

Semi-Annual Progress Report  
submitted to  
The Department of Energy (DoE)  
National Energy Technology Laboratory (NETL)

under

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for

**SEMI-ANNUAL TECHNICAL PROGRESS REPORT**

**Reporting Period:**

**10-01-2006 to 03-31-2007**

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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*submitted by*

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## **I. Executive Summary**

CMU completed the robot train prototype fabrication. The software development effort, at both the 8- and 32-bit levels, including the OCU, were completed and debugged and readied for obstacle test-script development and launching/recovery experimentation. During this reporting period, CMU successfully developed, debugged and demonstrated the robot's ability to automatically navigate the elbow, Y and t-turn obstacles required for implementation - a demonstration of this capability was given to the NGA-PM.

In addition, CMU developed the early stages of the angled launch/recovery scripts using an 8-inch pipe and a vertically-set Y-fitting - said experimentation was successfully completed. By the end of the reporting period, both the fitting, valve and pipe-spool pieces arrived from the manufacturer to develop the final and refined launching and recovery scripts based on a realistic field setup. This activity will be one of the main foci in the next reporting period in preparation for endurance and field-trial testing.

CMU also interacted with SwRI, the selected sensor provider. SwRI sent its brass-board electronics PCB setup with prototype software for communications control debugging in conjunction with the CMU robot-train and the OCU. Several software improvements both on the CMU- (already implemented and tested) and the SwRI side were identified. It is anticipated, based on SwRI projections, that the final fully-integrated RFEC sensor-modules will not be available for integration and testing until late April'07.

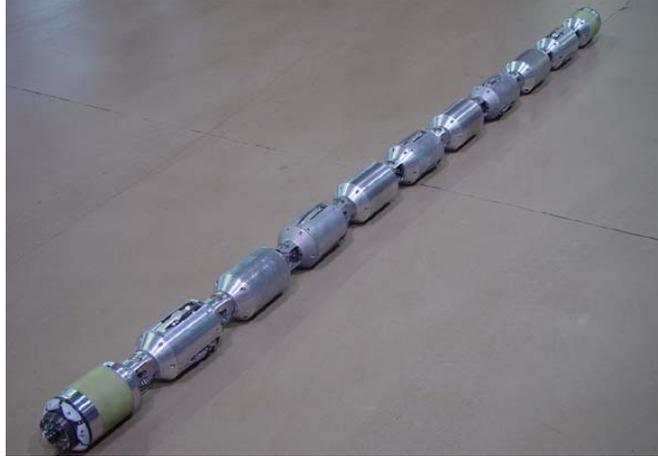
Software integration and debugging will continue for both the real-world setup for launching and recovery, as well as sensor integration and endurance-testing. Final pipe mock-up testing is expected from late April to late May 2007 with an acceptance demonstration planned to NGA/DoE/DoT by early June 2007. Continued complete system testing and endurance evaluations will continue in the outdoor test loop at CMU through July 2007, after which a final acceptance demonstration will be given to both NGA and the technology licensor and the field-trial utility(ies). A final field-trial in a pressurized live main are scheduled for sometime in August 2007, with a final report expected by September 2007, including the technology transfer to NGA and its designated licensee.

## 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:

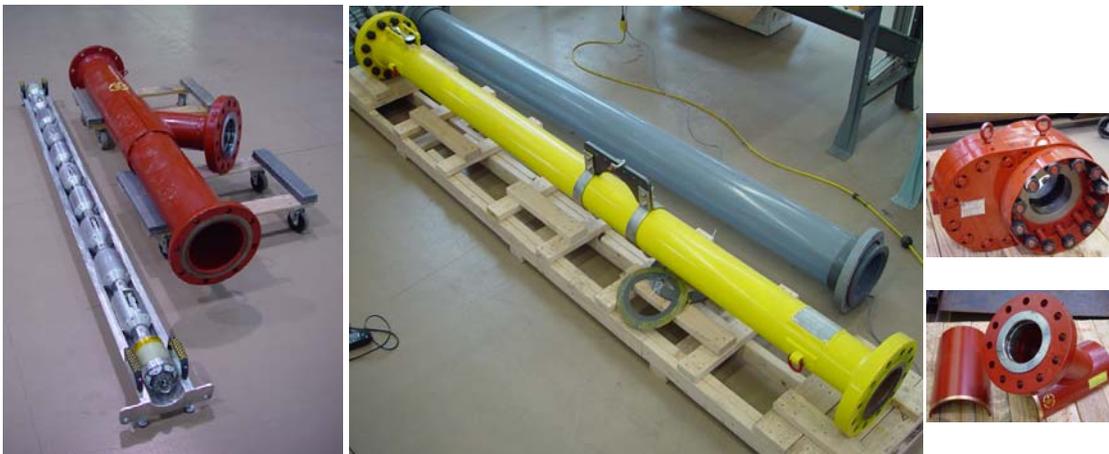
- **Prototype Assembly Activities**

The complete robot train, including debugged 8- and 32-bit software was completed by mid-reporting-period, including two dummy-modules to represent the sensor-modules (not yet available - originally scheduled for Jan'07, the new date was set by SwRI for Apr'07). An image of the complete robot-train assembly is shown in the image below.



- **Launcher Tube**

The launcher tube, as designed, was fabricated and delivered to CMU. It is available for adding to the field-fittings that were ordered and received in late March '07. Both the launcher tube and the fitting and pipe-sections for final launching/recovery testing are shown in the image below



- **Automated Obstacle Handling Software Development and Debugging**

The software development team, for both 8-bit and 32-bit embedded code as well as the topside GUI control and interface software spent the entire reporting period developing the software needed for script-development and testing. The goal was to complete automated turning routines based on gravity, angular and odometry feedback, to allow the robot to make turns in 90-deg and 45-deg elbows and Ys, as well as sharp Tees. This effort was completed successfully and required tuning and adjusting multiple hardware and software controller and planner parameters to reliably perform these movements. A demonstration of successful navigation for each of these three obstacles types (elbow, Y, T) was given to the NGA-PM.

- **Sensor Provider Interactions**

CMU hosted a 1-week visit by the SwRI lead embedded software engineer in late Mar'07. A brass-board setup of the electronics PCBs, running prototype software and interconnected by wire-harnesses, was hooked up to computers and the robot on the bench at CMU. CMU modified its CAN-messaging to suit the SwRI implementation and updated its operator interface ethernet protocol. Several bugs in the SwRI implementation of the communications software were uncovered, which SwRI promised to have fixed by the next visit. The next visit is intended to include the complete hardware set of modules with all internal harnessing and mounted PCBs and the ability to control the sensor-head and send/receive control strings and forward data from the head to the sensor control computer besides the operator. We are expecting the delivery of said modules by mid- to late April 2007.

### **III. Milestones**

The main milestones we were able to meet (based on the proposal) was the completion and debugging of the robot and control station software (Oct.'06). CMU also developed, tested and demonstrated the horizontal obstacle driving capabilities to NGA (Dec'06). CMU then developed and debugged and video-taped their ability to perform and angled launch through a larger pipe and vertical 45-Y fitting (Feb'07). SwRI came to CMU and CMU helped uncover several bugs on the electronics-only brass-board that SwRI provided, including several on the CMU side which were immediately fixed (Mar'07). We expect to host SwRI with their complete sensor-module assembly later in Paril'07, allowing us to complete sensor-integration and debugging activities leading to a field-trial by (new revised date) of June 2007, as long as the sensor-module delivery is not delayed beyond late April 2007. Prior to field-trials, CMU will also undertake endurance testing in their outdoor test-loop with the RFEC sensor, and demonstrate the system to NGA/DoE/DoT in both Jun'07 (X-II and Sensor Integration demonstration) as well as Jul/Aug'07 (prior to field-trials).

### **IV. Cost and Schedule Status**

#### **1.0 Cost**

• <b>Approved Budget:</b>	<b>\$1,378,815.-</b>
• <b>Spent to date (Mar. 31, 2007):</b>	<b>\$1,312,362.01</b>
• <b>Funds Remaining:</b>	<b>\$ 66,452.99</b>
• <b>% of funds expended</b>	<b>95.18%</b>

#### **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 July 2007.

• <b>% of Phase I expired (Oct'04 -Dec. 2005)</b>	<b>100%</b>
• <b>% of Phase II expired (Jan'06-Jul. 2007)</b>	<b>79%</b>

### **V. Accomplishment Summary**

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

1. Complete software and hardware checkout on the bench completed - October 2006
2. Turning routines developed and debugged - November 2006
3. Demonstration & video-recording completed for the 45/90/tee turns - December 2006
4. Launch-chamber received - December 2007
5. Spares and stand-by sub-system and module assembly completed - January 2007
6. Angled launching scripts in development and in debugging - February 2007
7. Angled launch testing in dummy pipe and 45-fitting completed - March 2007

8. Brass-board SwRI electronics testing completed - March 2007
9. Final fitting and test-pipe received for testing - March 2007

## **VI. Activities Planned for next Reporting Period**

The following activities are being planned for the next semi-annual reporting period (Apr.'07 - Aug.'07):

1. Robot capable of inclined (45-deg) launch & recovery - April 2007
2. SwRI RFEC-sensor delivery and readiness for integration - April 2007
3. Sensor fully integrated into robot with multiple pipe-runs completed - May 2007
4. Preliminary integration test-results of remote sensing in pipe-loop - March 2007
5. Acceptance demonstration to NGA & licensee - June 2007
6. Sensor fully integrated with multiple pipe loop sensing run data sets - June 2007
7. Final integration work and final GUI completed and integration validated - July 2007
8. Final acceptance test-runs completed and demonstration to sponsors - July 2007

The following activities are planned for the final reporting period (Aug.'07 - Sep.'07):

9. Readiness preparation and planning for field-trial completed - July 2007
10. Field-trial completed with licensee and demonstrated to sponsors - August 2007
11. Final report finalized and submitted to DoE - September 2007

## **VII. Actual and Anticipated Problems**

CMU has been delayed in its sensor integration tasks due to the late availability of the SwRI RFEC sensor (originally Jan'07, then Feb'07 and not expected until Apr'07 now). This pushes all testing and evaluation and endurance activities later in the schedule.

We expect that during the actual running of the complete (train to include sensor) robot in the indoor pipe-segment we will be discovering additional issues that will need to be fixed and resolved. The main reason is that this will be the first time that the system will be run with the complete sensor assembly generating and transferring data.

The interactions with SwRI as the selected single sensor-provider will conclude in the next reporting period and will also no doubt yield additional interface issues (electrical and software issues will hopefully have been resolved by SwRI by then based on the initial testing) that will be resolved as we go in the course of the integration efforts remaining in 2007. The goal will be to solve any problems so that during the remaining sensor-module integration effort, no road-blocks will be encountered, allowing for field-trials and successful technology transition/licensing to NGA by mid- to late-2007. It will in the end depend primarily on the delivery of the RFEC by SwRI and any integration issues that remain to be worked out.

## **VIII. Technology Transfer Activities**

NGA and CMU will 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 2007). NGA is currently in discussions with several sub-licensees for the complete system technologies.