A Cost Effective Multi-Spectral Scanner for Natural Gas Detection

Semi-Annual Progress Report No. 3

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on

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ABSTRACT

The objective of this project is to design, fabricate and field demonstrate a cost effective, multi-spectral scanner for natural gas leak detection in transmission and distribution pipelines. During the first year of the project, a laboratory version of the multi-spectral scanner was designed, fabricated, and tested at En'Urga Inc. The multi-spectral scanner was also evaluated using a blind DoE study at RMOTC. The performance of the scanner was inconsistent during the blind DoE study. However, most of the leaks were outside the view of the multi-spectral scanner. Therefore, a definite evaluation of the capability of the scanner was not obtained. Despite the results, sufficient number of plumes was detected fully confirming the feasibility of the multi-spectral scanner. During the second year, the optical design of the scanner was changed to improve the sensitivity of the system. Laboratory tests show that the system can reliably detect small leaks (20 SCFH) at 30 to 50 feet. Electronic design of the scanner to make it a self standing sensor is currently in progress. During the last six months of the project, the electronic and mechanical design will be completed and evaluated at En'Urga Inc.

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1. Executive Summary

The objective of this project is to design, fabricate and field demonstrate a cost effective, multi-spectral scanner for natural gas leak detection in transmission and distribution pipelines. The six specific tasks required for the completion of the project are: (1) Development of the research management plan, (2) Assessment of current technology, (3) Design and fabrication of a laboratory scale multi-spectral scanner, (4) Evaluation of the laboratory scale multi-spectral scanner, (5) Design and fabrication of a prototype multi-spectral scanner, and (6) evaluation of the prototype multi-spectral scanner.

The first task, which is the development of the research management plan, was completed during this report period. The research management plan has been submitted to the Department of Energy, NETL. This task was completed within the scheduled time.

The second task, which is the assessment of current technology, has been completed. A report has been submitted to the Department of Energy, NETL. In addition, an overview of the entire project was provided to NETL at a kickoff meeting on December 16. This task was also completed within the schedule time.

The third task is the design and fabrication of a laboratory scale multi-spectral scanner. The three components of the design are the optical design, mechanical design, and the electronic design for the scanner. The optical design for the scanner was completed using Zemax optical design software. The optical design is such that each of the four elements of the scanner will see the same spot. The RMS spot diameter obtained was much smaller than the individual detectors of the four-element detector. The optical components required for the multi-spectral scanner were purchased from a commercial vendor. The electronic design for the scanner was completed using Protel Electronic Design software. The electronic design was such that the four elements of the scanner have individual lock-in-amplification circuits at the output end. The electronic design was then evaluated using an electronic bread board. The performance of the system was found to be satisfactory. The custom PCB was fabricated by an outside vendor and delivered to En'Urga Inc. The scanner housing design was completed using ProEngineer software package. The mechanical engineering design is modular in nature with the scanner and optics in one module and the detector and PCB in another module. The housing for the scanner was fabricated and integrated into one package for evaluation.

The scanner was initially evaluated at En'Urga Inc. with a 10 SCFH leak of natural gas. The scanner could detect the leak while it was stationary. Further evaluation was conducted using a DoE organized test at RMOTC. Performance of the laboratory version of the multi-spectral scanner was satisfactory. However, further improvement in performance is required for vehicle mounted operations.

During the second year of the project, a rugged prototype version of the multi-spectral scanner will be designed, fabricated, and evaluated.

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The report is divided into five parts, corresponding to the different tasks completed during the first twelve months of the project, corresponding to the milestone chart.

1. Research Management Report

The first task of the project was the development of a research management report. The list of deliverables and target dates for the project are shown in Table 1.

Table 1: List of Deliverable and Target Dates

Item No.	Deliverable	Target Date
1	Research management plan	October 31, 2003
2	Technology status report/briefing	November 30, 2003
3	First bi-annual report	April 15, 2004
4	Second bi-annual report	October 15, 2004
5	Conference presentation	October 15, 2004
6	Third bi-annual report	April 15, 2004
7	Final report/briefing	October 15, 2004
8	Informal reports	Monthly

The list of milestones for the project, with target dates are shown in Table 2.

Table 2: List of Milestone with Target Dates

Item No.	Milestones	Target Date
1	Laboratory scanner design	February 29,2004
2	Laboratory scanner fabrication/calibration	May 29,2004
3	Laboratory scanner evaluation	September 30, 2004
4	Prototype PCB design and fabrication	January 31, 2005
5	Prototype scanner fabrication/calibration	May 31, 2005
6	Prototype scanner evaluation	September 15, 2005

A detailed description of the deliverables and milestones was provided to DOE during the first month of the project.

2. Technology Status Report

The second task of the project was the creation of a technology status report. The technology status report highlighted the current status of pipeline leak detection. A summary comparison of the different natural gas leak detection techniques is provided in Table 3.

Table 3: Comparison of Different Natural Gas Leak Detection Techniques

Technique	Feature	Advantages	Disadvantages
Acoustic sensors	Detects leaks based on acoustic emission	Portable Location identified Continuous monitor	High cost Prone to false alarms Not suitable for small leaks
Gas sampling	Flame Ionization detector used to detect natural gas	No false alarms Very sensitive Portable	Time consuming Expensive Labor intensive
Soil monitoring	Detects tracer chemicals added to gas pipe line	Very sensitive No false alarms Portable	Need chemicals and therefore expensive Time consuming
Flow monitoring	Monitor either pressure change or mass flow	Low cost Continuous monitor Well developed	Prone to false alarms Unable to pinpoint leaks
Dynamic modeling	Monitored flow parameters modeled	Portable Continuous monitor	Prone to false alarms Expensive
Lidar absorption	Absorption of a pulsed laser monitored in the infrared	Remote monitoring Sensitive Portable	Expensive sources Alignment difficult Short system life time
Diode laser absorption	Absorption of diode lasers monitored	Remote monitoring Portable Long range	Prone to false alarms Expensive sources Short system life time
Broad band absorption	Absorption of broad band lamps monitored	Portable Remote monitoring Long range	Prone to false alarms Short system life time
Evanescent sensing	Monitors changes in buried optical fiber	Long lengths can be monitored easily	Prone to false alarms Expensive system
Millimeter wave radar systems	Radar signature obtained above pipe lines	Remote monitoring Portable	Expensive
Backscatter imaging	Natural gas illuminated with CO2 laser	Remote monitoring Portable	Expensive
Thermal imaging	Passive monitoring of thermal gradients	No sources needed Portable Remote monitoring	Expensive detector Requires temperature difference
Multi-spectral imaging	Passive monitoring using multi-wavelength infrared imaging	No sources need Portable Remote monitoring Multiple platform choices	Expensive detectors Difficult data interpretation

The technology status report was completed and delivered to DOE at the end of the second month of the project.

3. Design and Fabrication of the Laboratory Scale Scanner

The third task is the design and fabrication of the laboratory scale scanner. The optical design for the multi-spectral scanner was completed using a ray-tracing algorithm (Zeemax). The electronic design of the circuit boards for the scanner was completed using a PCB design and layout software (Protel). The mechanical design was completed using a solid modeling package (ProEngineering). The circuit boards and the scanner housing were fabricated using outside vendors. A photograph of the final laboratory scale scanner is shown in Fig. 1.

Figure 1. Photograph of the laboratory scale scanner mounted on a tripod.

The scanner essentially consists of a four element, thermoelectrically cooled, lead selenide array with a 2-dimension scanner and associated optical elements to image a scene at four wavelengths. The power for the scanner and the four element sensor was supplied from an external power supply box, and the data was read out using a laboratory computer and a high speed data acquisition board.

4. Evaluation of the Laboratory Scale Scanner

The fourth task was to evaluate the scanner. First the scanner was evaluated at En'Urga Inc. using a small natural gas leak at En'Urga Inc. It was successful in detecting small leaks as long as the entire system was stationary, and the leak was near the sensor. A blackbody was also used for these tests, providing a very stable background. The scanner was then mounted inside a moving van and tested at RMOTC. The following conclusions were obtained form the tests.

1 Small leaks that are more than 50 feet from road cannot be detected when the multi-spectral scanner is configured to scan only up to 50 feet from the mount location.

2. The exact leak location cannot be determined unless the vehicle-mounted scanner is riding on top of the pipeline. If the scanner is on a moving platform and scanning some distance to the side, only approximate locations of the plume itself can be ascertained.

3. For future tests, it would be desirable to have an access way on top of the pipeline. Failing that, all leaks should be located within 50 feet from the middle of the road, or prior notice of the maximum distance of the leak location from the road should be provided.

4. Only one portion of the road could be scanned on each pass since the entire pipeline had to be inspected at 2/3rd the speed of an aircraft inspection.

5. Development of Prototype Scanner

The first task during the second year of the project is to develop a prototype scanner. The following describes the progress made on three key subtasks associated with the development of the prototype scanner.

5.1 Optical Design of the Prototype Scanner

Based on the results of the evaluation of the laboratory scale scanner at RMOTC, additional work is required to improve the optics so as to make it immune to vibration and dust. A new lens design was completed and fabricated. The new lens is currently placed inside the enclosure of the 4 element sensor. The new lens design inside the scanner and the resulting spot diagram is shown in Fig. 1.

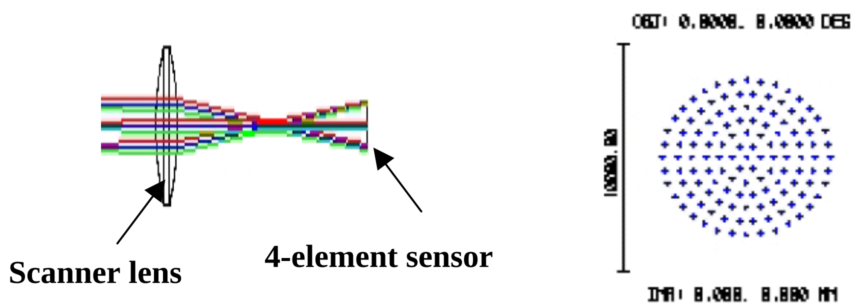

Figure 2. Modified design and spot diagram of the lens for the prototype scanner.

The new lens uses a larger curvature biconvex CaF_2 lens. This provides for a bigger spot diagram at all locations on the top of the four element detector. The SNR provided is expected to be higher than with the previous system, albeit at a higher cost for the optical components.

The lens system in conjunction with the multi-spectral scanner was tested from a stationary platform at En'Urga Inc. The scanner was placed outside on a tripod and scanned the surrounding areas. A sample result obtained is shown in Figure 3.

Two lines are shown in Fig. 3. The solid red line is a sample scan obtained over 400 seconds at 100 Hz using the multi-spectral scanner. The signal is reasonably steady at the beginning of the scan. During some portions of the scan, the signals rises a little bit. This could probably be due to some signals created by the moving shadows on the ground, dust blowing around, or some obstructions caused by persons/cars. The black scan was also obtained at the same location. After the first 100 seconds, natural gas was vented into the atmosphere at a flow rate of 20 SCFH and at a distance of 30 feet from the scanner. The big reduction in the background signal at 3.4 microns caused by methane absorption is clearly visible in the figure.

The feasibility and sensitivity of the multi-spectral scanner has been clearly confirmed at this juncture. Based on the above results, the optical design of the scanner was finalized.

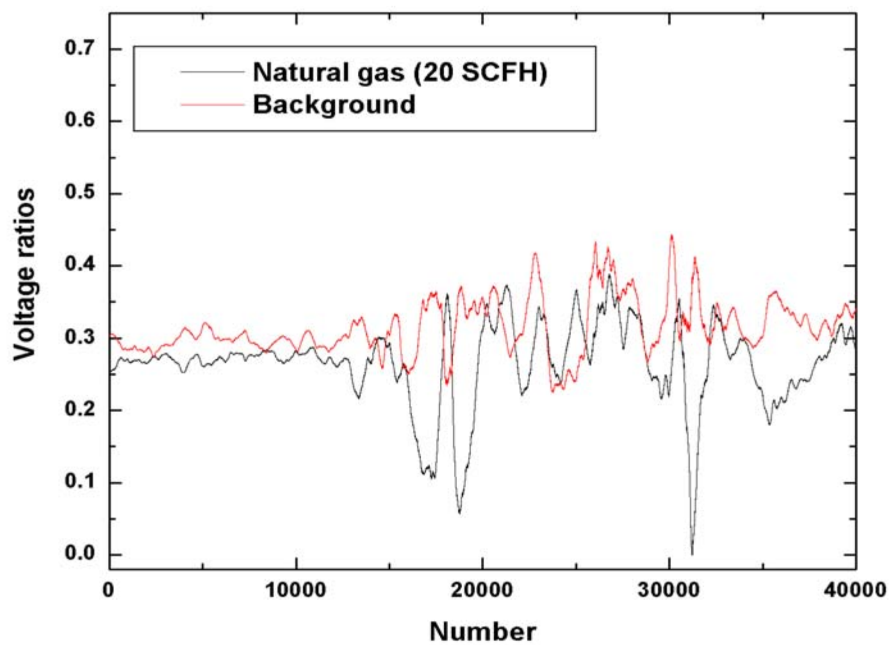

Figure 3. Natural gas leaks (20 SCFH) detected at a distance of 30 feet.

The feasibility and sensitivity of the multi-spectral scanner has been clearly confirmed at this juncture. Based on the above results, the optical design of the scanner was finalized.

5.2 Electronics Design of the Prototype Scanner

The next subtask is the design and fabrication of the electronic components of the prototype scanner. This subtask involves replacement of the data acquisition system and computer with a single board controller and a LCD display. A wide variety of commercially available boards were evaluated. Based on the evaluation, the optimal choice for the prototype scanner is the Tern 586-Engine-P.

A photograph of the single board controller chosen for the scanner is shown in Fig. 4.

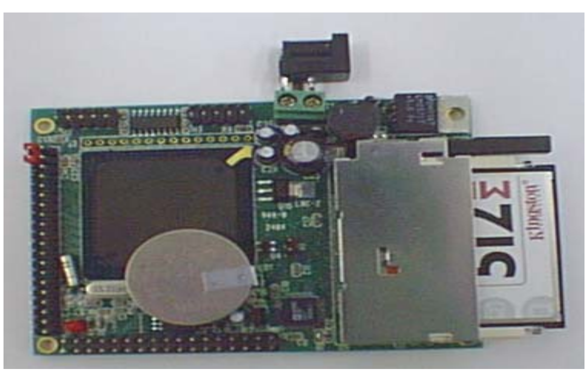

Figure 4. Photograph of the single board computer (microprocessor).

The 586-Engine-P has 4 channel high speed data acquisition capability and can be programmed in C/C++. This is ideal for the four element sensor used in the laboratory version of the multi-spectral scanner. En'Urga Inc. has purchased the single board processor. Programming of the microprocessor with the software required to obtain data from the four element sensor and display it on a LCD is in progress.

The first part of the program is to ensure that the microprocessor can collect four channels of data and directly display the data directly on a LCD screen. A photograph of the experimental arrangement used to verify the working of the microprocessor is shown in Fig. 5.

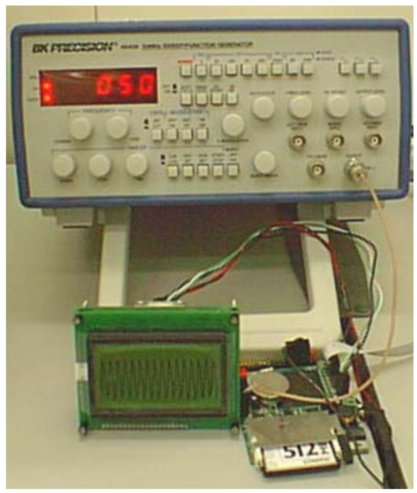

Figure 5. Photograph of the arrangement used for evaluating the microprocessor.

A sine wave pattern from a signal generator is fed into the A/D of the Tern microprocessor. The microprocessor is programmed to read in the data and display it on the LCD screen. The resulting pattern seen on the LCD is shown in Fig. 6.

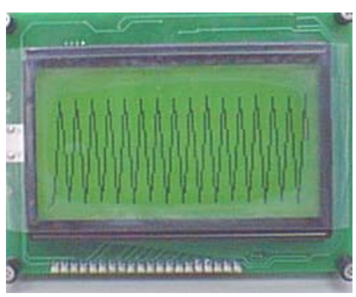

Figure 6. Photograph of the LCD screen during the evaluation tests.

The microprocessor faithfully captures the signal from each of the four channels and can display any channel on the LCD screen. The next step is to program the microprocessor so that the ratio of the voltages at different locations corresponding to the scene observed by the scanner is displayed on the LCD. This is currently in progress and expected to be completed during the next two months of the project.

5.3 Mechanical Design of the Prototype Scanner

The last subtask is to complete the mechanical design and fabrication of the prototype scanner. This task is currently in progress and will be completed within the next two months of the project.

6. Tasks Planned for the Next Report Period

During the next six months of the project, the fabrication of the prototype scanner will be completed. After the fabrication is completed, evaluation of the prototype scanner will be completed at En'Urga Inc. Further field tests will have to be completed outside the project period before commercialization of the sensor can begin.