Quarterly Progress Report
submitted to
The Department of Energy (DoE)
National Energy Technology Laboratory (NETL)

under

Contract # DE-FC26-04NT42264

for

SEMI-ANNUAL TECHNICAL PROGRESS REPORT

Reporting Period:
07-01-2005 to 12-31-2005

compiled as part of the project titled

Explorer-II:

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

Document Number: REP-GOV-DOE-051219

Date of Submission:
December 19th, 2005

submitted by

Carnegie Mellon University
The Robotics Institute - REC
#10 on 40th Street
Pittsburgh, PA 15201
(412) 268-2000

Administrative Contact:
Susan Burkett

Technical Contact:
Hagen Schempf, Ph.D.

I. Executive Summary

CMU has completed the overall system design to a final design review level. DoE and NGA participated in a design review held in December 2005 at CMU and approved the design for continuation into the Phase II prototyping and demonstration effort to conclude by end of 2006. CMU has fully designed every module in terms of the mechanical, electrical and software elements (architecture only). Substantial effort has gone into pre-prototyping to uncover mechanical.electrical and software issues for critical elements of the design. Design requirements for sensor-providers were detailed and finalized and provided to them for inclusion in their designs by Fall 2005.

CMU is expecting to start 2006 with a detailed design effort for both mechanical and electrical components, followed by procurement and fabrication efforts in late winter/spring 2006. The assembly and integration efforts will occupy all of the spring and summer of 2006. Software development will begin in earnest in 2006, and will result in porting and debugging on the module- and train-levels in late summer and Fall of 2006. Final pipe mock-up testing is expected in late Fall and early winter 2006 with an acceptance demonstration planned to DoE by the end of 2006.

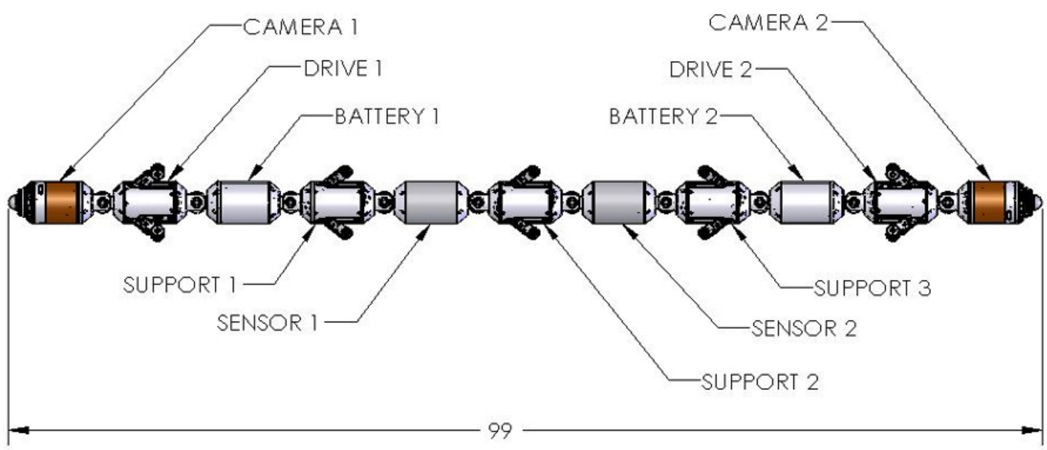
II. Work Results during Reporting Period

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 has been completed and culminated in a design review at CMU on December 15 and 16. DoE and NGA approved the design and gave the go-ahead to proceed into prototyping in 2006.

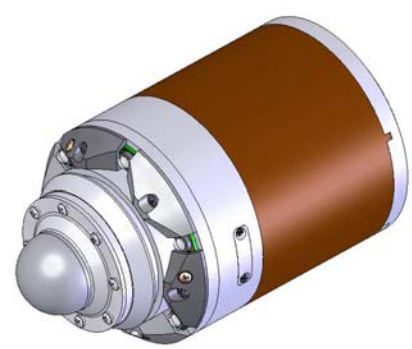
  The overall design layout can be summarized to state that the complete system is expected to weigh around 65 pounds and measure about 8 feet in length. The overall assembly of the system and its individual modules is as depicted below:



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

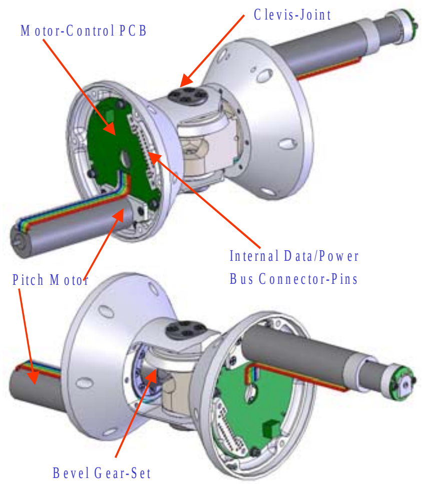
- *Camera-Module Design*

  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.



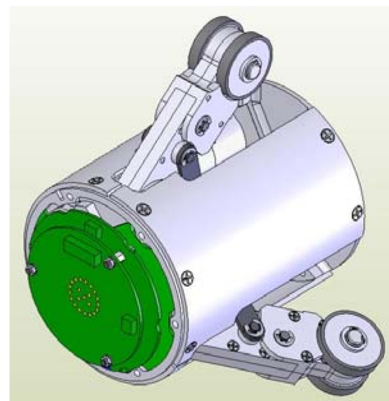
-*Steering-Module Design*

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.



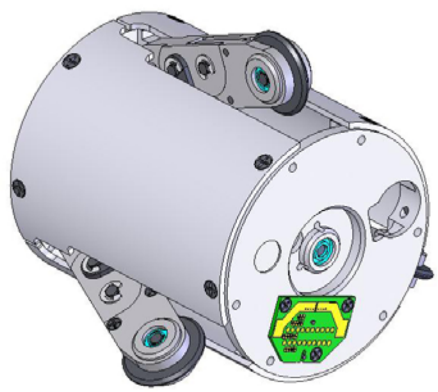
-*Drive-Module Design*

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.



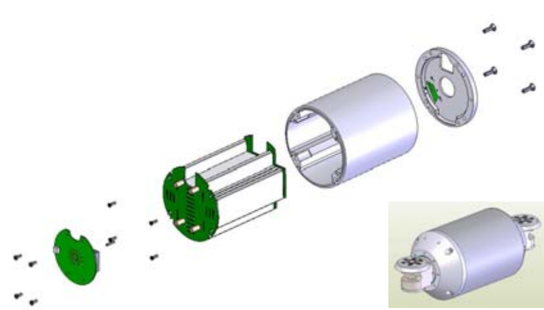
-*Support-Module Design*

The support module was designed 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 design for said module.



-*Battery-Module Design*

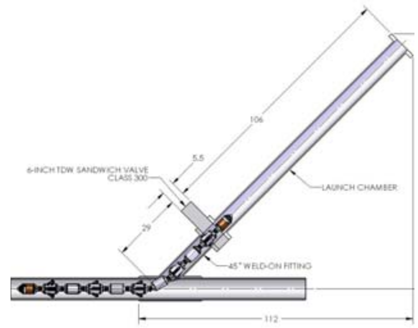
The battery-module design revolves around the use of lithium-based battery-cells combined into packs to provide 26 VDC and up to 15 Ahrs of energy to the robot for a meaningful 8-hr. mission. The battery-module will contain safety electronics and voltage converters to



allow monitoring of charge and discharge. An image of the layout of the module is shown in the inset image.

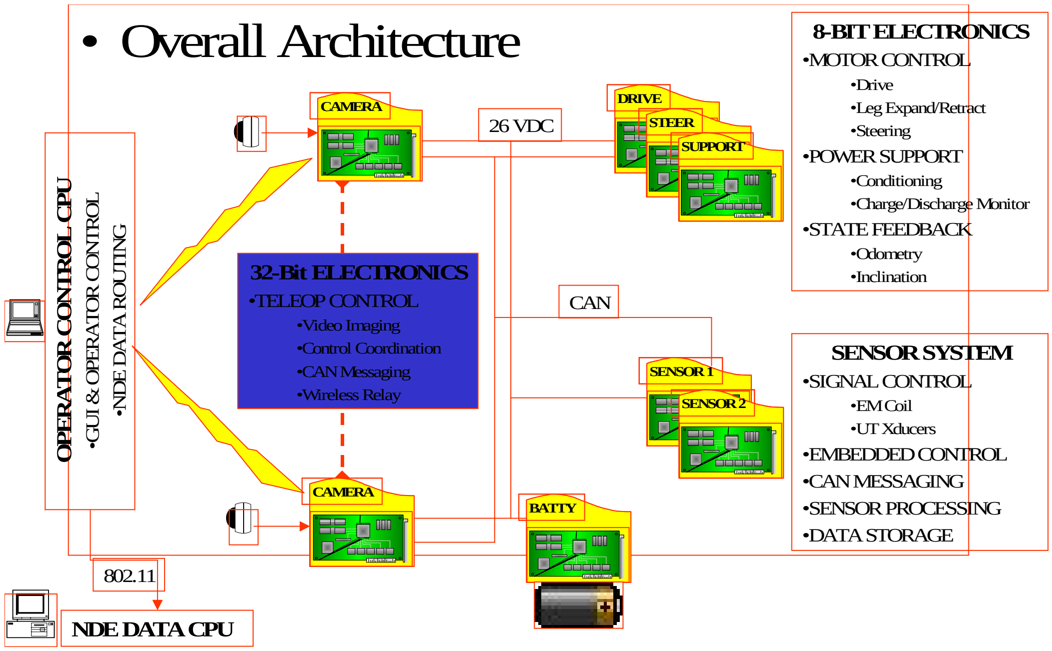
-Launcher Design

The launcher design is pending based on the selection of fittings. The fitting provider is in discussions with NGA member-utilities to provide the required data as to pricing and availability, before CMU can select the proper fitting and fabricate the launcher-tube and spool-pieces. A preliminary layout of the launcher-setup is shown in the inset image.



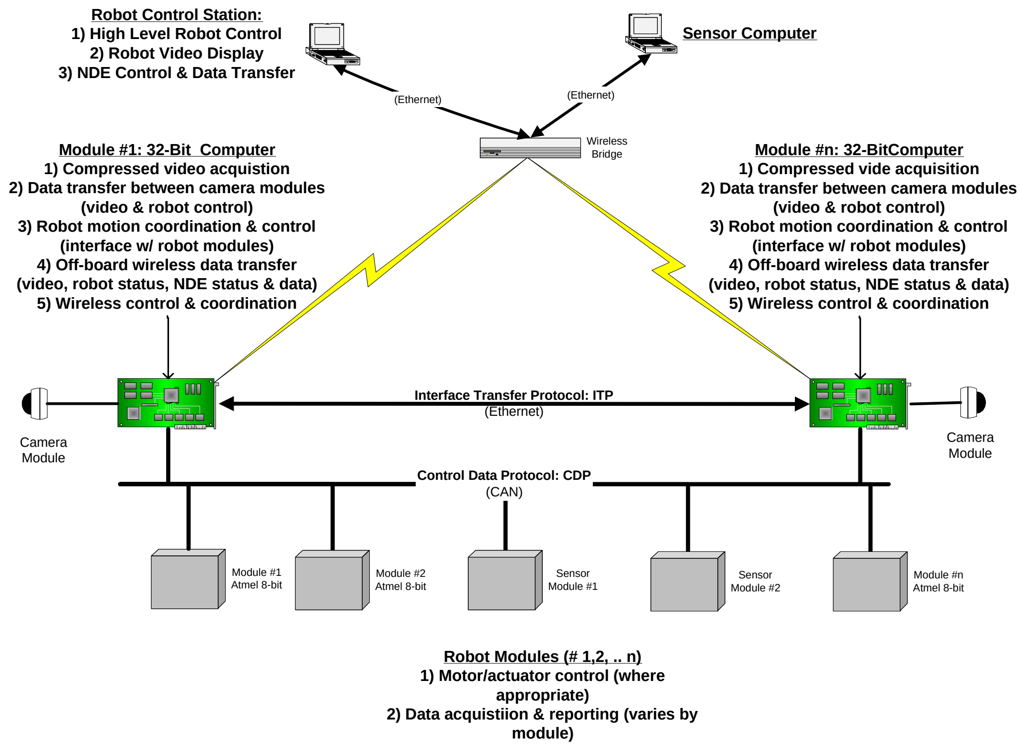
-Electronics Architecture Design

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:



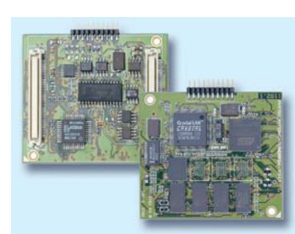
•Prototype Testing Activities

-*Pressure Testing*

All critical electronic components were tested under pressure in a setup rated to 750 psig. All components, including OEM PCBs were found to be tolerant to those pressures, excluding the video imager, which will have to be housed and pressure-protected. An image of the pressure test setup is shown on the right.

-*Computing-System testing*

The 32-bit OEM computer was acquired and tested in terms of its main I/O and the OS usability and CAN connectivity and wired/wireless networking hardware. It was discovered that CAN-compatibility 2.0b was not achievable, requiring all systems to be set for 1.1 compatibility. An image of the hardware is shown to the right.



-*Illumination System Testing*

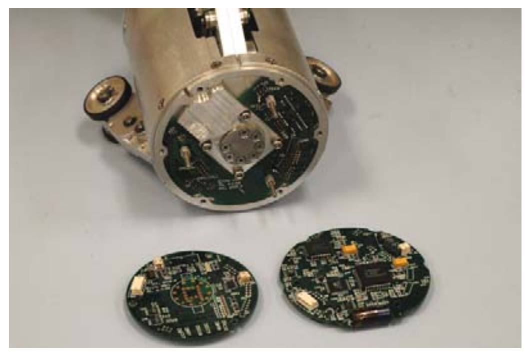
A prototype LED illumination ring was built and tested in a pipe to ascertain the power, heating and illumination achievable with the new LEDs and system design. An image of the setup is shown on the right.

-*Arm Jig*

A prototype test-jig for calibrating and testing strain-gauge based leg-force sensors was built and assembled and strain measurements taken to feed into the control algorithms to control bracing and contact forces. An image of the setup is shown on the right.

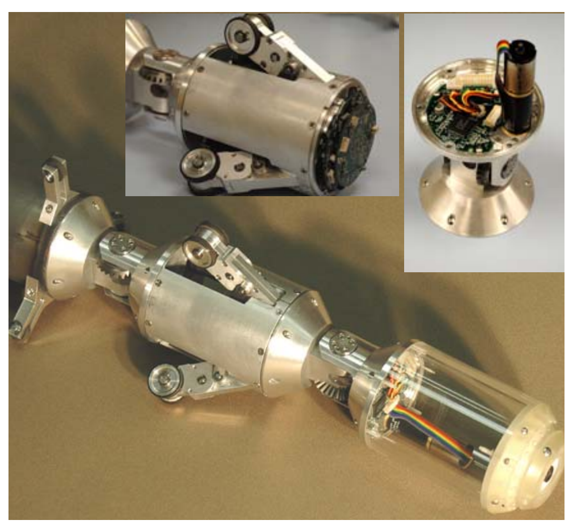
-*Prototype Electronics for testing*

A suite of preliminary PCBs was built and is undergoing testing for electrical functionality and preliminary software development. Circuits for the nose/camera and drive and steering modules have been developed and are shown on the right.



-*Pre-prototype partial robot train*

For more in-depth software and electronics testing a preliminary drive-, steering and nose-section were built and interfaced to the electronics and bench-top supplies for evaluation and software testing. It will be used by developers until the final robot is assembled and ready for software porting, integration and debugging. An image of the setup is shown above.



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

  A dummy (simplified) sensor-module was designed and the part-files transferred tot he 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.

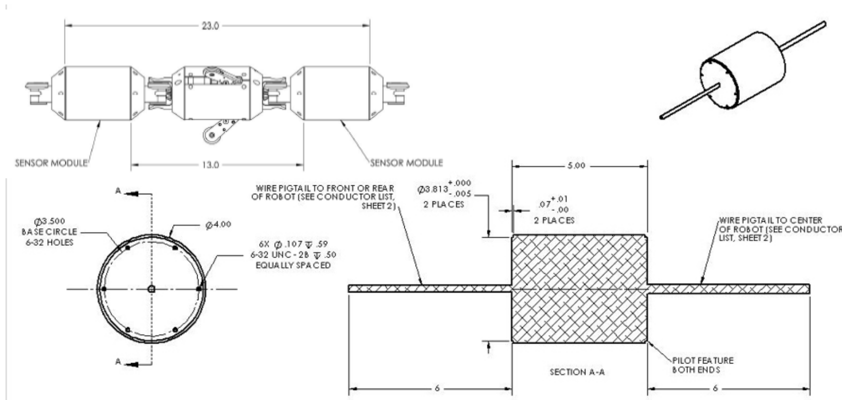
  - *Overall Requirements*

    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

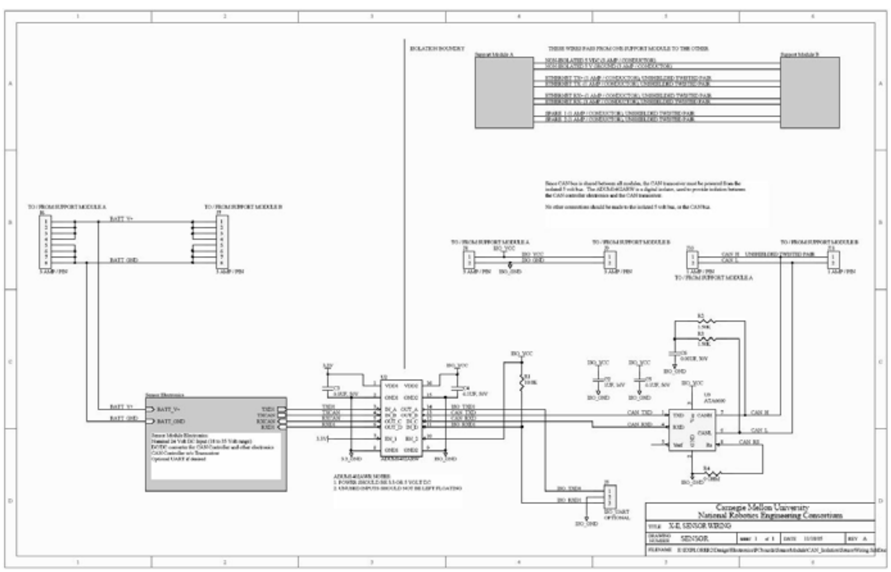
-*Mechanical Interface*

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



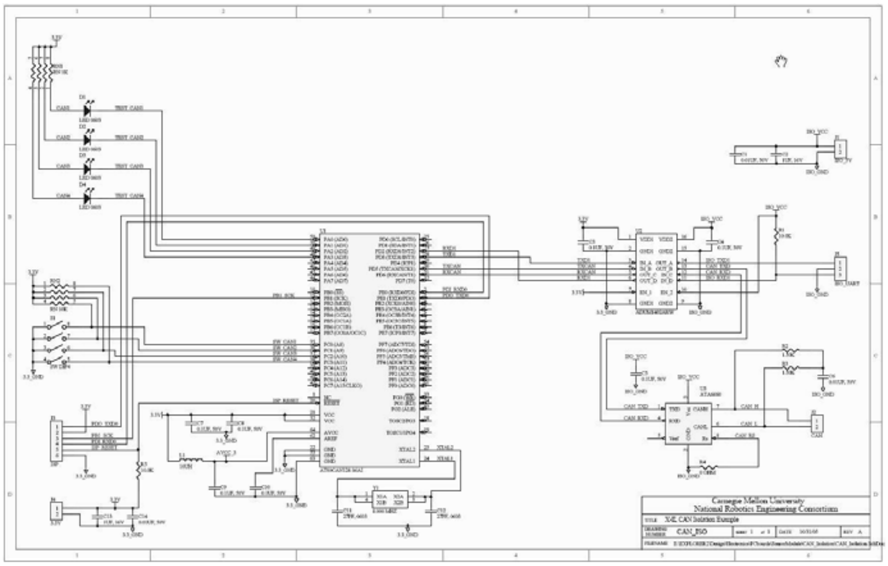
-*Sensor Wiring Schematic*

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 he preliminary design to both DoE and NGA by early July 2005, as well as the final design review held at CMU in December 2005. We expect to be able to meet the prototype development, integration, testing and demonstration milestone as expected by the end of CY 2005.

IV. Cost and Schedule Status

1.0 Cost

•Approved Budget:	**$1,378,815.-**
•Spent to date (Nov. 30, 2005):	**$ 414,867.-**
•Funds Remaining:	**$ 963,566.-**
•% of funds expended	**30.1%**

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)	**100%**
•% 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
3. Final system design completed and presented to DoE & NGA - December 2005
4. Prototyping phase approved for CMU - December 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).