A Cost Effective Multi-Spectral Scanner for Natural Gas Detection

Semi-Annual Progress Report No. 1

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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 six months of the project, the design for a laboratory version of the multi-spectral scanner was completed. The optical, mechanical, and electronic design for the scanner was completed. The optical design was analyzed using Zeemax Optical Design software and found to provide sufficiently resolved performance for the scanner. The electronic design was evaluated using a bread board and very high signal to noise ratios were obtained. Fabrication of a laboratory version of the multi-spectral scanner is currently in progress. A technology status report and a research management plan was also completed during the same period.

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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 Zeemax 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 electronic design was then turned over for fabrication of a custom PCB. The custom PCB will be fabricated by an outside vendor and delivered to En'Urga Inc.

The mechanical engineering design was completed using ProEngineer software packaged. 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 modular nature of the mechanical design will enable rapid modification of the design for the final prototype version of the multi-spectral scanner. Production drawings of the various components have been given to an outside source for fabrication.

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The semi-annual report is divided into five parts, corresponding to the different tasks completed during the first six months of the project.

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, 2004
5	Prototype scanner fabrication/calibration	May 31, 2004
6	Prototype scanner evaluation	September 15, 2004

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 using the Zeemax code was completed.
A schematic diagram of the optical design for the scanner is shown in Fig. 1.

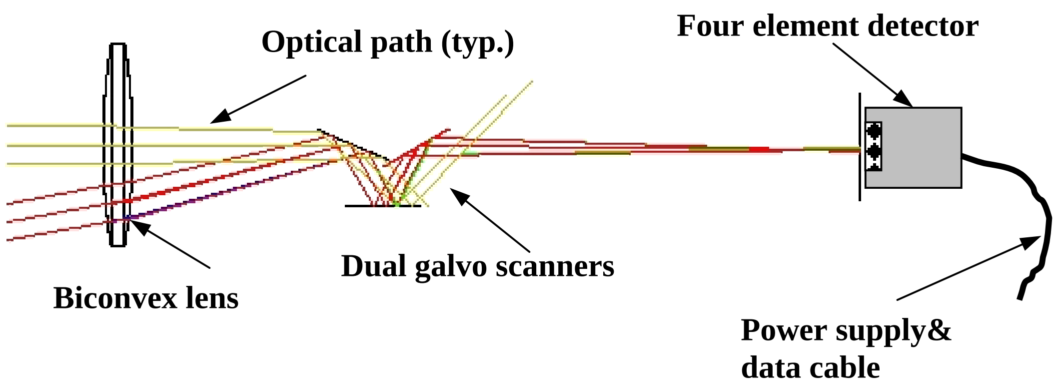

Figure 1. Schematic diagram of the optical design for the multi-spectral scanner.

The light from the ambient is collected using a Bi-convex lens (CaF_2) with a focal length of 150 mm, and a diameter of 38.5 mm. The field of view of the system was designed to be approximately 4 feet by 4 feet. This light is relayed through two galvo scanners that trace the image formed by the lens onto a four element detector. A four element detector was chosen instead of the three element detector proposed since these are cheaper and commercially available. The spot sizes that will be seen on each of the detectors is shown in Fig. 2.

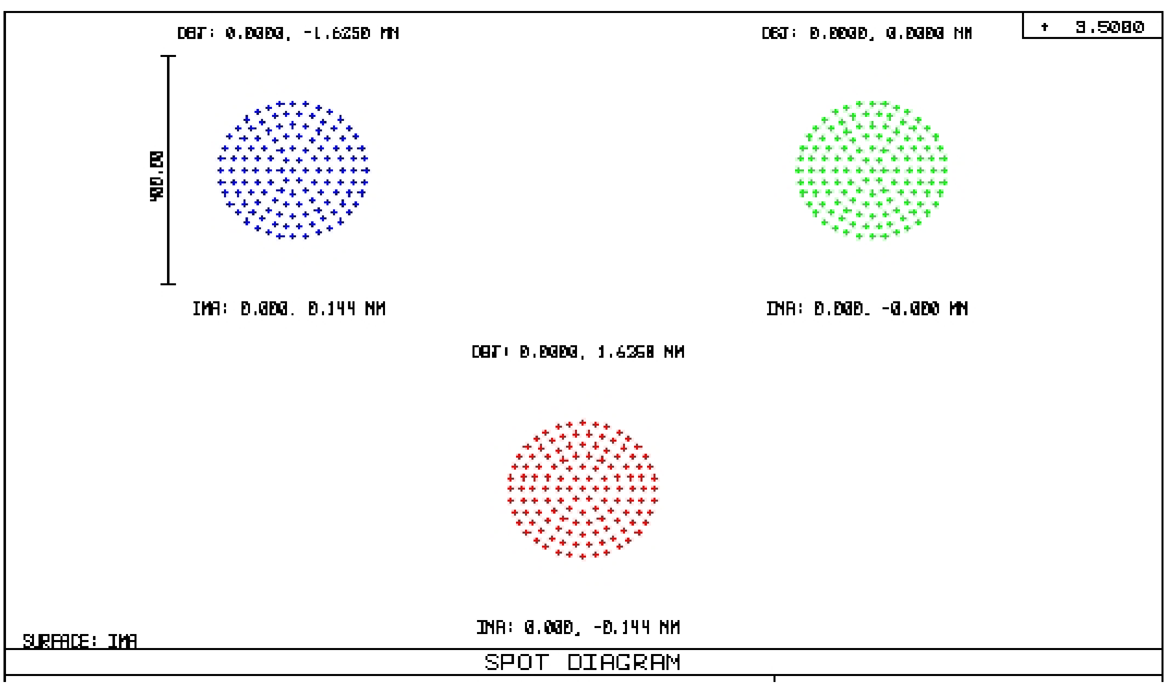

Figure 2. Optical performance of the scanner/lens combination for the multi-spectral scanner.

The RMS spot diameter is approximately 90 microns and the geometric radius is approximately 117 microns at the detector surface. Each of the four elements of the detector has a size of approximately 500 microns. Therefore, the spatial resolution of the system is sufficient.

Four filters with central wavelengths of 3.4, 3.8, 3.9, and 4.3 microns were purchased and delivered to the detector manufacturer. The filters will be mounted onto the detector surface, and delivered to En'Urga Inc.

The four element sensor was first tested out on a bread board to ensure that the detector assembly is working as intended. After testing on the bread board was completed, the PCB design was laid out using Protel Electronic Design Software. The schematic of the PCB to be utilized for the multi-spectral scanner is shown in Fig. 3. The circuit design for each detector of the four element sensor has three key subparts to them. The first subpart is shown in the blue dotted box in Fig. 3. This part essentially provides the basic biasing voltage to the detector and amplifies the output from the detector. The second subpart is shown in the red dotted box. This part is a lock-in amplifier. It utilizes the signal from the chopper that is placed at the front of the sensor to amplify the detector signal in a locked fashion. This provides for a very high signal to noise ratio (SNR). This high SNR is essential since the radiation level from the background sources are expected to be very low. The last subpart is shown in the green dotted block. This is essentially a low pass filter to remove high frequency noise from the sensor output.

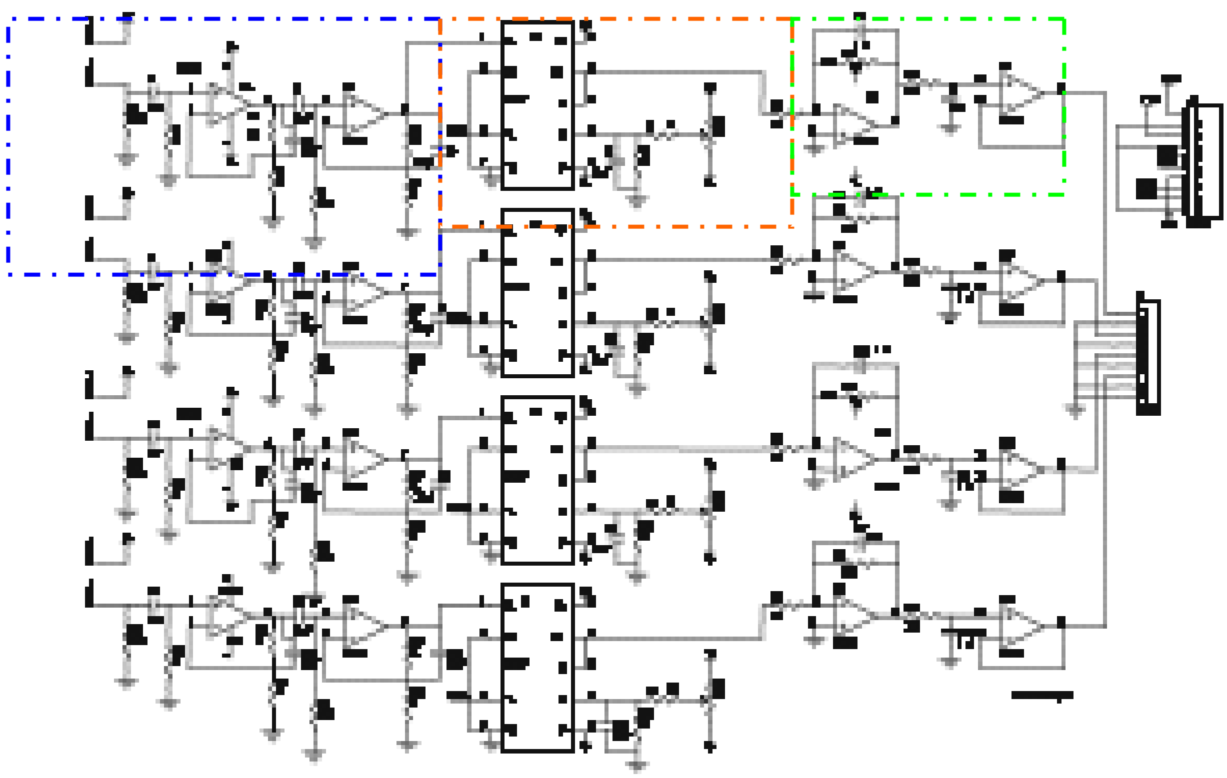

Figure 3. Schematic of the PCB for the multi-spectral scanner.

Two connectors are also provided for interfacing the laboratory multi-spectral scanner to a power supply as well as a computer with an A/D. Five PCB's was fabricated by an outside vendor and shipped to En'Urga Inc. One of the PCB's have been completely populated and bench testing of the PCB with the four element sensor is in progress. Calibration of the sensor is expected to be completed within the next two months.

Mechanical engineering design of the scanner housing was then completed. The scanner is to be fabricated in a modular type construction. The front module houses the lenses and scanners along with a sighting tube and a laser pointer. The read end module consists of the detector, chopper, and PCB.

The CAD drawing of the scanner that was given out for fabrication is shown in Fig. 4. The lenses and scanners are housed in a cylindrical aluminum tube, 3.25 inches in diameter and 4 inches in length. This is the only section that is theoretical required as the front end optics. However, for ease of use during the prototype stage, a laser pointer and a view port has been added. These two additional features increase the length of the front end optics to 5.875 inches as shown in Fig. 4. All detailed mechanical engineering drawings have been turned over to the local machinist for fabrication. Most of the fabricated parts have been delivered to En'Urga Inc.

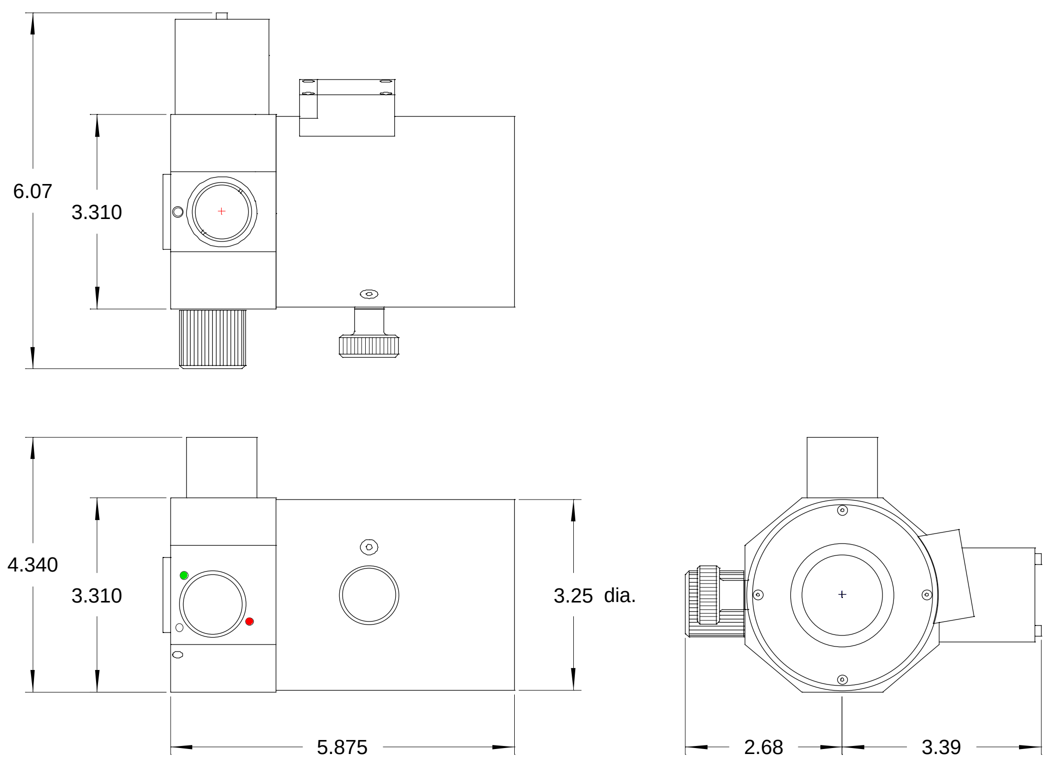

Figure 4. Engineering drawings of the housing assembly for the scanner optics.

The second module that houses the sensor, chopper, and PCB will be completed after the scanner has been assembled and tested. Initially it was planned to utilize an off-the-shelf electronic box. However, the need to mount the sensor on a vehicle for planned field tests at

RMOTC requires some vibration isolation for the sensor. This is currently being designed and will be completed during the next report period.

The data acquisition system which can utilize the scanner triggers and simultaneously grab data from the four elements of the sensor has been purchased. Programming of the data acquisition board has nearly been completed. The data acquisition board and a laptop computer will be used to calibrate the four element sensor.

4. Conclusions

The research project is currently on schedule. The fabricated scanner is expected to satisfy the requirements of high sensitivity and spectral selectivity. Calibration and evaluation of the scanner are scheduled for the next report period. If the calibration and evaluation is successful, then the project is expected to have a significant impact on future pipeline leak detection technology.

5. Tasks Planned for the Next Six Months

The sensor will be calibrated using blackbody source during the next two months. Programming of the data acquisition board will be completed during the next month. The assembly of the mechanical parts of the sensor will be initiated during the next month, and will be completed during the next two months.

The multi-spectral scanner with the A/D system is expected to be completed and calibrated by the end of July for the tests planned in August. During the first two weeks in August, in-house testing of the system with a natural gas pipeline will be completed.