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

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SEMI-ANNUAL TECHNICAL PROGRESS REPORT

Reporting Period:
04-01-2005 to 09-30-2005

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

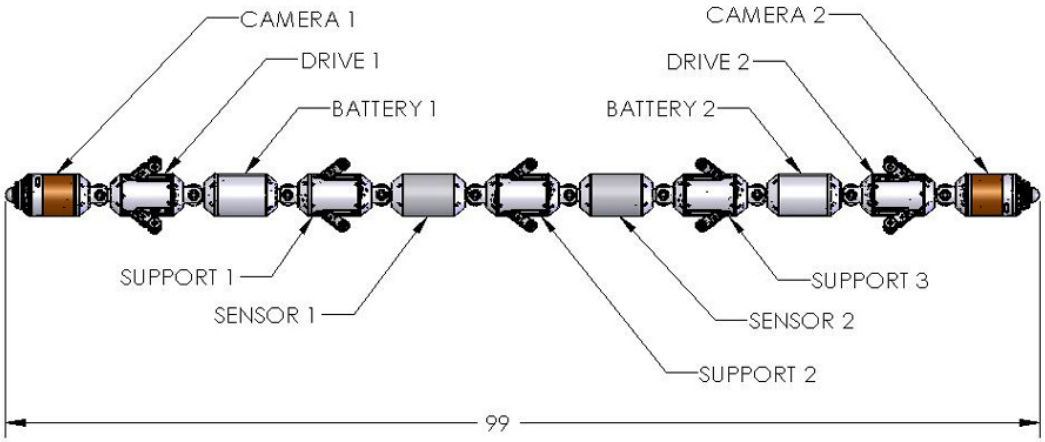
CMU continues to work on the overall system design to a final design review level. DoE and NGA expect to participate in a design review to be held in December 2005 at CMU in order to approve the design for continuation into the Phase II prototyping and demonstration effort to conclude by end of 2006. CMU continues the complete assembly design for every module in terms of the mechanical, electrical and software elements (architecture only). Design requirements for sensor-providers were fully detailed and finalized and provided to them for inclusion in their designs by Fall 2005.

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 Design**

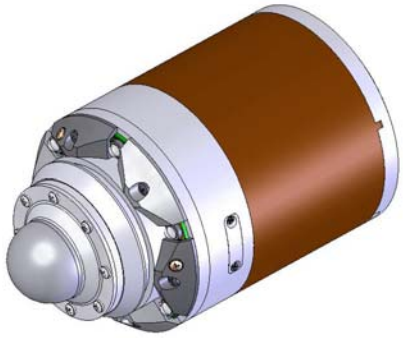
  The system design layout has been completed resulting in the firming-up of the robot overall layout (shown below). The overall design layout can be summarized to state that the complete system is expected to weigh around 65 pounds and measure about 8 feet in length. The overall assembly of the system and its individual modules is as depicted below:



The main elements of the design that were completed, include:

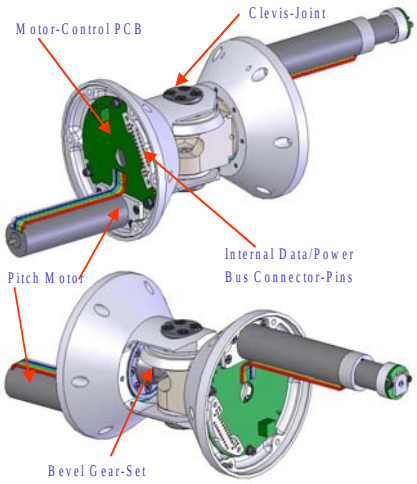
-Camera-Module Design

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



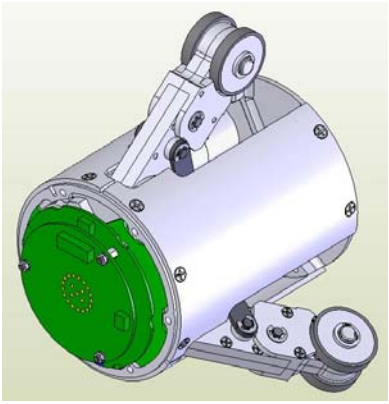
-Steering-Module Design

The steering module design 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 design resulting from this design effort is shown in the inset image.



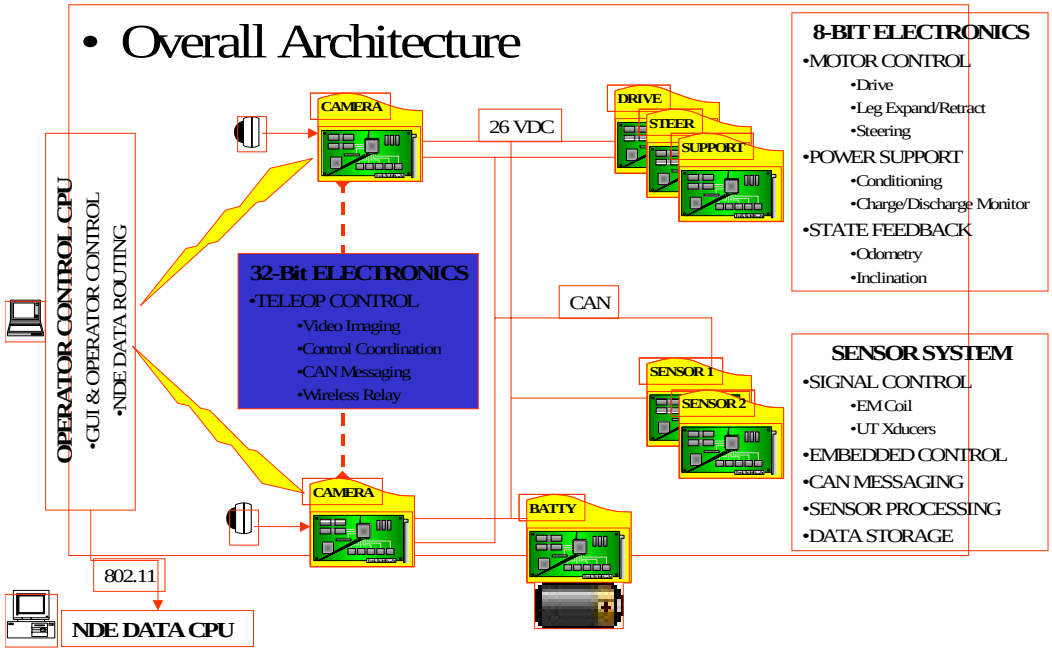
-Drive-Module Design

The drive-module design 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 design reflected by the inset image.



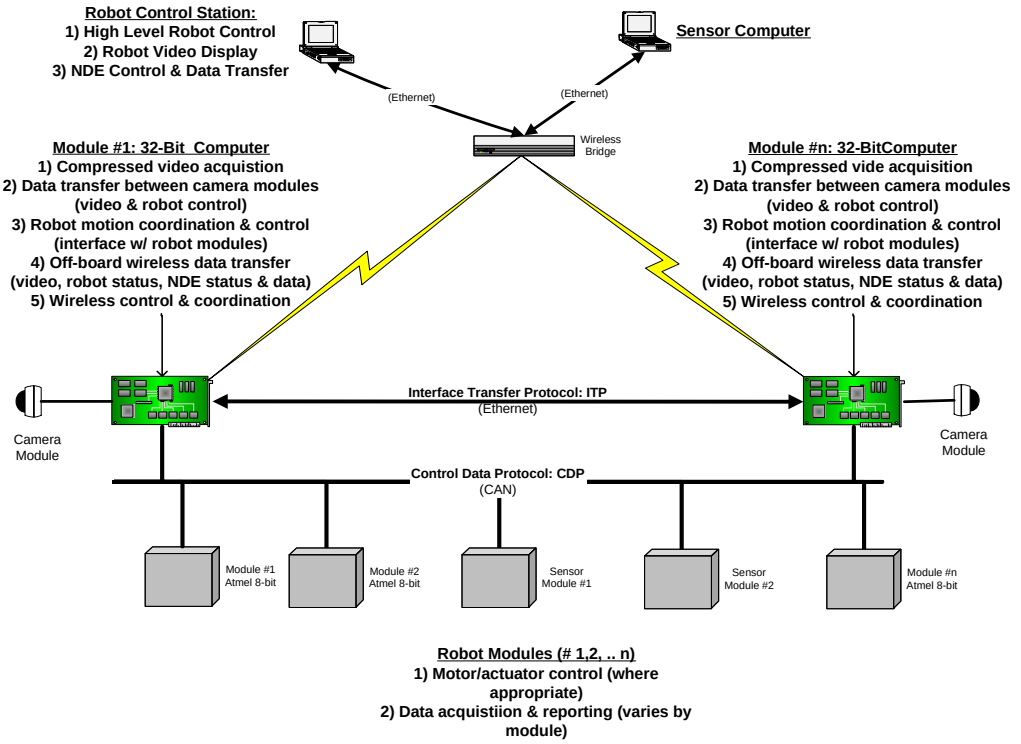
-Electronics Architecture Design

The electronics architecture for the platform and overall system was also finalized and can be summarized as shown in the inset figure below:



-Software Architecture Design

The software architecture for the platform and overall system was also finalized and can be summarized as shown in the inset figure below:



- **Dummy Sensor-Module Design and Hand-Over**

A dummy (simplified) sensor-module was designed and the part-files transferred to the senor-providers to fabricate in order to perform analyses as to interference with the eddy-current signals due to the presence of metallic mass near the sensor-head. Sensor-providers were to report back on their findings once their experiments were completed.

- **Finalized Sensor-Provider Specifications**

The sensor provider specifications were finalized and are summarized in key tables and interface drawings related to the mechanical, electrical and software specifications detailed in this section.

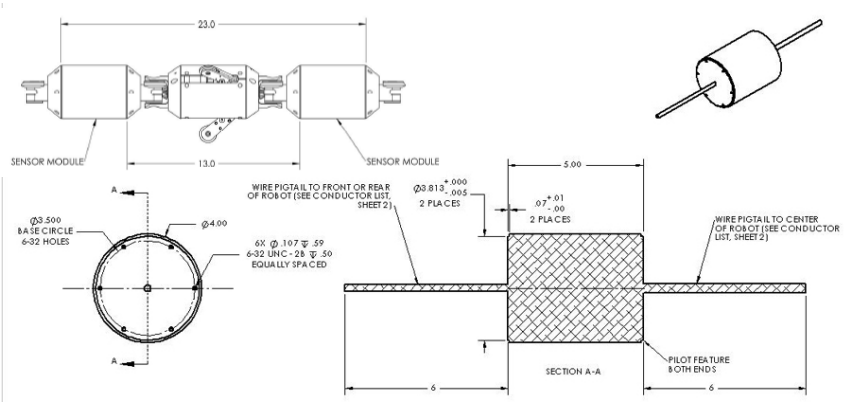
-Overall Requirements

The following tabular representation was agreed upon to capture all the main requirements of import to any sensor provider:

PARAMETER	CONSENSUS
# Modules	≤ int(2)
Size	5" L x 4" DIA cylinder
Weight	≤ 10 lbs
Spacing	23 inches
Angular Motion-Range	77^{o} - 80^{o}
System Data on Bus	Inclinometer, system time, odometer
Communications Bus	1 MHz CAN (2.0b)
Protocol	CMU-custom, TTP, 32 bit
Power Bus Specs	26 VDC nominal
Power Draw Specs	Deploy / Retract: 30 W for 2 minutes - (1.2 A @ 24 V dc) Scanning: 24W continuous - (1.0 A @ 24 VDC) Idle: 12W continuous (when not scanning) - (0.2A @ 24 VDC)
Data Storage / Transfer Specs	IDLE: ≤ 50 k bits/sec DATA DUMP: ≤ 450 k bits/sec INTEARCT: ≤ 150 k bits/sec
Sensor-Drag	≤ 1lbf total
Off-board NDE data transfer	Ethernet (802.11)
Inter-module Wiring	4 TP; 28 AWG
Protocol Documentation	**Approved by all**
Vibration Isolation	Standoff & Absorption tolerant
EMI Protection	Motor/Coil EMI to be expected; Isolation responsibility of ea. party
Pass-thru shielding	EMI shielding by Sensor-Providers

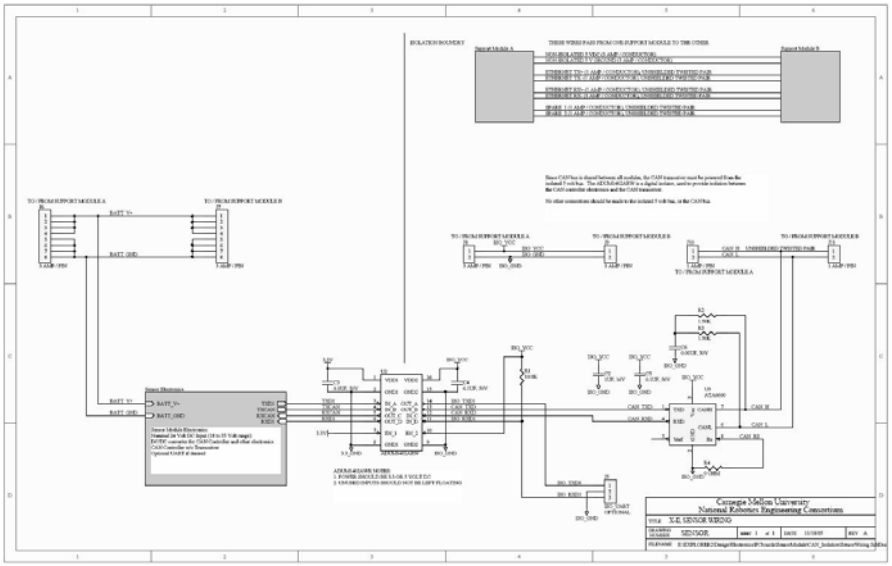
-*Mechanical Interface*

The volume and mechanical and wiring interface diagram were finalized and are reflected in the image below:



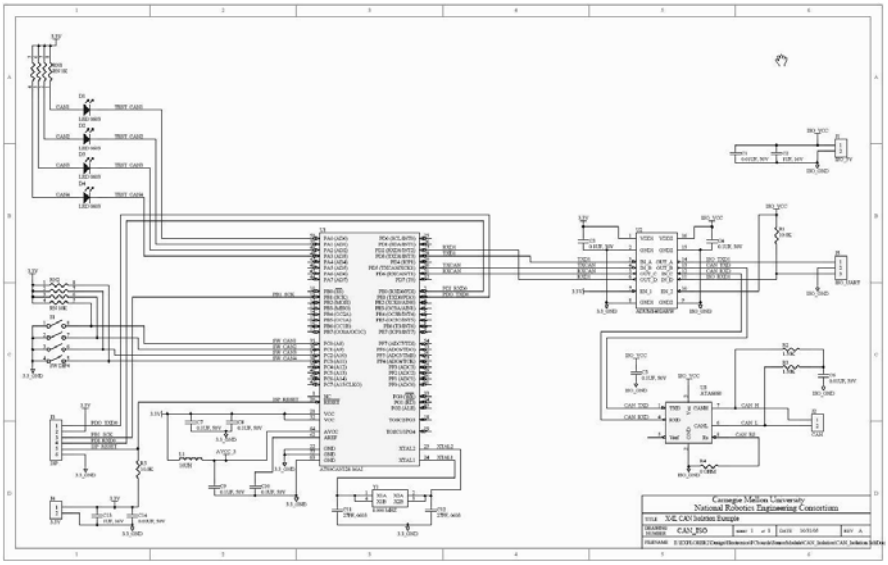
-*Sensor Wiring Schematic*

The sensor wiring diagram required to be followed was finalized and is depicted below:



- *CAN Bus Isolation Schematic*

In order to avoid any bus-crashes and -hogging', the following schematic was provided to ensure the availability and up-time of the bus on the robot:



III. Milestones

The main milestones we were able to meet (based on the proposal) was the completion and presentation of the preliminary design to both DoE and NGA by early July 2005, as well as the final inerface specifications for the sensor providers in September 2005. We expect to be able to meet the prototype detailed-design, development, integration, testing and demonstration milestone as expected by the end of CY 2006.

IV. Cost and Schedule Status

1.0 Cost

- **Approved Budget: $1,378,815.-**
- **Spent to date (Sep. 30, 2005): $ 382,634.-**
- **Funds Remaining: $ 996,181.-**
- **% of funds expended 28.8%**

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 December 2006.

- **% of Phase I expired (Oct'04 -Dec. 2005) 80%**
- **% of Phase II expired (Jan-Dec. 2006) 0%**

V. Accomplishment Summary

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

1. Preliminary Design Review successfully completed - July 2005
2. Final sensor-module interface specifications released - September 2005

VI. Actual and Anticipated Problems

To this point, due to the parallel pre-prototyping and design effort, any glitches or problems that were encountered, were immediately fixed and are not expected to re-surface during the prototyping stage. We do however expect, based on experience, that the integration and software debugging effort will result in additional problems that will be addressed at that time.

The interactions with a single (to be selected by DoE and NGA) sensor-provider will no doubt yield

additional interface issues (primarily electrical and mostly software-related) that will be resolved as we go in the course of the prototyping and final design-detailing efforts in 2006. 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.

VII. 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 the next phase (December 2006).