Semi-Annual Progress Report
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National Energy Technology Laboratory (NETL)

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for

SEMI-ANNUAL TECHNICAL PROGRESS REPORT

Reporting Period:
10-01-2007 to 03-31-2008

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 has updated the robot's kinematic model, turn scripts and communication protocols to accommodate integration of extra modules necessary to carry heavier sensors.

CMU also introduced a new configuration map mechanism that encapsulates configuration of individual modules as well as of the train, and facilitates switching between basic and extended platform configurations, modifying and replacing modules, and keeping track of individual module parameters.

In parallel, CMU developed a CAN software update mechanism for 8-bit controllers, which enables faster and easier software updates over the entire robot, particularly for development and debugging and for configuration-changes of the robot in the field (different modules, different configuration, etc.)

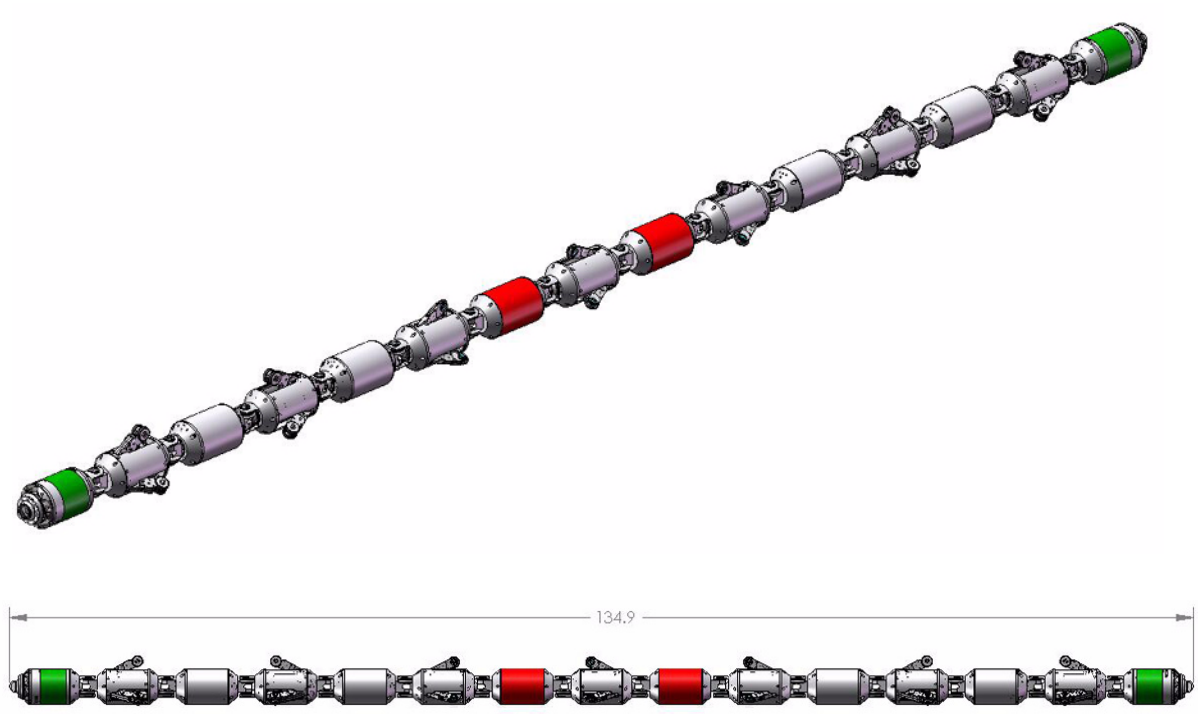
Electronics parts have all been ordered and received and will undergo software porting, burn-in and testing, while mechanical parts were also ordered and are beginning to be received for future checkout and assembly.

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:

- **Configuration Design**

  CMU has completed the configuration of the X-II-MFL train, by adding the additional required drive, battery, steering and support modules to the train, to allow the system to be configured into a test-train - the image of the final design-configuration is shown below:



- **Parts Ordering**

  CMU has ordered the required PCBs and additional modules and subsystems and is expecting to receive the PCBS for software porting, burn-in and testing early in the next reporting period. The additional modules (beyond those used from existing spares), should be received in assembled fashion by late May 2008, allowing for testing in June/ July, and integration with the dummy MFL module in August for final testing.

- **Mock MFL Sensor**

  The subcontracted MFL mock-up sensor unit(s) have gone though a conceptual design stage, and CMU expects to see the final design early in the next reporting period and the prototype delivered by mid-summer 2008.

- **XML configuration map**

  The new X-II "extended" MFL-sensing platform complicates logistics of configuration management in two ways. Firstly, the number of new modules, both active and spare, makes it difficult to manage sets of specific parameters, associated with each electronic

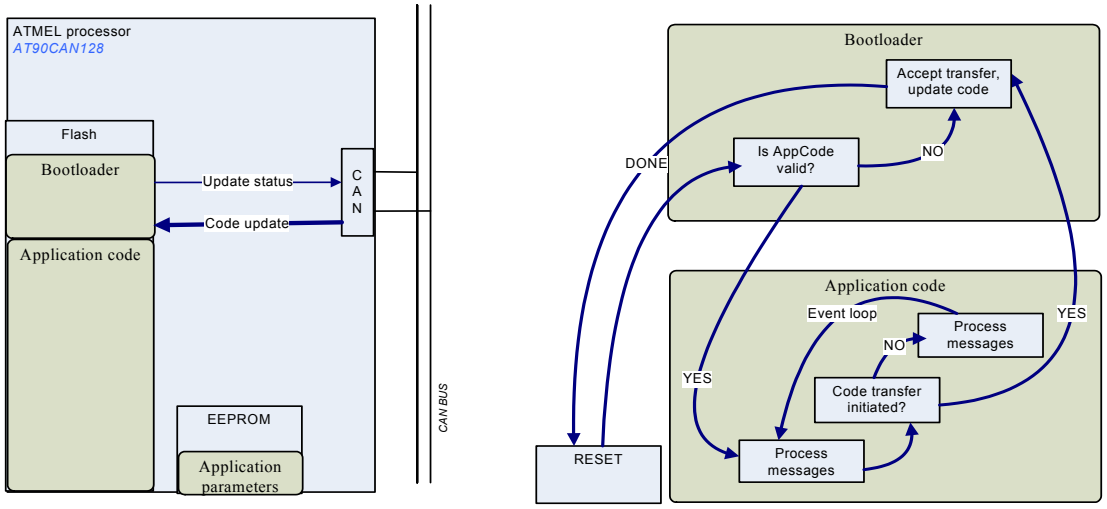
board and mechanical assembly. Secondly, a mechanically simple transition from extended to basic platform configuration or vice versa must be reflected in three software components: user interface, motion controller, and module controller, spread over as many as 16 distinct processors. CMU developed a configuration map mechanism, which solves both the problem of keeping track of specific module parameters and the problem of synchronizing configuration changes seamlessly over the multiple software layers.

- **Kinematic model update.**

CMU's original implementation of robot's kinematics relied on having two linear actuators (modules with active drive actuation) in the head and rear of the robot train. Increase in weight and drag associated with extra modules and the anticipated magnetic drag of the extended platform required an increase in number of linear actuators, and thus in complexity of linear actuation control. CMU implemented changes to the motion controller and its scripts to accommodate any number of drive actuators arbitrarily positioned in the drive train.

- **CAN code updates**

CMU developed new functionality to facilitate 8-bit controller code updates. Since both the size and the number of modules in the expanded platform makes manual code update over the entire train a burdensome affair, an in-situ software update mechanism has been developed (see image below).



Each 8-bit board connected to the CAN bus is assigned a unique identifier at the time of assembly and may be commanded to switch into update mode to receive a code update over the CAN network. This functionality in conjunction with the robot configuration map in principle allows software update over the entire robot triggered by the press of a single button.

- **Augmented CAN protocol**

CMU expanded the CAN Control/Data protocol to accommodate the increase in number of modules of each type, and to implement transfer of software code and associated handshaking over the CAN bus.

- **Code base maintenance**

  CMU continued to optimize and augment the existing software, eliminating several non-critical errors in the process.

III. Milestones

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

- **Configuration Design completed (Dec.'08)**
- **Hardware (PCBs, parts) identified and ordered for additional module fab (Jan'08)**
- **Software Architecture Update and Test-Code Implementation completed (Mar.'08)**

IV. Cost and Schedule Status

1.0 Cost

•Approved Budget:	**$1,778,635.-**
•Spent to date (Mar. 31, 2008):	**$1,708,032.-**
•Funds Remaining:	**$70,603.-**
•% of funds expended	**4%**

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)	**78%**

V. Accomplishment Summary

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

1. Evaluated robot pipe centration as a function of deploy arm pressure - Oct - Nov. 2007
2. FInalized the mechanical train configuration design - Dec. 2007
3. Updated robot's kinematic model to accommodate arbitrary configurations - Dec. 2007
4. Ordered all PCB and electromechanical components for additional modules - Jan 2008
5. Created XML module configuration file format - Jan 2008
6. Augmented CAN protocol for extended robot model - Feb. 2008
7. Introduced CAN protocol extensions for over-CAN code updates - Feb.-Mar 2007
8. Continued software codebase maintenance - Oct 2007 - Mar 2008
9. Received delivery of all final PCBs (untested) for certification - Mar. 28, 2008

VI. Activities Planned for next Reporting Period

The following activities are being planned for the next semi-annual reporting period (Apr.'08 - Sep'08):

1. Receiving delivery of all new PCBs and software porting, burn-in and validation
2. Return of PCBs to vendor for additional module assembly
3. Receipt of additional modules from vendor
4. Integrating additional drive/battery/support modules into robot train.
5. Testing and completing new software functionalities with expanded platform.
6. Receipt and integration of mock MFL-sensor from vendor
7. Implementing automated battery charging software.
8. Testing modified driving/launching scripts for expanded MFL robot train with the mock MFL sensor while inside of real-world pipes in a laboratory setting (in air; unpressurized).
9. Collecting test-data and interpreting results and generating conclusions and recommendations for the final report
10. Submitting final project report to DoE - September 2008

VII. Actual and Anticipated Problems

CMU did not encounter any problems during this reporting period. However, the next portion of this phase will focus on integrating the expanded robot train, and we expect, based on experience, that introduction of new modules into the train may result in additional problems that will be addressed and resolved as they arise.

VIII. Technology Transfer Activities

The Northeast Gas Association (NGA) signed an exclusive license with CMU, effective February 2008 for the X-II system as designed up to the point of October 2008, when the final field-trial was carried out as part of the NGA co-funded X-II Phase II effort.