Intel Cornell Cup Proposal

GT Night Rover

Georgia Institute of Technology

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1. Project Summary

The Intel Cornell Cup will provide a platform on which to perfect engineering designs and computing algorithms for the GT Night Rover. The GT Night Rover aims to store and utilize electrical and/or thermal energy efficiently while investigating systems for prolonging the useful mission life of a robotic planetary rover (planetary in the general sense). The final prototype will be an autonomous rover that locates sources of solar energy and continues moving through a full day/night cycle. This challenge will serve as a proof of concept for a more robust system and provide a platform for the design and construction of a rover that will survive in and provide persistent functionality over multiple day/night cycles while moving and collecting useful information. The use of the Intel Atom board will enable the implementation of more complex programming control algorithms while allowing for a clear margin of power usage in future versions of the rover, exploring novel capabilities of the Atom board and pushing the boundaries of engineering design.

2. Challenge Definition

The GT Night Rover is the initial phase for pursuing the NASA Night Rover Centennial Challenge, which is to develop a solar powered autonomous robotic vehicle that can travel continuously through three Earth day/night cycles. The motivation for this competition is to improve low-cost means of implementing solar power for rovers which must survive long periods of darkness, in which they must rely on batteries, fuel cells, or complete shutdown to survive. NASA has often lost rovers through failure to restart after shutdown, and better operation of stored solar power would allow increased productivity of these lower-cost vehicles.

Missions to the moon present several problems for solar power. Due to the harmonic orbit of the Moon, it experiences a day/night cycle in excess of 28 Earth days. The period of darkness lasting over 14 Earth-days is an extremely different environment than any NASA rover has experienced on Earth or Mars - each having just over 12 hours of darkness per day.

In response to this problem, NASA has announced a Centennial Challenge open to the general public from Spring 2012 to Spring 2013 to investigate possible solutions to the problem of the Moon's extended darkness. The NASA Night Rover competition encourages industry members, research scientists, and students to build mobile systems capable of harvesting and storing energy for extended use during day/night cycles. **The winning entry in the NASA challenge is measured by the maximum distance traveled over a 3 day period, while success for the Intel Cornell Cup will consist of efficient and full operation over a single day/night cycle. Table 1** presents the team challenge definition and sub-definitions.

Radiation hardening and power restrictions have limited NASA physically and economically in terms of computational power. Previous computational units sent into space provided up to 128MB of memory paired with a 22MHz processor using as little as 10W. The computational specifications for previous NASA missions are small compared to 1GB of on board memory, a 0.6GHz clock speed and an average power usage of 3.3W by the Intel Atom board's processor. The rover will be a working model with some experimental peripherals for navigation and light sensing and the complex vision and planning algorithms allowed by the Atom architecture. Some general functionality requirements are presented in Table 2. The power consumption of the peripherals and the atom board will be used as an upper bound while the GT Night Rover team prepares to scale its design for full competition in the NASA Night Rover Centennial Challenge.

Table 1: The table below details the Challenge definitions.

Challenge Definitions
1. Effectively convert solar power to motion
1a. Track sources and manage power systems to effectively capture and store solar power
1b. Manage power resources so that a robot may continuously function throughout a single day-night cycle

Table 2: detail of Functionality requirements.

Functionality Requirements
1. Collect solar power
2. Store solar power in on-board reservoirs
3. Path planning and obstacle detection
4. Navigate terrain through a day-night cycle
Optional:
1. Radio transmission of data
2. Miscellaneous science operations

3. Proposed Solution

3.1 Solution Overview

A basic model of the proposed solution is given in Figure 1. The GT Night Rover solution will include:

1. **A Functional Rover**
    a. <u>The rover shall utilize electric propulsion</u>
    Up to two electric bicycle motors will drive the rover. Two motors will allow simplified directional control. These motors will be indirectly linked to axles and/or tires by a bike chain. Gears will not be used. Motors will be controlled by hobby or DIY control boards.
    b. <u>The rover shall navigate using EM sensing</u>
    CMOS cameras would provide basic optical detection in the infrared and visual spectrum. However, the team intends to prioritize the integration of an XBOX Kinect, as the Atom board should allow for optimized use of the Kinect detection and laser grid features. Further detection in the radio frequencies would enhance rover navigation, however such detection will likely be represented with ultrasonic sensors due to cost and complexity. Combinations of all detection equipment will depend upon the total power budget.
    c. <u>The rover structure shall be low mass</u>
    The structure will be designed to efficiently carry operational loads, and materials will consist of metals or composites, or a combination thereof. Bicycle components will be utilized where possible to reduce the cost of the system, while custom parts will be manufactured in on-campus facilities.
2. **A System to Efficiently Collect and Store Solar Power**
    a. <u>A 100 W Photovoltaic solar panel will provide electricity for the rover systems</u>

Systems of levers or pistons will be used to orient the photovoltaic panel for optimum alignment with the sun. Lithium Phosphate (LiPO), Lithium-Iron-Phosphate (LiFePO), or Li-ion batteries or matrices of batteries will provide energy storage in addition to capacitors for specific applications if necessary. The power control system will depend on the Atom chip to ensure efficiency.

3. **An Autonomous Control System for the Rover**
    a. A system of micro-controllers will work with the Atom board to control the rover
    b. The Atom board will allow for the implementation of autonomous navigation
    Radio communication would be utilized to report data back to the team, not for command of the rover. Autonomous control algorithms will be optimized for power consumption. The rover operating system will be chosen such that the board will have optimal sleep capability. Custom algorithms will implement computer vision.
    c. Common software will be implemented across micro-controllers for quality control and standardized peripheral communication

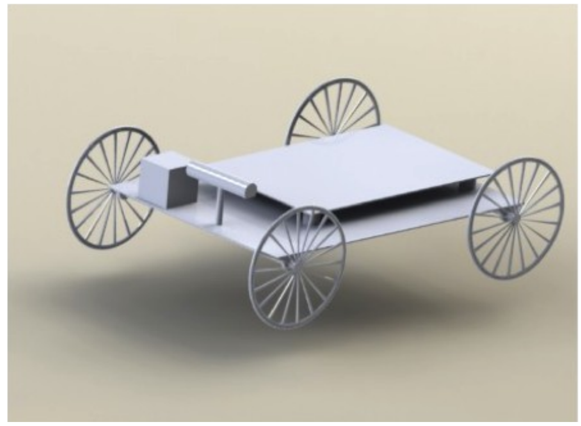

Figure 1: The above figure presents a theoretical configuration of the rover. Detailed in the model is a turret with XBox Kinect for navigation, a computer box, solar panel on pistons, and chassis.

The intention of this project is to demonstrate a working model of solar energy collection and storage for autonomous vehicles that shall operate continuously over one day/night cycle. These functionalities will be exhibited in videos of full experiments and brief demonstrations of the working system seeking stronger sources of light when shaded from direct sunlight.

3.2 Computing

The Intel Atom board will serve as the primary computational unit. This computer will handle all computer vision algorithms, decision-making heuristics, and any other high level computational task required to move the rover and navigate obstacles. The rover will also carry an array of smaller microcontrollers in charge of various peripherals. These peripherals will sample the rover's orientation and environment to make real-time decisions based on the latest data available, communicating with the Atom board via its USB capabilities. These microcontrollers will also execute tasks handed down to them by the Atom board reporting feedback to the board. The software stack is defined in Figure 2.

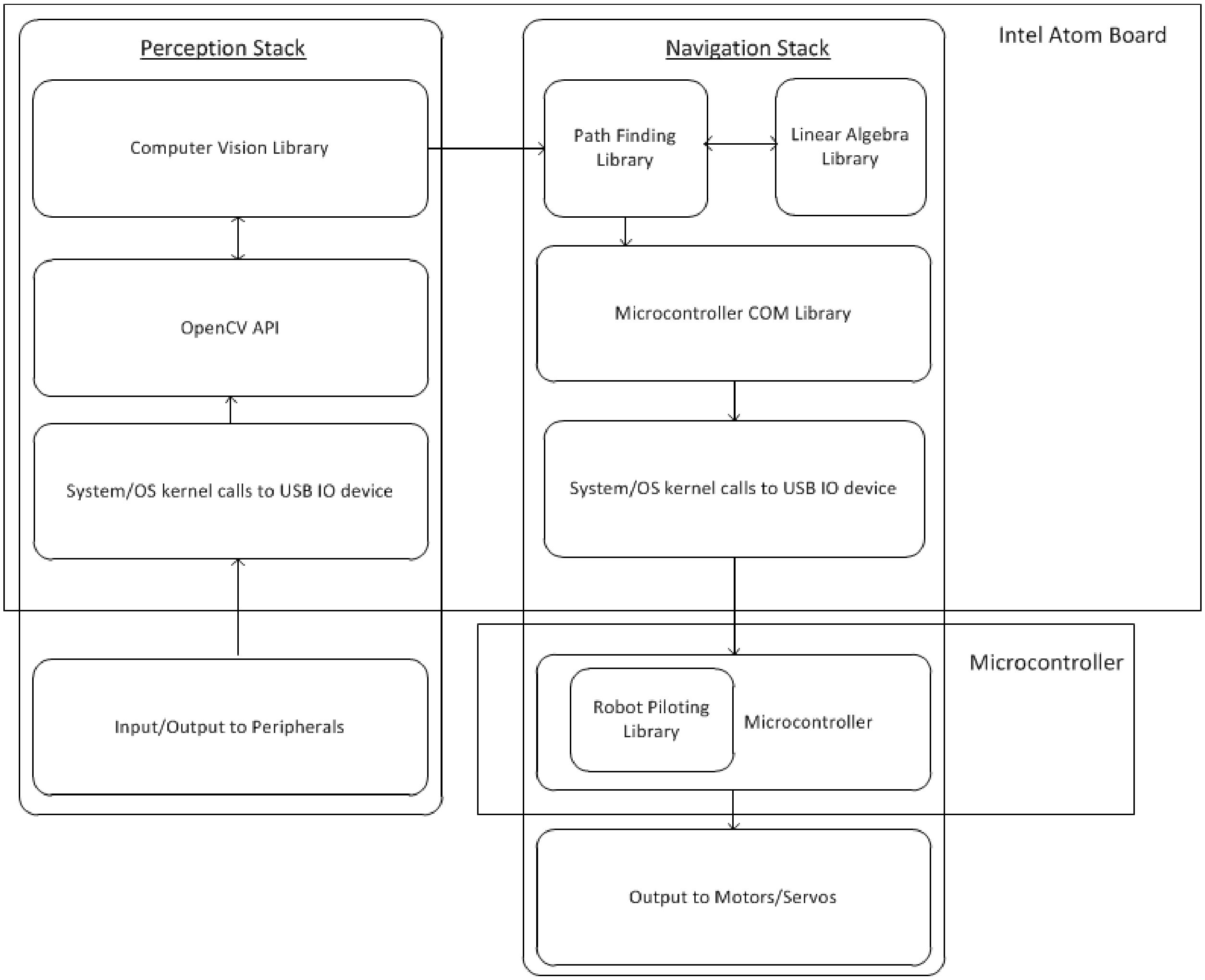

Figure 2: Software architecture of the perception and navigation libraries according to their respective hardware environments.

The Atom board is an ideal experimental platform on which to build the rover's computing backbone. The board's starting clock speed of 600 MHz exceeds past rovers ranging from 20-200 MHz. This massive gain in chip performance will allow the rover to take on more computationally intensive tasks such as computer vision and path planning algorithms. The computing power of the Atom board allows for the ability to carry out parallelized complex tasks outside the scope of the challenge definition.

While this massive performance gain is impressive it should be noted that radiation hardening has put limits on chips intended for space missions[14]. The computational power for this project will not be limited as radiation hardening is not a constraint; however, computational limits of radiation-hardened technologies will be kept in mind through out the design and implementation of this project.

This architecture, with the implementation of an embedded systems operating system on the Atom board, will allow for a maximization of sleep time of the Atom board while providing the speed necessary for carrying out complex computations - optimizing computing power and purpose with total power draw.

3.3 Navigation and Sensing

The GT Night Rover shall investigate multiple methods of light intensity detection. Current research is being done at Georgia Institute of Technology using Microsoft's Xbox Kinect to interpret analyze and communicate using sign language[10]. As an auxiliary investigation, they are attempting to fix false depth readings due to infrared feedback from high concentrations of intense light such as the sun. The intense light creates blind spots in Kinect images. Results from their experiments could be used to supplement light seeking algorithms. Detecting these blind spots represent the sources of greatest light intensity allowing for navigation to these areas and optimal solar panel orientation. While the Atom board is an ideal platform to interface the Kinect, it currently draws excessive amounts of power that could be detrimental to energy conservation efforts. Possible solutions could include physical alterations to the Kinect system to minimize power usage or a version of the same technologies with lower power requirements. As a default low-power solution, using photometers to measure light intensity should be sufficient. The use of any previously mentioned peripherals for light detection would allow the rover to rotate solar power collectors in the direction of the highest concentration of energy. Figure 3 defines the power and data dependencies for the GT Night Rover.

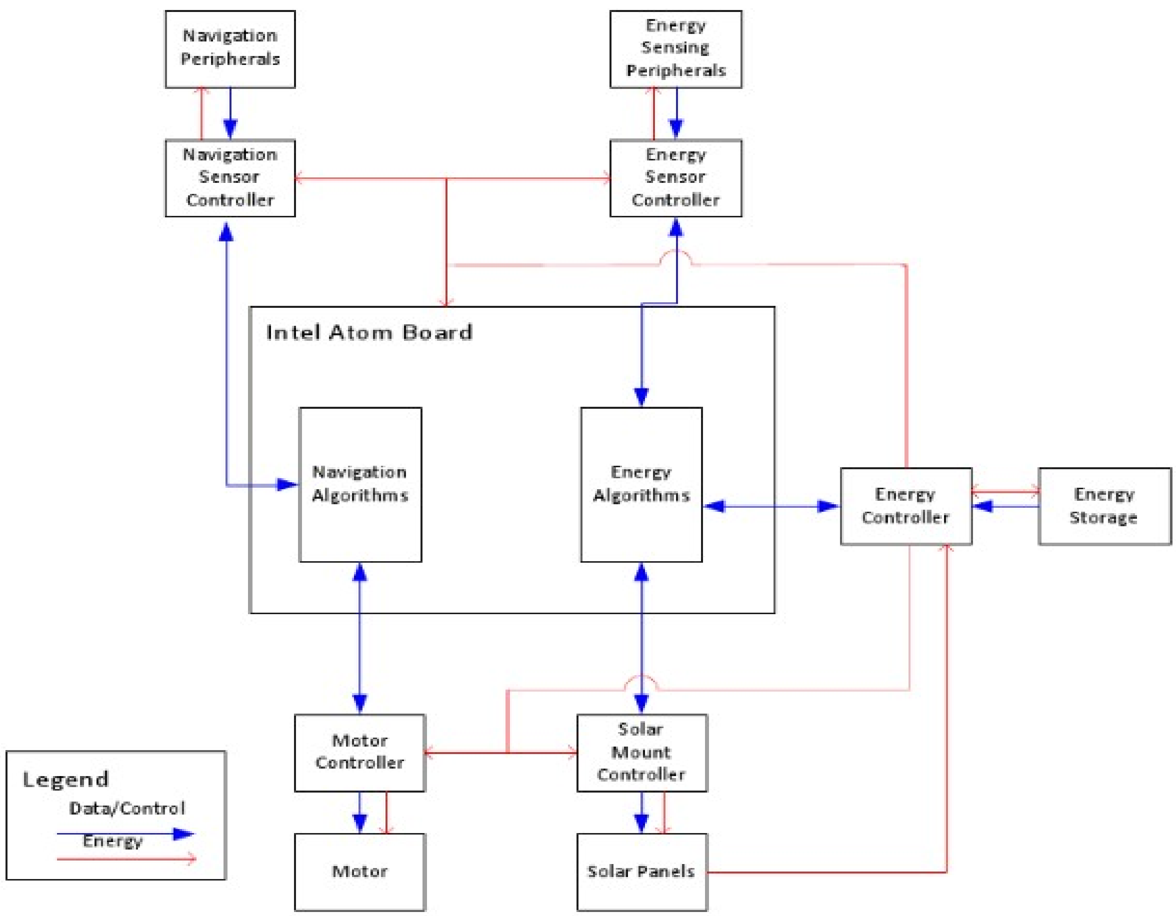

Figure 3: Blue lines indicate data passing to and from the Atom board and its peripherals via USB ports. Red lines represent directed flow of energy from sources of energy to peripherals and the atom board.

The energy controller shall effectively provide an interface over which the Atom board can mediate power consumption over all peripherals. Naturally, navigation algorithms running on the Atom board will communicate with the navigation and motor controllers while energy algorithms will communicate with all controllers related to power detection, intake, and consumption.

Centralized control of all peripherals allows the Atom board to fine-tune power consumption across all controllers. Thus elongated periods of darkness, the Atom board can adjust power usage on each and prioritize each microcontroller to ensure optimal usage of remaining power.

The rover will also carry a set of sensors for the detection of obstacles in the immediate path. Ultrasonic and Infrared technology provide cost effective methods allowing the rover to sample surroundings in real time and maintain it's heading accordingly.[1] Furthermore, small-scale digital cameras may be used to obtain data for computer vision algorithms and obstacle avoidance. An array of at least two of these cameras on the front of the rover could provide a less energy intensive solution to extra sensors during day cycles using stereo Imaging.

Stereo imaging is the process of emulating depth imaging of the human eye by finding correspondences between points that are seen by one camera and the same points seen by the other camera. Using the correspondences of the two cameras provides a known baseline separation between cameras, we can compute the 3D location of the points[11].

Another solution of using cameras without other sensors to measure depths would be using coded apertures. Conventional fish-eye lens filter could provide a cost effective solution. This allows the recovery of both the image and the depth. Using coded apertures would give a solution that does not require the need to take multiple pictures saving electricity, storage space, and data transmission size. This solution does not require the use of multiple cameras, saving electricity and construction costs. Coded apertures work because they use deliberate patterns within an image that cause the blurring of an image to be a function of depth with the blur being a scaled version of the aperture shape that can discriminate between different depths[12].

A bird's eye view would provide ideal perspective for navigation, but this would require additional resources such as satellites or an aerial vehicle. While there are satellites that orbit the moon and mars (i.e. the deep space network or abbreviated as the DSN), this is technology that may cost too much to use continuously and that may restrict continuous access[13]. Furthermore, this would limit the rover to the moon and mars and not other terrestrial bodies that are within the usable range of solar panels from the sun.

Three-axis accelerometers and light meters will provide further sensing. Three-axis dynamical and luminosity data will allow better tracking of goals and solar energy sources. A separate microcontroller will be dedicated to the control of peripheral sensors.

[1] Ultrasonic sensing provides a potentially low-cost alternative to RADAR systems on the surface of planets that have an atmosphere, such as Earth or Mars.

3.4 Power Storage

Our solution will include high performance batteries, potentially lithium iron phosphate, in order to provide adequate charge storage. The exact storage choice will depend primarily upon the power budget as it is developed, however, one such solution is the A123 LiFePO battery. Lithium Ion and other high-density rechargeable battery systems may be considered in addition to the use of capacitors for supplying extra bursts of power as needed by the computer, sensors, control systems, or otherwise. These power storage methods, while providing fewer amp hours than lead-acid batteries, do provide better storage density thanks to low weight. Lower-weight should increase the efficiency of the drive mechanism, leading to less power consumption to propel the rover.

3.5 Structures

The chassis may be constructed using an aluminum or fiberglass framework. There are two possible configurations for the drive system. The drive system could include 4x26" diameter bike tires. Electric bike motors or other motors will likely be used to power chain-gear systems. Powering all four tires gives full turning ability. The second option would be two powered tires with a third trailing tire for stability. A full size of 5' by 2' or 3' should be sufficient, however this size is constrained as necessary by the dimensions of the power supply system. A separate motor controller will be dedicated to the operation of the motors.

3.6 Power Supply

The power supply system will provide electricity to the batteries, motors, microcontrollers, and the Atom board. The supply system will most probably be photovoltaic. The team is currently investigating implementing a 100 W solar panel into the design. This solar panel should provide enough power to operate all systems simultaneously once the batteries have been charged. Depending on the quantity of excess power, further instruments and devices will be designed and implemented so that the rover may complete other tasks such as wireless communications and science experiment during the day half of the cycle rather than imaging and movement.

4. Performance Measures

4.1 Power Systems Performance

Continuous operation throughout a day/night cycle will constitute a successful completion of the rover mission. Continuous operation constitutes a 100% up-time of the electrical systems through out the mission. Successful completion will be verified via data logging on board the robotic vehicle as well as potential ground station transmission and communication with the autonomous vehicle for data storage purposes. Data such as power storage, usage and efficiency will be used to measure performance of the vehicle to further analyze success and failure of the mission. The collected data will aid in future optimizations to structural, mechanical and electrical systems. Temperature sensing allows for precise thermodynamic analysis of the electrical system, providing a detailed description of the temperature ratios, power output, and power consumption. The GT Night Rover Team will compare the power production and consumption of the rover to other solar vehicles such as the Solar Impulse airplane, current spacecraft and robotic missions, and baseline photovoltaic production. Existing solar vehicles as mentioned above will provide necessary measures for potential future improvements. Theoretical models may be used to project gains in efficiency in low-atmosphere environments to create projections of capabilities on the Moon, Mars, and elsewhere.

4.2 Drive System Performance

The drive system shall provide an average velocity greater than 0.11 miles per hour (2 inches per second). This 0.11 mph velocity is a lower bound estimate determined by using the ratio of a bike tire diameter to the diameter of the wheels of a mars exploration rover, multiplied by the average velocity of the mars exploration rovers multiplied by two to incorporate the added efficiency for path planning using the Intel Atom board; this velocity will effectively double that of the mars rover.

Performance Measures
1. Energy reserves will remain fully charged and periodically replenished by solar power during the daylight period. Energy Efficiency will be measured as a ratio of harvested energy to used energy normalized over a period of time: $$E(p,s) = \frac{s}{p\Delta t}$$ where *p* is the total power consumed by electrical systems and *s* is the total power generated from solar harvesting over a time period of Δ*t* in hours. We would like to maximize this ratio and expect to achieve a ratio greater than 1.0.
2. Electrical systems will remain online through the entire period of darkness. Up-Time will be measured as weighted percentage: $$U(e) = \frac{e}{\Delta t}$$ where *e* is the total time the electrical system is functional. We introduce a second measure with a bonus from operation of mechanical systems: $$U(m,e) = \frac{e+2m}{\Delta t}$$ where *m* is the total time the mechanical system is running over a period of darkness with length Δ*t* in hours. We would like to maximize these ratios and expect to achieve ratios of 1.0 and greater than 1.5 respectively.
3. The vehicle will provide 200 yards per hour average velocity including prediction time while executing path planning algorithms and other tasks. Average Travel velocity will be calculated as a simple average $$D(x) = \frac{x}{\Delta t}$$ where *x* is the total distance traveled over a period of Δ*t* in hours. We provide a second measure to normalize the average distance against a projected goal: $$D_{normalized}(x,g) = \frac{D(x)}{g}$$ where *g* is the predefined goal velocity. We would like to maximize this ratio and expect to achieve a ratio of greater than 1.0.

5. Timeline and Milestones

- November 11th:
    - Structural Design Drafts Due
- November 18th:
    - Structural Design Review
    - Purchase Structural Hardware
    - Begin Chassis Construction
    - Electrical Design Drafts Due
- December 15th:
    - Electrical Design Review
    - Purchase Electronics
    - Integrate Electronics in Chassis
    - Software Design Documents Due
- December 18th
    - Software Design Review
    - Start Path Planning Code
- January 1st:
    - Test Motor Systems
- January 10th:
    - Finish Mobile Prototype
    - Test Path Planning Library
- January 20th:
    - Start Computer Vision Code
    - Test Solar Panel Orientation
- February 1st:
    - Fully Operational Electronics
    - Mid-Review
- March 1st:
    - Test Computer Vision
- March 15th:
    - Fully Functional Prototype
- April 1st:
    - Final Testing
    - Final Documentation
- April 23rd:
    - Final Review

Each of the following rows is a sequential period of development.

Hardware Goals	Days to Complete
Build Chassis	30 days
Build/Integrate Motor Electronics	15 days
Solar Panel Orientation Functionality	20 days
Fully Functional Electronics	10 days
Fully Functional Mechanical/Electronic Systems	45 days
**Finished Prototype	15 days

Software Goals	Days to Complete
Write Path Planning Library	**30 Days**
Write Computer Vision Library	**30 Days**
****Finished Prototype**	**15**

**Note: Hardware and Software schedules will meet at a common point on March 15th. 2011 leaving 35 days for testing and final changes. The 35 days of testing and final changes apply to both Hardware and Software aspects of the project.

6. Feasibility & Resources Available

The GT Night Rover team has already begun designing the chassis of the robotic vehicle. The chassis will be designed for operational flexibility in addition to low-mass construction. Utilization of on-campus manufacturing facilities - including the Georgia Tech Invention Studio, and various labs - will provide inexpensive access to water jets, 3D-printing, laser cutters, circuit board development, soldering services, and other capabilities. The array of talent on the team should allow for rapid development of the project. Team members have participated in projects that will influence the design of the robot. The projects include NASA University Student Launch Initiative, Arduino and pic microcontroller programming for custom circuitry, computer vision and motor control on a Rovio robot, large scale systems and software engineering design projects, and other projects in related disciplines.

Careful planning and detailed work along side the specialization and experience of each team member will provide the foundation for a fully functional project completed on time.

6.1 Invention Studio

The Invention Studio is a machine shop available to all Georgia Tech students. With a minimum training period, any student may use the laser cutter, the water jet, the drill presses, and the 3D printers. Further machines may be accessed (mills, lathes, etc) with more training time with specialized appointments.

7. Potential Concerns & Alternative Plans

Problems may occur in the charging of the batteries, efficient distribution of power, proper operation of all components, and general failure of the structures. Structural failure will be addressed by design review of the structural design. Proper machining practices will be followed in construction. Battery charging and power management will be handled by the Atom board and support circuitry. We will first implement existing open source solutions and use careful testing to develop our own. Several de-scope options exist for various parts of the rover system, including the use of fixed versus adjustable solar panels, the use of fewer microcontrollers, working around computer vision, and other possibilities. De-scope options should permit scaling back the project timeline and will be implemented should the full design begin to fail reviews or miss important deadlines. The January 20th date would allow for a fully thought out decision date for inclusion of specific features and functionalities.

Solar powered robotic systems have a long history of application in space programs. Perhaps the most famous recent solar robots have been the Mars exploration rovers Spirit and Opportunity. These rovers are entirely powered by the Sun and any stored electricity. The key components of this project will be to design efficient and effective charging circuits and to choose correct storage mechanisms for our power usage. Rotating solar panels may not be necessary - and this is a likely de-scope option to decrease mechanical complexity and some extra power consumption. More exotic would be attempts to implement solar thermal power systems - yet it may be possible to circumvent the need for parabolic dishes by using thermal generators as heat sinks for the solar panels. This will require an analysis of power gained vs. cost increase and mass increase.

8. References

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14. http://atc2.aut.uah.es/~mprieto/asignaturas/satelites/pdf/rad6000.pdf

Application Pledge:

We, the student team, agree if accepted as finalists to the competition, to complete the project we have proposed in this application to the best of our ability and to fully participate in the final Intel-Cornell Cup competition event which includes completion and submission of all elements of the final report, travelling to and participating in the competition's demonstration expo, and the submission and delivering of a final presentation to the judge committee. We also agree to conduct at least 2 formal design reviews as required by the competition and will record their completion and results with the Intel-Cornell Cup.

Team Member Signatures

Print name: David Esposito Sign name: ______ Date: 11/4/2011

Print name: Farzon Lotfi Sign name: ______ Date: 11/4/2011

Print name: Kevin Reilley Sign name: ______ Date: 11/6/2011

Print name: Roberto Pereira Sign name: ______ Date: 11/06/2011

Print name: Richard Zappulla II Sign name: ______ Date: 11/06/2011

As the academic advisor(s), although I may plan to meet with the student team regularly, I agree to conduct at least 2 major reviews throughout the academic year. Should the team be accepted as a finalist, I also agree that at least 1 academic advisor will be in attendance for the final event at Walt Disney World and I will review their submitted written materials as well as their final presentation and final competition expo display. I will also be responsible for receiving and managing any resources awarded to the team.

Team Advisor Signature(s):

Print name: Jay Summet Sign name: ______
Date: 11/4/11

Team Advisor Mailing Address:

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