

A Cost Effective Multi-Spectral Scanner for Natural Gas Detection

Semi-Annual Progress Report No. 2

Reporting Period Start Date: April 1, 2004

Reporting Period End Date: September, 2004

Principal Authors: Yudaya Sivathanu, Jongmook Lim and Vinoo Narayanan

Issue Date: October 25, 2004

Contract Number: DE-FC26-03NT41857

Submitting Organization: En'Urga Inc.
1291-A, Cumberland Avenue
West Lafayette, IN 47906

Semi-Annual Progress Report No. 2

on

A Cost Effective Multi-Spectral Scanner for Natural Gas Detection

Yudaya Sivathanu, Jongmook Lim, and Vinoo Narayanan

DISCLAIMER NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

A Cost Effective Multi-Spectral Scanner for Natural Gas Detection

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, a rugged prototype scanner will be developed and evaluated, both at En'Urga Inc. and any potential field sites.

TABLE OF CONTENTS

Title Page	
Disclaimer Notice	1
Abstract	2
List of Figures	4
Executive Summary	5
1. Research Management Report	6
2. Technology Status Report	6
3. Design and Fabrication of Laboratory Scale Scanner	8
4. Evaluation of the Laboratory Scale Scanner	12
5. Tasks Planned for the Next Six Months	15
6. Conclusions	16

List of Figures

<u>Figure Title</u>	<u>Page No.</u>
Figure 1. Schematic diagram of the optical design for the multi-spectral scanner.	8
Figure 2. Optical performance of the scanner/lens combination for the multi-spectral scanner.	8
Figure 3. Schematic of the PCB for the multi-spectral scanner.	9
Figure 4. Photograph of the custom PCB for driving the scanners.	10
Figure 5. Engineering drawings of the housing assembly for the scanner optics.	10
Figure 6. Side view and front view of the scanner assembly.	11
Figure 7. Photograph of the housing with sensor and PCBs.	11
Figure 8. Experimental arrangement used to evaluate the multi-spectral scanner.	12
Figure 9. Photography of the multi-spectral scanner mounted on a tripod.	13

A Cost Effective Multi-Spectral Scanner for Natural Gas Detection

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.

A Cost Effective Multi-Spectral Scanner for Natural Gas Detection

The report is divided into five parts, corresponding to the different tasks completed during the first twelve 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 CO ₂ 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.

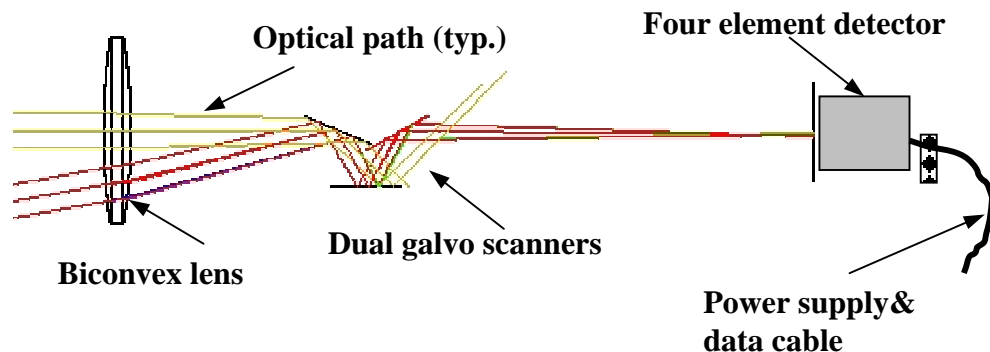


Figure 1. Schematic diagram of the optical design for the multi-spectral scanner.

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.

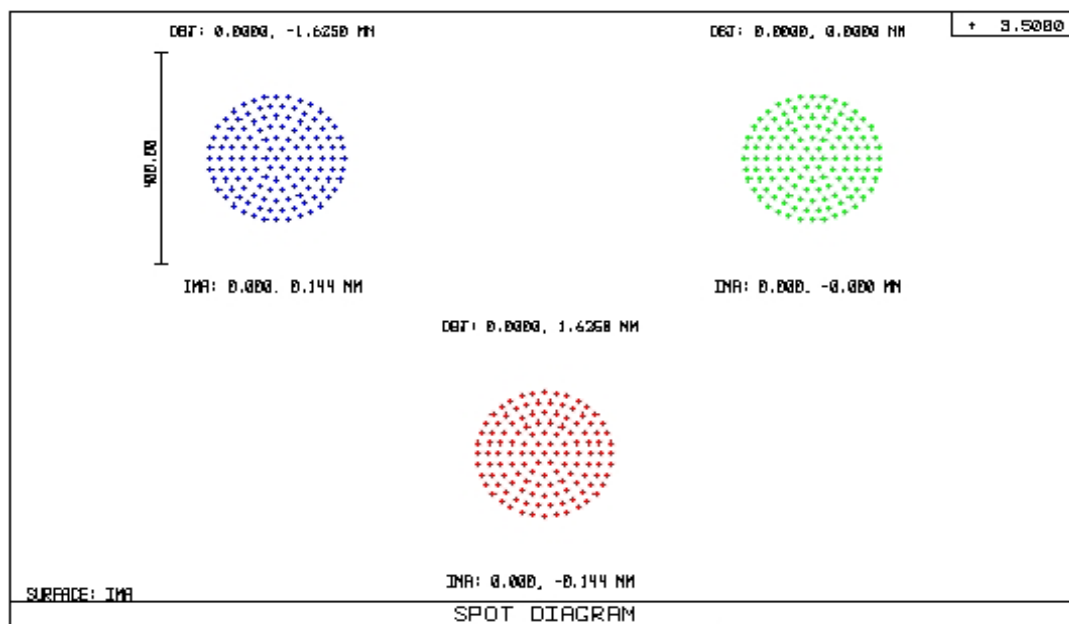


Figure 2. Optical performance of the scanner/lens combination for the multi-spectral scanner.

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 were 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 sensor PCB utilized for the multi-spectral scanner is shown in Fig. 3.

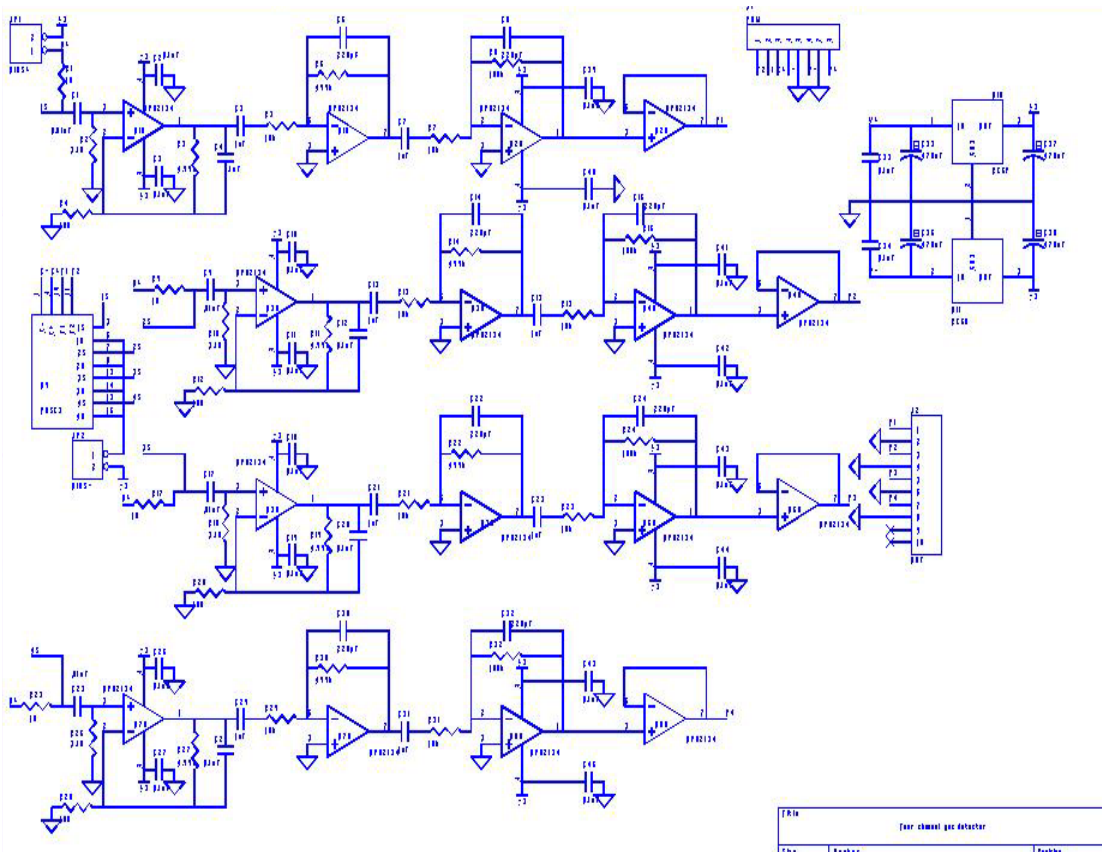


Figure 3. Schematic of the PCB for the multi-spectral scanner.

The circuit design for each detector of the four element sensor has three key subparts to them. The first subpart essentially provides the basic biasing voltage to the detector and amplifies the output from the detector. The second subpart 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 a low pass filter to remove high frequency noise from the sensor output. Two connectors were also provided for interfacing the laboratory multi-spectral scanner to a power supply as well as a computer with an A/D. This is one of the three boards that go into the scanner housing. The second board is the PCB for powering the four element sensor, and amplifying the signals from the detector before sending them out to the data acquisition board.

The last board is the scanner driver. Five PCB's each were fabricated by an outside vendor and shipped to En'Urga Inc. A picture of the PCB populated with the necessary electronic components for driving the scanner is shown in Fig. 4.

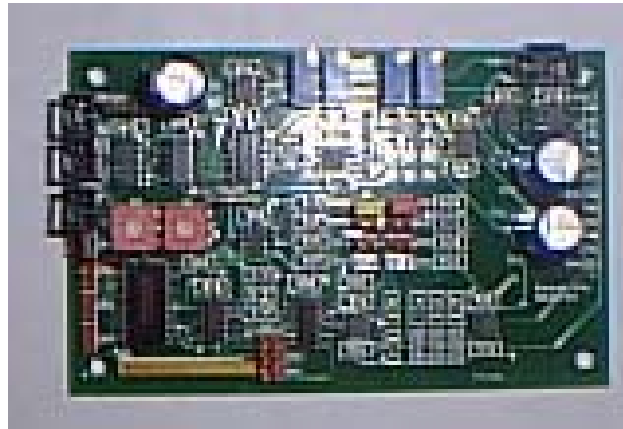


Figure 4. Photograph of the custom PCB for driving the scanners.

The mechanical engineering design of the scanner housing was completed in tandem with the electronic design. The scanner was designed to be modular. 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 engineering drawing of the scanner is shown in Fig. 5.

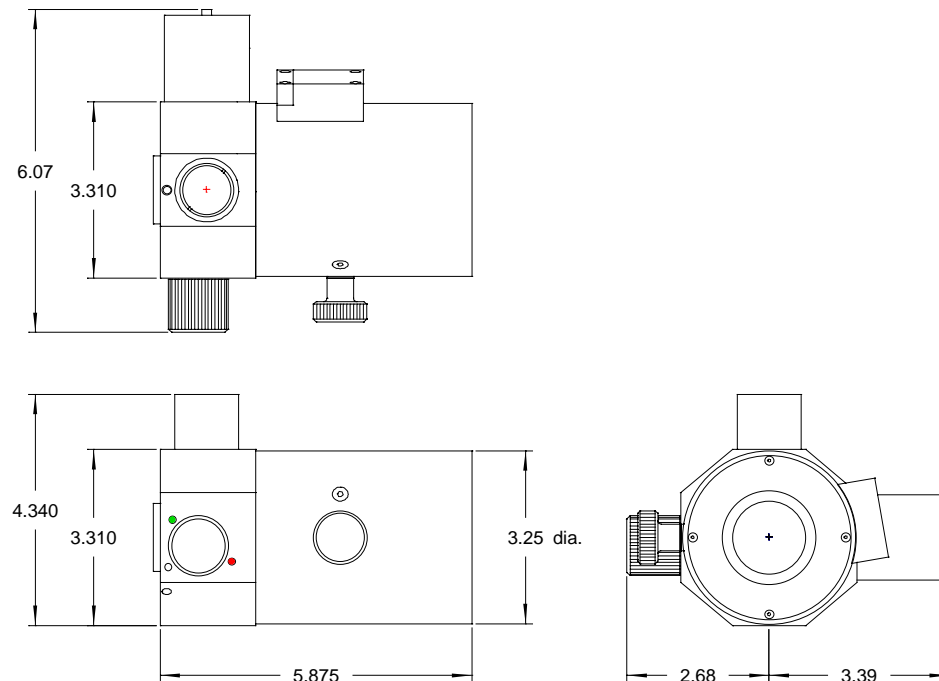


Figure 5. Engineering drawings of the housing assembly for the scanner optics.

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 theoretically 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. A photograph of the fabricated scanner is shown in Fig. 6.



Figure 6. Side view and front view of the scanner assembly.

The side view of the scanner is shown on the left hand side of the figure and a front view of the scanner is shown on the right hand side of the figure. On the left hand side of the side view, a knob for viewing the image visually is provided. The sensor housing mounts directly on the back end of the scanner assembly.

The second module that houses the sensor, chopper, and PCB was completed in an available electronics box. A photograph of the housing for the sensor and the custom PCBs is shown in Fig. 7.



Figure 7. Photograph of housing with sensor and PCBs.

The housing contains the sensor, sensor PCB, and the scanner PCB. In addition, couple of optical elements to image the entrance slit of the housing to the four element sensor is provided within the housing. The entire system is mounted on an optical bench that is floating

inside the housing on rubber pads. The sensor is to be evaluated in the field using a truck. Unlike a stand-alone application, this can cause serious vibration problems. Therefore this modified design was adopted rather than the one specified in the proposal.

The power for the scanner and the four element sensor was supplied from an external power supply box. The scanner housing also has two connectors attached to it. One connector supplies power to the scanner and the four element sensor. Another connector transfers the signal from the multi-spectral scanner to the data acquisition board on the computer. Initial evaluations showed that the amplification circuit had to be modified. Therefore, a new PCB with greater amplification was fabricated and integrated with the sensor. The new circuit provides higher SNR at faster scanner time. This completed Task 3 of the project.

4. Evaluation of the Laboratory Scale Scanner

The last task planned for the first year of the project was to evaluate the scanner. First the scanner was evaluated at En'Urga Inc. using a small natural gas leak. A schematic of the experiment arrangement is shown in Fig. 8.

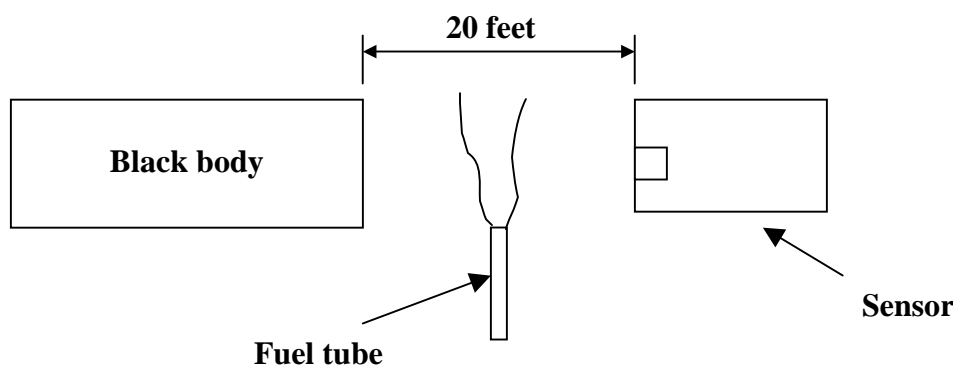


Figure 8. Experimental arrangement used to evaluate the multi-spectral scanner.

A blackbody was placed behind the sensor to mimic the external radiation. A fuel tube was placed in between the sensor and the blackbody. Small amounts of natural gas were passed through the tube. The sensor was easily able to pick up natural gas at flow rates as low as 5 SCFH as scanning speeds of 0.1 Hz. For most stationary and hand mounted operations, these speeds are sufficiently fast. However, the second set of tests planned was at the DoE RMOTC facility. These tests require that a pipeline of 9 miles be scanned in one and a half hour. The above speed of the scanner is too slow. However, it is anticipated that at higher speeds, the scanner will still be able to pick out larger leaks. It was decided to modify the scanner after the RMOTC tests and during the second year if the field evaluations are not satisfactory.

The field tests were conducted during the second week of September, at the RMOTC facility in Casper, Wyoming. For the tests, leaks of different sizes were present along a nine mile corridor. En'Urga Inc. and six other equipment providers used different methods to detect these leaks. For the leak tests performed at RMOTC, the system was mounted on a tripod inside a mini-van. The computer and data acquisition system was also placed within the mini-van.

Data was collected continuously during the drive-through and analyzed later to provide the leak locations. The high speed required to scan a long pipeline from a moving platform, as opposed to a stationary platform, required data collection in one step and subsequent analysis off-line. Therefore, it was not possible to stop at suspected leak sites and obtain more definite data.

A photograph of the multi-spectral scanner, mounted on a tripod is shown in Fig. 9. The



Figure 9. Photograph of the multi-spectral scanner mounted on a tripod.

front end of the system houses the two dimensional scanner. The four element detector, the drive circuit and power supply PCBs are housed in a cast aluminum enclosure. The system is designed to look at a 50 feet wide path across the pipeline.

The pre-test checks conducted were to ensure that the system was obtaining sufficient signals from the background radiation. At Wyoming, during all the tests, a minimum of 0.2 V was obtained from the background radiation at all times. This is sufficient to detect leaks from the natural gas pipe lines.

The data acquisition system collected the voltages on the four channels at a frequency of 10 Hz. Due to the difficulty in changing the orientation of the scanner, only one side of the road was scanned during each run. One continuous file of data was collected for each segment of the road, marked by the road crossing symbols, RC1, RC2, etc. Each file was named RCx-Rcy_date.scn, where x and y are the two neighboring road crossings. The data files were analyzed off-line to determine the absence/presence of natural gas leaks. The location of the leak was approximated by interpolating between the GPS readings of the two road crossing locations, with the ratio being determined by the position of the leak indication in the data file. This was necessary since the current system was not capable of simultaneously obtaining and displaying the leak at sufficiently high speeds required by the specific RMOTC test conditions.

The system was tested on five separate passes. Only a portion of the pipeline was covered during each pass, as described in the following. In addition, most of the test leaks were well beyond 50 feet from the roadway. Therefore, these leaks cannot be detected and only the plumes from large leaks that are far away from the system were detected.

The section of the pipelines scanned, the leaks along that section, and the results obtained from the scanner are shown in Tables 4-8. The tables are broken down into the separate runs for each test. Comments on the performance of the sensor are also provided in the tables

Table 4: September 13, Morning Run

Leaks along scanned pipes	Leak detected		Comments
	Yes	No	
1	X		Calibration leak close to road
2B		X	Small leak, 78 feet from road
	X		Some plume detected probably from upstream location 5
6	X		Plume detected

Table 5: September 13, Afternoon Run

Leaks along scanned pipes	Leak detected		Comments
	Yes	No	
1	X		Calibration leak close to road Plume possibly detected at RC2
3		X	Big leak, 44 feet from road, even the plume was not detected, could be due to a very high wind condition
4		X	Small leak, 90 feet away
5		X	Leak not detected at site, 59 feet from road and uphill. Therefore leak location not scanned
P2	X		Plume detected, could be from 6
P5		X	Very small leak

Table 6: September 14, Morning Run

Leaks along scanned pipes	Leak detected		Comments
	Yes	No	
1	X		Calibration leak close to road
3	X		Big leak, 44 feet from road
4		X	Medium leak, 90 feet from road
2D		X	Small, 100 feet from road
5	X		Plume detected downstream
6		X	Small leak 170 feet from road
	X		A plume detected here, probably from upstream location
P5		X	Very small leak

Table 7: September 14, Afternoon Run

Leaks along scanned pipes	Leak detected		Comments
	Yes	No	
1	X		Calibration leak close to road
	X		Some plume detected here, probably from upstream location 3
P1	X		Big leak 78 feet from road
P2		X	Small leak, 240 feet from road

6		X	Small leak 170 feet from road
P3		X	Small leak, 114 feet from road
P4		X	Medium leak, 66 feet from road

Table 8: September 15, Morning Run

Leaks along scanned pipes	Leak detected		Comments
	Yes	No	
1	X		Calibration leak close to road Also plume detected at RC2 Calibration leak close to road
2C		X	Small leak, 122 feet from road
3		X	Small leak, 44 feet from road
4	X		Plume detected downstream
2D		X	Small leak 100 feet from road
5		X	Leak not detected at site, 59 feet from road and uphill. Therefore leak location not scanned
			Some plume detected here, probably from upstream location P4
P5	X		Very small leak

Based on tests, we drew the following conclusions.

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. Tasks Planned for Next Report Period

During the second year of the project, a rugged prototype sensor will be designed and fabricated. During the next six months, the design of the prototype sensor is expected to be complete. In addition, fabrication of parts of the prototype sensor will be completed. During the last six months of the project, the sensor will be assembled and evaluated, both at En'Urga Inc. as well as potential field sites.

6. Conclusions

This research project is currently on schedule. Laboratory evaluation and field evaluation of the scanner shows the feasibility of the system. It is unfortunate, that the field evaluations could not be used to set limits on the sensitivity of the sensor. It is hoped that during the second year, a further round of tests at RMOTC, with access provided directly over the pipelines is possible. This would allow the sensitivity limits on the sensor to be fully established.