Oil & Natural Gas Technology

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Semi-Annual Progress Report
(4-1-07 to 9-30-07)

Wireless Self-Powered Visual and NDE Robotic Inspection System for Live Gas Distribution Mains

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SEMI-ANNUAL TECHNICAL PROGRESS REPORT

Reporting Period:
04-01-2007 to 09-30-2007

compiled as part of the project titled

Explorer-II:

Wireless Self-powered Visual and NDE Robotic Inspection System for Live Gas Distribution Mains

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I. Executive Summary

CMU completed the scripting and testing of the robot's launching and retrieval capabilities. Verification of the same was carried out in a field-fitting and gate-valve on a spool-piece fitted for the laboratory test setup. In addition to dozens of launches/retrievals, CMU also tallied dozens of obstacle turns (elbows, Ts and Ys) in preparation for the acceptance demonstration.

The SwRI RFEC sensor module was also added to the train (with preliminary integration) in order to carry out the acceptance demonstration of the system to the sponsoring government and industrial entities. During the demonstration the trains ability to negotiate pipes, including in scanning mode, as well as launch and recover the system, were demonstrated and data was relayed live to the audience with video-feed and live interpretative data-displays of the pipe-wall thickness being inspected.

CMU also completed the integration of the sensor with SwRI in time for complete pressure-tests in air (pressure tolerance) as well as natural gas (chemical inertness and safety-level). The former was carried out at CMU using the launch-tube as the test pressure vessel and pressurized air to 750 psig, while the latter was carried out with a partnering utility near Pittsburgh with natural gas in the launch tube at 500 psig. Both tests were completed successfully (with a minor camera-imager upgrade) without any noticeable degradation or performance reduction of the system.

The final month of this reporting period culminated in a field-trial in a live 8-inch gas main in rural mid-western PA (Brookville, PA) under the auspices of the partnering utility National Fuels, Inc. The robot system was deployed multiple times (4+) through a live launch-setup into the live main and travelled 2,950 feet total and generated ~400 feet of inspection data over a total of the 5 days on site, with about a total of 4+ hrs. of in-the-pipe runtime (excl. out-of-pipe preparation and launcher setup/purging/pressurization time).

II. Work Results during Reporting Period

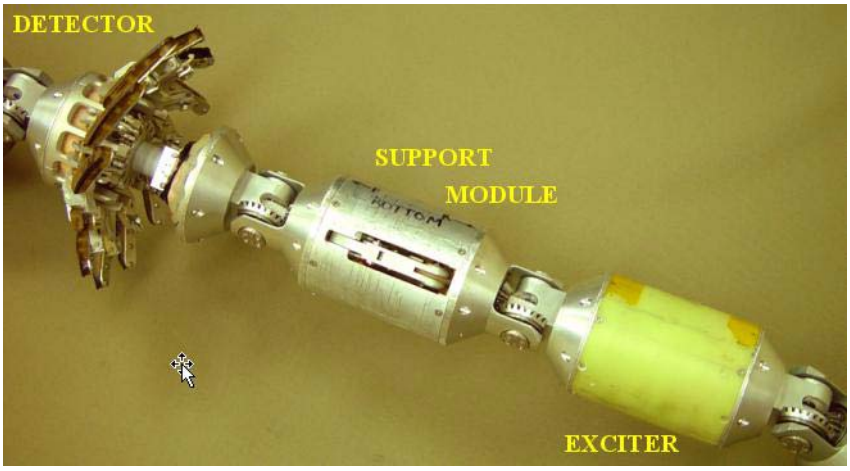
During the current reporting period for this project, the following main activities and associated outcomes took place in this project:

- **Robot Obstacle Handling Testing completed - Launch/Recovery**

  The complete robot train was successfully used with a customized script to launch and recover through a filed-fitting, valve and spool pipe-section in the laboratory. Multiple dozens of launches and recoveries were carried out to verify the repeatability and robustness of the platform and launch-script. An image of the test-setup and the hardware (fittings & valve) and the robot, are shown below:

- **SwRI RFEC Sensor successfully integrated onto robot train**

  The RFEC sensor was successfully integrated onto the robot train over multiple months of testing and repairs at SwRI until its final successful integration in late August 2007 prior to being pressure and live-NG tested. An image of the two sensor-module sections (sensor and exciter), are shown below:



- **Acceptance Demonstration of system at CMU**

The complete robot, sensor and GUI systems were demonstrated to the sponsors (DoE, NGA & DoT) on June 7th, 2007. The demonstration consisted of a complete launch, 90-deg elbow and T-turn drive through about 25 feet of 8-in pipe, and a subsequent run in a a corroded pipe to show off the real-time data-collection and display capabilities of the sensored train to the audience on a large visual display. Selected images from the demonstration run are shown below:

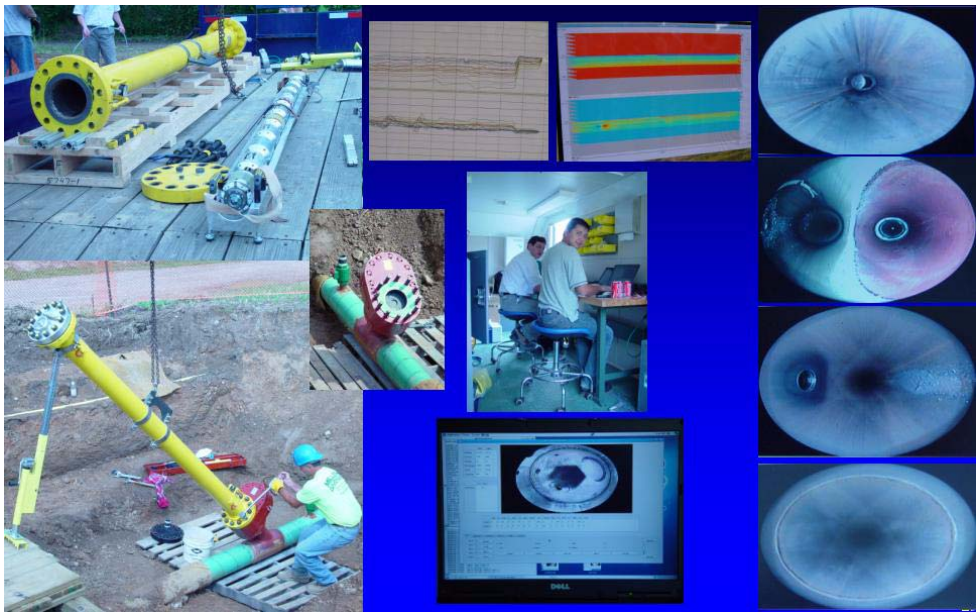
- **Pressure and Safety Testing of the complete system**

The complete robot (incl. the RFEC sensor) was tested in the launcher-tube with pressurized air to 750 psig, without any component failure being evident. Only a camera-upgrade was needed and tuned focussing on the imager to eliminate excessive image de-focussing during pressurization.

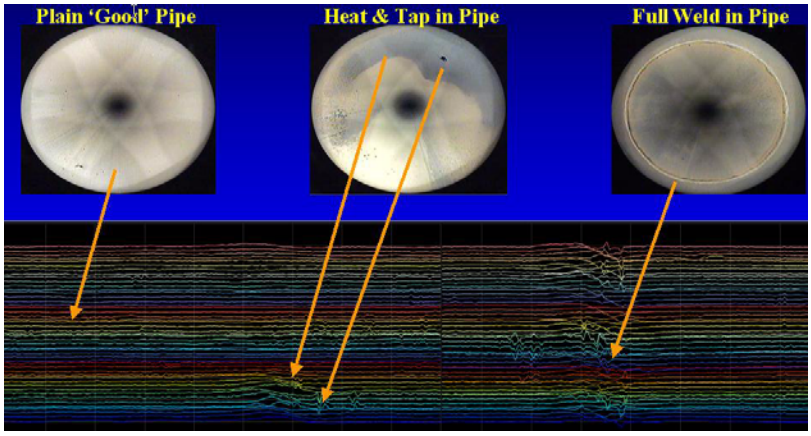
In addition, the robot and launcher were brought to a natural gas test station in NW PA (Henderson), and with the assistance of National Fuels technicians, the system was pressure and safety-tested (incl. all purging and powering procedures) to 502 psig in natural gas without any problems and without losing any functionality nor degrading its performance. Selected images from the NG testing setup are shown below:

- **Field-Trials in a live field-pipeline**

The CMU and SwRI team spent a week in the field in Brookville, PA at a site supplied by National Fuels, Inc. (NFI) to deploy and 'image[1]' a live 8" steel main operating at around 100 psig. The CMU-supplied fittings and valve were provided to NFI ahead of time for installation and readiness along a rural site along Rte. 28. The week was spent overcoming both a robot drive-failure (with subsequent retrieval and repair for continued operation), as well as re-installation of flawed antenna-fittings and removal of steel-coupons from the line prior to being able to complete multiple runs during which the robot collected visual as well as sensory-data to provide as a baseline data-set for said pipe-section to NFI for potential submission to DoT. A few selected images from the field-trial are shown below, including the excavation and fitting/launch setup, operators and their GUIs (robot and sensor), as well as imagery from inside the main showing launcher, clean pipe, taps as well as weld-seams.



In addition, a preliminary (uncalibrated) data-set was collected that clearly shows the correlation between imaged features in the pipe (weld, tap, heat-affected zone) as well as a set of sensor data verifying that a section of pipe corresponding to the data was seemingly free of flaws and defects[2].



1. both via camera imagery and RFEC sensors
2. a final report for the data was to be generated and provided by SwRI to NGA and DoT

III. Milestones

The main milestones we were able to meet (based on the proposal) were as follows:

- **Launching and Retrievals completed successfully (4+ dozens)**
- **Obstacle-handling (Elbows, Ys and Ts) completed successfully (3+ dozens)**
- **Acceptance Demonstration successful to DoE, NGA & Dot - June 2007**
- **Successful Integration of SwRI RFEC NDE Sensor - August 2007**
- **Successful Pressure testing in air to 750 psig without failure - August 2007**
- **Successful NG pressure-test (for safety) to 750psig - August 2007**
- **Successful 1-week field trial on 8" live gas main in Brookville, PA - September 2007**

IV. Cost and Schedule Status

1.0 Cost

•Approved Budget:	**$1,778,635.-**
•Spent to date (Sep. 30, 2007):	**$1,386,377.-**
•Funds Remaining:	**$ 392,258.-**
•% of funds expended	**77.95%**

2.0 Schedule Status

The CMU team is on track as planned and proposed. The current program has been extended, with a propose completion-date of September 2008.

•% of Phase I expired (Oct'04 -Dec. 2005)	**100%**
•% of Phase II expired (Jan'06-Sep. 2008)	**73%**

V. Accomplishment Summary

The following accomplishments can be summarized as having occurred during this reporting period:

1. Completed all functional system testing - May 2007
2. Completed extensive indoor pipe network obstacle handling & launching - June 2007
3. Successfully completed Acceptance Demonstration to DoE/NGA/DoT - June 2007
4. Continuously engaged with SwRI to integrate the RFEC NDE Sensor - Jun.-Aug. 2007
5. Completed more extensive endurance testing and outdoor operations - August 2007
6. Successfully completed pressurized air testing of unit to 750 psig - August 2007
7. Successfully completed natural gas pressure test to 502 psig - August 2007

8. Completed week long field trial in live 8” gas main in PA - September 2007
9. Completion and submission of semi-annual report - September 2007

VI. Activities Planned for next Reporting Period

The following activities are being planned for the next semi-annual reporting period (Oct.’07 - Mar’07):

1. Ordering additional drive/battery/support modules for robot train
2. Developing modified driving/launching scripts for expanded MFL robot train
3. Commissioning a dummy permanent-magnet MFL sensor mock-up for testing
4. Submitting next semi-annual report to DoE - April 2007

VII. Actual and Anticipated Problems

CMU did not expect the very lengthy RFEC sensor-integration period due to its need to be upgraded and modified several times as part of the testing results by SwRI in TX. This required multiple dis-assemblies spanning weeks and multi-week efforts by the CMU team to collaborate with the SwRI sensor team. The effort did in the end pay off, as the sensor was successfully integrated in time for the pressure tests and the field-trial.

The overall field-trial logged number of launches/recoveries and distance travelled was much smaller than expected, due to the fact that we had a robot drive-failure, as well as substantial in-field problems with the OEM launching and fitting setup that the utilities and contractors successfully resolved, but at the price of several days loss in run-time.

Nonetheless, CMU and SwRI were able to carry out multiple live in-pipe launches/recoveries as well as scans inside a live 8” natural gas main in Brookville, PA owned by National Fuels, Inc.

The next portion of this phase will focus on an expanded robot train, which will have its challenges in terms of the fabrication, integration and re-programming, which we expect to carry out as proposed based on the experience we have gathered so far.

VIII. Technology Transfer Activities

The CMU team has filled out and submitted an Explorer-II internal Invention Disclosure Form to its Intellectual Property Office. NGA and CMU continue their efforts to fully transition the Explorer-II based technologies and know-how to NGA for successful commercialization by the end of this phase (Fall 2008). NGA continues to be in discussions with several sub-licensees for the complete system technologies.

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