Semi-Annual Progress Report
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SEMI-ANNUAL TECHNICAL PROGRESS REPORT

Reporting Period:
04-01-2006 to 09-30-2006

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 prototype module-building effort and has assembled the first incarnation of the X-II robot train using dummy sensor modules. The system will now be tested and software integration and debugging will begin. The goal will be to have the system operational and able to drive and circumvent obstacles before the end of CY 2006 for a demonstration to NGA as part of their technology licensing efforts.

This reporting period saw multiple activities in the areas of (i) assembly of components (custom and OEM) into subsystems and individual modules (multi-units built for the robot train), (ii) development of 8- and 32-bit embedded software for communication (CAN and wireless), (iii) drafting of a GUI layout for the operator and (iv) overall assembly of the robot-train with stand-in (weighted and dimensioned) sensor-modules (2 ea.).

CMU also interacted with SwRI, the selected sensor provider. We participated in their kickoff and final design reviews and provided substantial input to ensure the success of integration in early 2007. CMU also built and programmed a CAN-protocol simulator for the SwRI integration effort, allowing SwRI to test and certify their protocol (one-directional) prior to shipping the sensor unit(s) to CMU for integration.

Software integration and debugging is well underway, and will result in porting and debugging on the module- and train-levels over the next few months. Final pipe mock-up testing is expected in late Fall and early winter 2006 with an acceptance demonstration planned to NGA by the end of 2006 for the purposes of technology licensing (demonstration to selected licensee). A video summary of the system demonstration will be provided to the DoE COTR before the end of 2006 as evidence of the successful demonstration.

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:

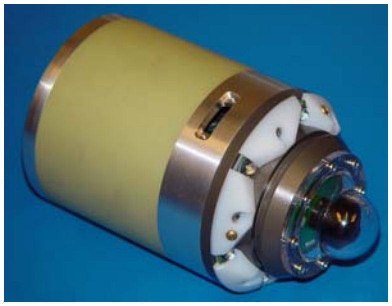
- **Prototype Building and Integration**

  The approved system design, and pre-prototype testing was completed in the previous phase, and as part of this phase resulted in the building and assembly of the individual robot modules and the integration of the same into a robot train (with dummy sensor-modules as place-holders).

The main elements of the robot that were built, include:

-*Camera-Module*

The nose- or camera-module was built to integrate computing, wireless communication, video-sensing and lighting and emergency-locator systems into a single monolithic module. The resulting prototype is shown in the inset image.



-*Steering-Module*

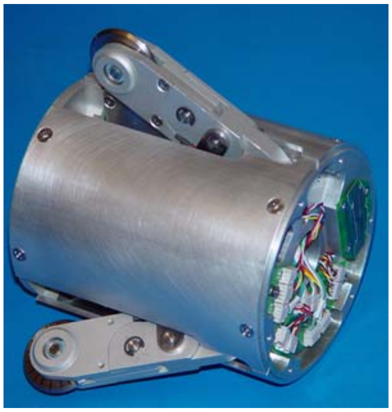
The steering module prototype includes the ability to roll and pitch any so-designed joint using motors and custom gearing and control electronics. The setup of the joints is based on allowing the ends of the train to roll, while all other joints only pitch. The common steering joint prototype is shown in the inset image.

-*Drive-Module*

The drive-module prototype was completed and includes the ability to center and brace the module inside the pipe and allow for the driving of the legged arm-wheels. All the required mechanical elements and electrical PCBs and subsystems were integrated into a final prototype reflected by the inset image.

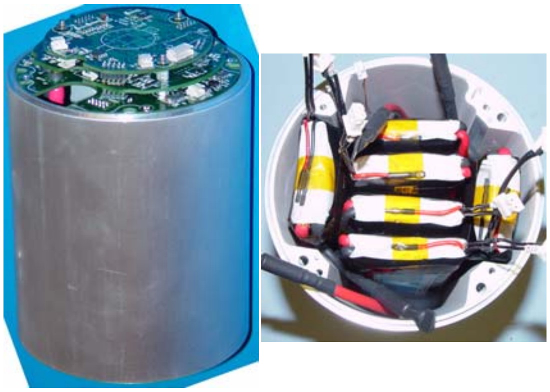
-*Support-Module*

The support module was prototyped and is to provide the necessary centration and passive encoding for position determination. The necessary mechanical and electrical systems were integrated and reflected in the inset image of the prototype for said module.



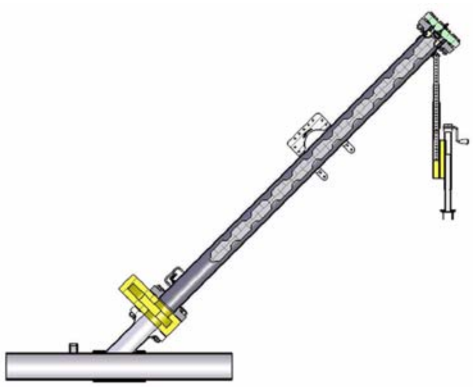
-*Battery-Module*

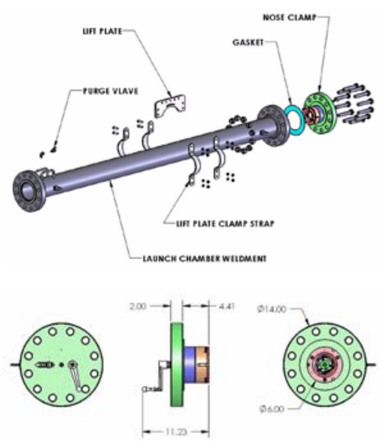
The battery-module prototype is based on the use of lithium-based battery-cells combined into packs to provide 26 VDC and up to 15 Ahrs of energy to the robot for a meaningful 8-hr. mission. The battery-module now contains safety electronics and voltage converters to allow monitoring of charge and discharge. An image of the prototype of the module is shown in the inset image.



•Launcher Design

The launcher design was completed based on the selection of TDW fittings. An angled fitting approach was selected, and the launch-chamber and associated endcap unit were designed and released for quote and fabrication. A layout of the launcher-design is shown in the inset image, including the endcap.





- **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 communications (CAN) between modules, as well as off-train (wireless), developing code for on-module control and monitoring (motor-controllers and feedback sensing), coupled to the 32-bit SBC which was to orchestrate combined and multi-joint motions to allow the robot train to move and articulate in a coherent fashion. In addition, software development was undertaken to create a reliable digital video-stream connection with bi-directional control and status data over the wireless connection to the operator control computer and the GUI. This effort was in preparation for the script-development and testing effort for the indoor and outdoor pipe network for a acceptance demonstration to the NGA before the end of CY 2006 (to be reported on in the next semi-annual report).

- **Sensor Provider Interactions**

The CMU PI travelled to a kickoff as well as a final design review at SwRI for the RFEC sensor module. Feedback was continually provided to the sensor team to ensure their sensor module would meet the required specifications and would be as easily integrated as possible.

CMU interacted with SwRI to define and test the CAN-based on-robot communications bus protocol, by drafting and finalizing a standard recorded in a document, and by also building, programming and sending SwRI a stand-alone CAN-simulator PCB that allowed SwRI to test their CAN-based interface (hardware) and protocol (software) implementation.

- **Prototype Assembly Activities**

The robot modules described in the previous section, were assembled in multi-unit quantity and then coupled in a pre-determined sequence to form the robot train for testing. The train was to utilize stand-in (weighted and sized) 'dummy'-modules to represent the sensor-modules to be provided by SwRI later in this phase (early 2007).

- *Prototype module assembly*

A complete set of modules to assemble a robot train was built and assembled, including all electro-mechanical (active & passive) components, circuit boards and internal wiring. An image of the partial set of modules is shown on the inset image

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- *Prototype robot train*

A complete robot train was assembled on the bench, and used to port low-level code and test out all electronic and wire harnessing at the low-level. The SBC software core OS was loaded and is being used to begin the testing of coordinated behaviors and control, as well as wireless communications. The goal will be to run the robot off its own batteries with weeks and to perform all communications wirelessly once at that stage. That will allow the software development team to begin the development and debugging of turning and obstacle-handling routines in the indoor pipe-network. An image of the complete robot-train assembly is shown in the image below - note that not all covers are on all the modules as of this time, allowing the electrical and software team members to conclude the final low-level control software debugging.

III. Milestones

The main milestones we were able to meet (based on the proposal) was the completion of the robot assembly for all modules and the train (Sep.'06). CMU also attended the SwRI sensor design review(s) and provided input to the sponsors (DoT). We expect to be able to meet the robot-train (without sensor) integration, testing and demonstration milestone as expected by the end of CY 2006, as well as the 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 much beyond January 2007.

IV. Cost and Schedule Status

1.0 Cost

•Approved Budget:	**$1,378,815.-**
•Spent to date (Sep. 30, 2006):	**$1,109,549.-**
•Funds Remaining:	**$ 269,266.-**
•% of funds expended	**80.5%**

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.

•% of Phase I expired (Oct'04 -Dec. 2005)	**100%**
•% of Phase II expired (Jan'06-Jun. 2007)	**50%**

V. Accomplishment Summary

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

1. Design review kickoff for sensor-module at SwRI - April 2006
2. Subsystem assembly and module assembly begun - June 2006
3. Main components (OEM) all received at CMU - July 2006
4. Final sensor design review at SwRI - August 2006
5. All system modules assembled & robot train in assembly - September 2006
6. Module control software (8-bit level) completed and debugged - September 2006

VI. Activities Planned for next Reporting Period

The following activities are being planned for the next semi-annual reporting period (Oct.'06 - Mar.'07):

1. Complete robot train assembly running on battery & wireless - October 2006
2. Robot capable of T, elbow and 45 obstacle navigation (manual) - November 2006
3. Launch chamber assembly completed - November 2006
4. Robot capable of automated turns (t, 90, 45) in horizontal plane - December 2006
5. Acceptance demonstration to NGA & licensee - December 2006
6. Robot capable of inclined (45-deg) launch & recovery - January 2007
7. Endurance testing (multiple Ts, Ys and elbows) completed - February 2007
8. SwRI RFEC-sensor delivery and readiness for integration - February 2007
9. Preliminary integration test-results of remote sensing in pipe-loop - March 2007

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

1. Sensor fully integrated with multiple pipe loop sensing run data sets - April 2007
2. Final integration work and final GUI completed and integration validated - May 2007
3. Final acceptance test-runs completed and demonstration to sponsors - May 2007
4. Readiness preparation and planning for field-trial completed - June 2007
5. Field-trial completed with licensee and demonstrated to sponsors - June 2007
6. Final report finalized and submitted to DoE - July 2007

VII. Actual and Anticipated Problems

CMU had to make minor improvements and changes to the electro-mechanical design of the drive and steering motor-stages due to as-built variations from the manufacturer. Wiring the individual modules was the biggest investment in time for the assembly, as was the assembly, tuning and calibration of the strain-gauge beams for contact-force measurement.

We expect that during the actual running of the 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 sued to develop the actual scripts that will allow the robot to make the turns and launches in an automated fashion. We are also expecting additional development required for the odometry system (reliability, repeatability and accuracy are critical) as well as continuous improvements to the system GUI.

The interactions with SwRI as the selected single sensor-provider will continue in the next reporting period and will also no doubt yield additional interface issues (primarily electrical and mostly software-related) that will be resolved as we go in the course of the integration efforts in early 2007. The goal will be to ease any problems so that during sensor-module integration in early 2007, no road-blocks will be encountered, allowing for field-trials and successful technology transition/licensing to NGA by mid-2007. Towards that end, CMU and SwRI have worked out several paths, including CAN-simulator hardware and software exchanges as well as the possibility of an over-the-internet pre-debug test-phase (TBD).

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 (June 2007). NGA is currently in discussions with several potential sub-licensees and is expected to make a final selection by the end of calendar year 2006.