire disk drives are available in >100GByte storage capacities and can support real-time, continuous video streaming over the interface.

3) **Real-time clock** - includes a battery-backed up real-time clock in. This can be used to trigger capture sequences on a periodic interval or at a very specific time of day. For instance, end of day reports could be generated and e-mailed to an external site at midnight of every day.

4) **USB interface** - this interface was included to facilitate the interface of an external mouse and keyboard to the camera. While this may not be useful in all remote monitoring applications, it would be very useful in the laboratory during post field capture data evaluation. The Sherlock camera runs an embedded version of Linux and thus makes a good standalone platform to support data analysis activities after field use.

5) **Ethernet interface** - a 10Base-T ethernet interface built into the camera. This allows direct internet hook-up of the Sherlock camera. This will support numerous software applications. Ethernet MAC addresses would uniquely identify individual Sherlock cameras on a network throughout the world.

6) **External Video output** - in addition to the internal LCD display on the camera itself, the Sherlock has both an S-Video and Composite NTSC compatible video output. This allows the use of large computer monitors or projection systems to be used with Sherlock. Also, since a standard NTSC compatible signal is output, all standard video support electronics may be used in conjunction with the camera. These include video distribution amps and switches for remote distribution of video images as well as VCR recording equipment to support data archiving operations.

7) **RS-232 Interface** - the serial interface on Sherlock can be used for those applications that wish to use a dial-up connection to the internet. In those cases a standard computer modem could be interfaced to Sherlock to allow communication over the dial-up telephone network.

8) **Video Processing functions** - The image processing logic is implemented in an FPGA device that allows reprogrammability. This would allow any improvements in detection algorithm remotely upgrade field cameras over the internet thus greatly easing the cost and reducing the downtime of firmware upgrades. Also, several different algorithm implementations could be swapped out on the fly. This could be useful for using Sherlock for multiple applications or need to custom tune an algorithm for specific sites that may have local environmental issues that would affect the camera operation.

9) **Video Compression** - it is possible to include hardware assisted video image compression such as MPEG to allow for greater storage capacity of the internal CompactFlash/IMB mini-drive or to support real-time video over the ethernet port. This feature is also made possible by the use of FPGAs for the image processing logic.

10) **WLAN interface** - It is possible to interface Sherlock to an internet connection via an 802.11b interface. Intel and other manufacturers sell these interfaces that can connect via the host computer's USB interface. The Sherlock USB port could be used for this function as well.

11) **Internet based management** – Sherlock in the future could supply an internal web server that would allow the remote monitoring and configuration of the camera. Thus interface to a Sherlock camera could be made from any computer utilizing a web browser. Remote file transfers would be done via FTP. With this capability a central location could monitor numerous Sherlock cameras placed any where in the world.

12) **Remote Alarm reporting** - the Sherlock camera could generate alarms based upon a predetermined trigger threshold and report them over the internet. For instance an e-mail could be sent anytime an alarm is detected.

13) **Security camera** - although primarily designed for gas leak detection operations, since the camera could be deployed widely throughout a facility, it could double as a standard surveillance camera. Not only could alarms be

generated for gas detection but for unexpected human entry events. Sherlock application software could implement motion triggered alarms. This could save the cost of installing two systems to monitor gas leaks and security systems.

14) **Linux based applications** - since Sherlock is running an embedded version of the Linux operating system, many standard Linux desktop-based applications could be run on the camera. These could be useful in post data collection activities when analyzing the collected data. For instance, a version of Sun's Open Office application spreadsheet could be used to analysis collect video data in the lab. This also opens up the use of other tools as well, such as web servers, FTP file transfer, e-mail, and other utilities used during normal housekeeping of the Sherlock camera. In addition, running Linux makes the Sherlock environment instantly familiar to third party software engineers that may wish to write application software for the camera.

15) **Remote Panning** - interface to a remote panning device via the Sherlock internet connection is possible. This would allow remote control of the look angle of the camera at a particular installation.

Figure 9. Sherlock camera during final system integration and testing.

Shown in figure 9 the prototype Sherlock camera, which is a hand held imaging spectrometer that weighs 12 pounds, is 12(d) x 6(w) x 8(h) inches in size. It is battery operated or can be run off line power.

4 CONCLUSION AND FUTURE WORK

A spectral imaging battery operated camera useful for petrochemical, pharmaceutical, medical and military applications, has been developed by Pacific Advanced Technology and was field tested in early 2003. It demonstrated that it could see hydrocarbon leak rates as low as 5 ccm. This camera 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 only.

The first version of Sherlock was designed for gas leak detection in mind. However, other applications for the camera are possible and user specific algorithms can be applied to perform numerous different functions.

In the future the Sherlock camera will be upgraded with algorithms that can not only detect gas leaks but can quantify them as well. Other applications such as flare monitoring, and chemical/biological agent detection are currently being investigated.

5 ACKNOWLEDGEMENTS

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References:

[1] Michele Hinnrichs, James Jensen, Gerald McAnally, "Handheld Hyperspectral Imager for Standoff Detection of Chemical and Biological Aerosols, SPIE Photonics East October 27-31, 2003.

[2] Michele Hinnrichs, "Imaging Spectrometer for Fugitive Gas Leak Detection", Industrial and Environmental and Industrial Sensing, SPIE, Boston September 19-20, 1999.

[3] Michele Hinnrichs "Remote Sensing for Gas Plume Monitoring Using State-of-the-art Infrared Hyperspectral Imaging", SPIE, Industrial and Environmental Monitors and Biosensors Nov 2-5, 1998.

[4] Michele Hinnrichs, Mark Massie "New Approach to Imaging Spectroscopy Using Diffractive Optics", SPIE San Diego, July 199.
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[5] Hinnrichs, Michele, Mark Massie and Jeff Frank (Amber), "Hyperspectral Imaging Radiometer Using Staring 128 x 128 InSb Focal Plane Array and Dispersive Techniques", SPIE AeroSense 1995, Imaging Spectroscopy Session, Orlando, 1995.