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Abstract
In this paper, we explore the lessons learned from the work of the York University Rover Team, which designed, built, and operated prototype rovers for the University Rover Challenge 2008 and 2009, placing third in the first year, and winning first place in the second year. We outline the competition and the team with a brief description of the York University space engineering program. The design of the rover is described with emphasis on the technical challenges of engineering a reliable system. Also, the value of this project as an educational medium is evaluated with respect to traditional classroom learning. The University Rover Challenge 2008 took place in June 2008, at the Mars Research Desert Station (MDRS) near Hanksville, Utah. Under a simulated Martian environment, competing teams remotely performed four mission critical tasks using one remotely-operated robotic system (a rover) of maximum 50kg mass. The competition was continued in June 2009, with some changes to the tasks and requirements. This is one of several engineering projects aimed at providing experiential education to engage science and engineering students through hands-on experience. With participating students from wide range of disciplines, the project proved to be an inter-disciplinary, cooperative educational tool.
1 INTRODUCTION

1.1 Space Engineering at York

The space engineering program at York University is the only such accredited program in Canada. Underpinning the program is a long and distinguished record of of York’s engineers and scientists, who have particular strengths in satellite instrumentation and research. The program offers a wide range of training opportunities with an emphasis on the theoretical knowledge, coupled with the practical experience needed by industries involved in space science and engineering. As part of the engineering education process, we also recognize the significance of “soft skills” in the engineering curriculum that are rather difficult to introduce in a conventional classroom setting. The following aspects are often identified as the challenging areas in engineering education: systems level thinking, creative processes for problem solving, marketing aspects, and project management. The University Rover Challenge presented a unique and effective method of introducing a project-oriented educational opportunity with components in theoretical science and engineering and a wide range of soft skills.

1.2 The University Rover Challenge

The Second Annual University Rover Challenge (URC) took place in June 2008, at the Mars Research Desert Station (MDRS) in Hanksville, Utah. Under a simulated Martian environment, competing teams remotely operated mobile robotic systems to perform four mission critical tasks: geology, soil characterization, emergency navigation, and construction. The theme was that of a manned base on mars using robotic rovers to perform tasks remotely, so that humans can save considerable time and resources. Each team was allowed one robotic system (a rover) which must be a stand-alone, off-the-grid, mobile platform with no tethers or external power sources allowed during the operation, and without any direct observation by the operator except through remote cameras. Total mass, excluding backup power and rover accessories could not exceed 50 kg, with no more than 20 kg of extra, mountable equipment, including spare batteries. The traction had to be able to handle a 15% slope, and the operations had to be able to resist airborne dust, light rain and temperatures of 38°C. The York University Rover Team designed the rover to accommodate four task-specific payloads: a spectrometer for geological analysis, soil analysis tools (consisted of a soil-water concentration meter, a temperature probe and a pH meter), a GPS unit for navigation, and an impact wrench system for the construction task.

The third annual competition was held in May 2009 at MDRS with nine teams and a slightly modified four tasks: extremophile search, site survey, emergency navigation, and construction. The emergency navigation and construction tasks were largely unchanged, though held at more challenging sites. The extremophile search task was judged as a science task, where a team was required to search for and report on likely sites for finding cyanobacteria. The site survey task required a team to calculate the positions of distant markers from their rover using GPS coordinates. The common theme of the URC is that although the events are designed such that a team must understand many aspects of a particular mission, from the intricacies of navigation to the science of finding life on mars, the success of each team ultimately depends, first and foremost, on the engineering quality of its rover.

1.3 York University Rover Team

The York University Rover Team (YURT) was formed in 2007 with the intention of designing and engineering a Mars rover prototype for the University Rover Challenge. The team started with only a few enthusiastic undergraduate students with a common interest in space robotics. Soon after, a number of graduate students joined the group to support the research effort. With support from the faculty and the university, the team expanded into a multidisciplinary, multi-year diverse student team. By 2009, YURT consisted of over 40 student members from space, geomatics, computer engineering, biology, space science, environment science, business, geography and computer science programs among others.

In 2008 (the second annual URC), YURT competed for the first time as the only Canadian entry, and came in a respectable third place in an international field of 11 teams. Building on this experience, YURT expanded its member base, completely redesigned its rover, and competed in the third annual URC in 2009, again as the only Canadian entry. Thanks to the dedication, and engineering and management skills of its members, YURT won first place in URC 2009 against 9 experienced international teams, more than doubling the score of the second-place entry.

2 THE ROVERS

2.1 Design Requirements

The rover was designed to be a remotely operated, self-powered, GPS navigated mobile platform. Although the concept is similar to that of the the NASA Mars Exploration Rovers[1], there was no requirement for partial or full autonomy. Due to the significant time and budget constraints on the team, a “keep it simple” approach was
maintained throughout the design and build process. The URC rovers were designed to be easy to fabricate and repair using inexpensive components sourced whenever possible from local distributors. In addition, the rover had to be light and agile enough to climb rocks and steep grades, but capable of mounting all the hardware needed to perform the various tasks. On-board computers needed to be small and power-efficient, and a Linux operating system running open-source software was used to provide a free, easy-to-use platform for development of control programs and sensor systems. The rovers also needed to be robust and able to withstand rough terrain, high temperatures, collisions, demanding tasks, and transportation to and from the competition. Engineering the rovers proved to be complex and arduous, but also a very rewarding experience for the members of YURT. The rovers from 2008 and 2009 are shown in Figures 1 and 2 respectively.

2.2 Mechanical Design

2.2.1 Chassis

The frame of the 2008 rover was constructed of sturdy 1-inch aluminum profile. To keep the center of gravity low, the chassis was built as a cross-shaped 0.6 m by 0.5 m frame with steel plate bottom, drilled through for lightness. Two aluminum struts were used to secure the top of the arm positioner in an "A-frame" arrangement. The chassis in the 2009 rover was made stiffer yet lighter by using extruded magnesium alloy angle beams obtained and welded with sponsorship from M&B Mag. Rather than a planar design, a box truss design of 0.75 m x 0.5 m x 0.22 m with a 0.2 m extension for mounting the arm provided improved rigidity while minimizing weight and creating a secure place to house the onboard systems.

The new chassis, although slightly heavier overall than expected, proved to be very durable and functional. In concert with the suspension, the box truss withstood the shifting weight of the rover and the dynamic loading of the wheels and mast with minimal bending and no discernable damage over the course of the competition.

2.2.2 Suspension

The 2008 YURT rover had no suspension. Wheels and support bearings were directly mounted to the frame during development. A suspension system was finished days before the competition, but it made the rover overweight and could not be used. As a result, the rover rode only 6 cm above ground on 22 cm wheels, frequently lost traction on rocks or rough soil, and became stuck on small
bushes in the Utah desert, requiring human intervention and the loss of time and points in URC 2008. In contrast, the suspension system for the 2009 rover was planned and fabricated in parallel with the rest of the chassis. It featured fully-independent support for each wheel through upper and lower equal length control arms, which are supported from the chassis via a coil-over strut, as shown in Figure 7. The strut is connected to the center of the upper control arms to allow springs with less travel and greater stiffness to be used. The motor for each wheel is mounted directly to the shaft bearing, between the control arms, and is protected by them. With the addition of much thicker 28 cm off-road wheels and more powerful motors, ride height was increased to about 20 cm.

The suspension system made a vast difference to mobility. The 2009 rover rode straight over rocks and bushes with ease, crossed ditches and gullies without consequence, and could climb a 45° slope at speed. In the field, the suspension and drivetrain outperformed all expectations, and the rover never lost balance despite the increase in ride height. In URC 2009, YURT was the only team to locate the astronaut during the emergency navigation task, and the rover never required human intervention during any task.

### 2.2.3 Arm and End Effectors

The first rover arm designed by YURT was expressly designed for the 2008 construction task, since the other tasks needed only basic arm functionality. Rather than a conventional jointed arm, a two-axis Cartesian positioner constructed with lead screws was used for vertical and horizontal movement of a single joint, which could be angled and rotated. This greatly simplified the arm kinematics, so that an operator could easily locate a target in three dimensions using only camera feedback. The end effector was task-specific. For the construction task, a DC motor socket wrench was attached to a telescoping slide, to facilitate grasping and tightening a bolt. For the soil task, a moisture probe and thermometer was lowered into the soil. For the geology task, an infrared Argus spectrometer donated by Thoth Technologies and a USB camera formed the end effector for examining rocks. In the second year of the competition, the arm was modified to be lighter and have better reach using two servos in place of the rotating angled joint. Also, a visible-spectrum Red Tide spectrometer donated by Ocean Optics was used for the extremophile task, in which YURT earned 95 points out of 100. Figure 3 and Figure 4 show the end effectors for the construction task in 2008 and 2009.

These simple arm designs proved so effective and controllable, that YURT dominated the construction task in both years of the competition. Because of the low speed and high torque generated by the lead screws, tightening bolts on a flat panel or aiming a spectrometer was easy even without the use of inverse kinematics or feedback motor control. The 2009 plan included a set of four laser pointers to automatically align the arm to the construction panel, but due to time and reliability issues, this component was not used during URC. The most difficult part to design and control was the angle joint, which had lower torque and controllability despite the use of servo motors in 2009.

### 2.2.4 Mast

Due to the complex terrain encountered in the Utah desert, it was essential to maintain contact with the rover’s antenna by line of sight, and to have a high vantage point for observing the terrain and rover itself. The antenna and a steerable camera were located at the top of the 2008...
rover’s frame, about 1m from the ground, and proved to be a vital feature in navigation, though it was not sufficient to complete the navigation task.

Because of this, the 2009 rover was designed with a 2 m aluminum mast, which was used to mount the 0.6 m antenna and a set of four steerable cameras for a “bird’s eye” view of the surroundings. Despite the height of the mast, shown in Figure 9, the rover never tipped over, even on 45° slopes, because about 90% of the rover’s mass was concentrated in the chassis close to ground level. This mast was removed for the short-range extremophile task, but was essential in the other tasks for both communications and imaging.

2.3 Electronics

In the 2008 rover, the batteries, communications, and onboard computer were housed in the bottom chassis, while a wooden box was used to hold the power and control electronics, and motor controllers. The wooden backplane could quickly mount components in arbitrary positions, but this methodology resulted in very disorganized wiring harnesses which were difficult to debug and isolate, as shown in Figure 5. Also, the box was very badly sealed even after the addition of Lucite walls and cloth covers, and sand, dust, and metal fragments from the chassis often accumulated inside, reducing reliability.

The priorities for the 2009 rover were to organize the "rat’s nest" of power and data connections that resulted from the single wooden backplane, and to seal the electronics away from environmental contaminants. The team decided to use a modular system design methodology, containing each system component (power supply, motor controllers, arm control, onboard computer, etc.) in separate metal boxes that could be removed for development and debugging, then sealed and mounted within the chassis using Velcro, as shown in Figure 6. The boxes were connected using standard DE9 connectors and RS-232 serial cables and placed above the heavy battery packs. Polarized, locking Molex connectors were used for routing power and connecting the drive and arm motors. This modular system design and sealed electronics boxes proved to be robust and manageable, although the arm wiring still included enough individual connections to require time-consuming reconnection.

2.3.1 Batteries

For both years of the competition, power for the rover was stored in packs of nickel-metal hydride (NiMH) cells. 12V was used for the onboard systems and arm control motors, while 24V was used for the drive motors. Packs
of SAFT NiMH D-cells were obtained from a local distributor in 2008, and for 2009, smaller Tenergy NiMH C-cell packs were used in an effort to lower costs and make the batteries more modular.

Both systems worked well, though ultimately the SAFT batteries proved more robust. Due to the established need for maximum torque and electrical isolation between high-current and low-current systems, in the 2009 rover, two switched 12V lines and one 24V line were used to direct power separately through a distribution box as well as a bank of 5V linear regulators to provide power to the USB hubs, cameras, and arm servo motors. This provided higher reliability and manageability of power on the rover.

2.3.2 On-Board Computer (OBC)

As the rovers were essentially remote-controlled robots, with little or no on-board autonomy, the processing requirements were light. To save power, a stack of Virtual COGs based on the i.MX21 ARM9 processor and running embedded Linux were originally planned to function as an onboard computer, localization system, and camera. However, the COGs proved to be unreliable, difficult to develop with, and badly supported. As a result, the COG stack was abandoned late in development in favor of a simple VIA Epia-N 1GHz x86 motherboard running Gentoo Linux from a solid-state hard drive. An ALIX.2D2 SBC from PC Engines, based on a 500MHz AMD Geode x86 CPU and using CF card storage, was used in the 2009 rover, using a Linuxstamp ARM9 development board connected via ethernet as an I/O extender.

The Epia-N functioned well as a quickly-fieldable OBC, but was much more powerful than needed, and used 18W of power even when lightly loaded, which limited battery life. The ALIX board not only consumed less than 5W of power on average, but also provided two Mini-PCI card slots, which were used for communications and extra serial ports. The board ran Debian GNU/Linux very well, and could run the SpectraSuite software for the Red Tide spectrometer over a remote X11 session, although slowly. An identical ALIX board was used as a base station router, for wirelessly connecting to the rover and relaying communications to team members’ computers. More Mini-PCI slots would have been helpful, but the ALIX OBC performed very well overall. The serial ports provided sufficient I/O that the Linuxstamp was not needed, and was later used as a superior replacement for the Epia-N on the 2008 rover.

2.3.3 Communications

Due to the bandwidth requirements for video from the rovers, and the need to manage several concurrent data connections to different onboard systems, wireless ethernet was chosen as the medium for long-range rover communications. For better range and non-line-of-sight performance, 900MHz ISM band radios were used rather than the conventional 2.4GHz radios. The 2008 rover used a 1 Mbit Digi Xtreme Wireless ethernet bridge and a dipole antenna. To improve bandwidth and flexibility, the 2009 rover used Ubiquiti XR9 Mini-PCI wireless cards on both the rover and base station computers to create a network bridge between the rover and base. A larger, enclosed dipole antenna was used on the rover, and two large sector antennas were used at the base station.

The 1Mbit ethernet bridge worked very reliably, but provided barely enough bandwidth for a single medium-resolution video feed, and required an ethernet connection to the OBC. Using the cards on the 2009 OBC allowed much more detailed configuration of the link and the addition of other computers on the rover as needed, with the OBC acting as a router. However, it took several weeks of testing to configure the wireless link and network routing properly, and the Linux network drivers for the card needed to be compiled and configured. The actual bandwidth obtained over the 900MHz link was usually only 5-10 Mbps, but ultimately, the Ubiquiti radios performed much better overall than the wireless bridge, particularly in the Utah desert where there were no strong interfering radio sources.

2.3.4 Motor Drives

The drive motors in the 2008 YURT rover were powered by a pair of Devantech MD03 20A motor controllers, which used an F2C bus for communications. The arm control motors were powered by a set of simple H-bridge ICs, controlled by PWM from an Atmel AVR microcontroller. The 2009 rover was designed to be much more electrically...
robust. Because of the higher torque and current requirements of the chassis and the new larger motors, a pair of Dimension Engineering Sabertooth motor controllers were used, with current capacity of 25A per channel. The arm was controlled with 13A Pololu Qik 2s12v10 motor controllers.

Although the MD03 controllers used in 2008 performed near-flawlessly, the simple H-bridges proved very unreliable. Although the ICs were rated at 36V and driven at 24V, they would short and fail frequently from back-EMF and high motor current, damaging the microcontroller in the process. After multiple failures, and because of time constraints, it was decided to run the arm motors from 12V, which prevented further failures but decreased the speed and power of the arm. In 2009, the Sabertooth and Qik motor controllers proved very reliable and easy to program. Although I2C was considered as a control bus, this choice of hardware necessitated packetized serial protocols and multiplexing of serial lines, which required amplification of the outgoing signal with a transistor and merging of the incoming signals with an AND-gate.

### 2.3.5 Software

The rovers used separate programs running concurrently on the OBC to manage the onboard hardware. In 2008, the system was quite simple, using the UNIX socat utility to redirect network packets directly to the drive and arm controllers via serial ports. Motion JPEG video from the cameras was streamed over a network port by using the program mjpegsreamer, a simple but reliable embedded video streaming server. Thanks to better knowledge of the needs of a remote vehicle, and the contributions of a larger development team, the 2009 rover used a suite of custom-built programs for motor control, video streaming, and task-specific functions such as surveying. Each program was assigned a specific network port on the OBC network interface starting at port 30001. In this way, each rover onboard system could be directly accessed remotely, as well as locally. Port 30000 was reserved for the process control program, which is loaded at boot-up and dynamically starts and stops all other programs when commanded.

To provide intuitive, comprehensive control of all the rover’s functions, a Graphical User Interface (GUI) was written in Java using the Eclipse SWT toolkit, which could be run on most common OS platforms and allowed the process control, cameras, motor control, and other programs to be managed clearly. A screenshot is shown in Figure 8. In the GUI, joysticks could be used for motor control, which made precise movements much easier than using keystrokes. Secure Shell (SSH) network access was used to provide a command-line interface for running control programs directly, which served as a fallback for debugging or in case of problems with the GUI. Overall, this software architecture worked extremely well, being only constrained in its success by the amount of time to add new features, and the SSH fallback proved effective in the rare cases of GUI problems.

### 2.3.6 Cameras

In both years, all vision and control feedback was obtained via Logitech Orbit AF and Quickcam for Notebooks Pro AF 1.3MP USB webcams, with software autofocus capability. These were determined to be the easiest to use (through the Linux uvcvideo driver) and most cost-effective digital cameras available. Tests were performed with TCP/IP security cameras, but all tested models proved to be unusable because of hardware reliability issues and the use of proprietary video formats. Serial cameras were a viable alternative, but had low framerates and require video transmission software to be written. Powered USB hubs ensured that all cameras were provided with sufficient current to operate.

Although the USB webcams proved to be excellent performers individually, running more than 2 or 3 simultaneously overtaxed the available bandwidth of the radio link even at low resolution and framerate. Also, under the variations in voltage, temperature, and vibration experienced, single cameras frequently disconnected while transmitting, or did not initialize properly, requiring a restart of the whole USB camera system. Although at least minimal video was always restored when needed, the use of many inexpensive USB cameras seems less desirable as having two or three very reliable, highly-configurable cameras, such as IEEE1394 or PCI-bus cameras.
2.3.7 Localization

The primary method of determining the rover’s position on the ground was by using an embedded SiRF Star III chipset GPS receiver located on a USB “mouse” GPS unit on the 2008 rover, and on the Serial Mini-PCI card on the 2009 rover. Additional USB GPS units were connected to improve accuracy and as failover devices, but the serial GPS unit performed most reliably throughout the competition. The rover’s position was tracked by sending GPS data with the “gpsd” network daemon, and receiving it with the open-source program “roadnav”.

The roadnav program was ideal for rover navigation because it not only uses free vector-based TIGER/Line files from the U.S. Census Bureau, but also buffers and overlays scaled U.S. geological terrain maps. Several local Utah maps of different resolutions were cached before the competition, and the resulting wealth of information regarding terrain features and layout were invaluable in all the tasks, particularly the emergency navigation and site survey tasks in 2009.

2.3.8 Site Surveying

In the third annual URC in 2009, the site survey task was introduced, requiring teams to find the UTM coordinates of a set of fixed markers in the desert, most of which were unreachable by the rovers. It was necessary to develop an inexpensive method of determining the location of a distant point, the equivalent of an automated Total Station used for surveying. The solution YURT developed was to modify a Celestron NextStar SE motorized telescope with webcams fixed to the eyepiece, and use an AVR microcontroller to change the telescope focus via stepper motor. It is visible in Figure 2. The telescope could be angled with arc-second accuracy via serial port commands, and by recording the precise angles to a distant marker from two or more known GPS points, re-sectioning could be used to triangulate the position of the marker. A Java GUI was written specifically for recording GPS points and performing this calculation.

In theory, this method could be used to locate points more than a kilometer away with less than a few meters of error. However, the actual accuracy of the system was significantly lower, partly due to limited GPS accuracy. Also, limited time was available to practice with the system before the competition, and it took longer than expected to perform the measurements in the field. As a result, the team ran out of time during the task and could not properly resection some points, but still performed several measurements and gave a solid performance under difficult circumstances. More testing and practicing will be performed in the future to avoid these kinds of problems in the field.

3 EXPERIENTIAL EDUCATION

3.1 Project Management Skills

A number of research studies have shown the significance and necessity of hands-on engineering practice. In a 1995 paper[2] Coleman reviewed the STudio for Engineering Practice (STEP) program at the University of North Carolina where such a hands-on engineering component was introduced at the first-year level. In his paper, he argued the necessity of “multi-disciplinary experience and vertical and horizontal integration of skills and teamwork.” Since then, we have seen several programs where engineering practice was integrated either into the class-room setting or project-based courses.

Compared to such structured design courses and programs, the University Rover Challenge offered a unique opportunity where the students were allowed full freedom to exercise their design creativity and research choices.
While the competition offered the same benefit of "multi-disciplinary experience and vertical and horizontal integration of skills and teamwork" that Coleman showed, it also allowed students to choose the amount of effort, level of involvement, and the type of activities they were involved with.

Also by working with students from first year to PhD level in their academic careers, each member gained valuable experience in working within a large team setting. Note that in the space engineering program at York University, the subject of project management is discussed in the second year of the undergraduate program. Several students in the rover team expressed their deep appreciation of the concepts discussed in the classroom setting, and applied in the practical aspects of the rover design, including work breakdown structures, risk management, responsibility matrix, and most importantly, time management skills.

As the team grew from 6 members to over 40 students with diverse background and interest (including space, computer, and geomatics engineering, physics, biology and chemistry), it naturally divided itself to sub-groups. In 2009, the team was officially divided into 5 groups: mechanical design, development, science, finance and accounting. Each sub-group elected a team leader, who then reported the progress to the team captains and the faculty advisor. Without a formal implementation, the team worked under a conventional cooperation structure with more experienced senior students in the leading roles, as described on the team website[3]. A picture of the team in 2009, including many of the 2008 members, is shown in Figure 10.

In addition to the design and fabrication experience, students were offered diverse opportunities including machine shop training, safety instruction, and electrical assembly techniques. Several workshops were held throughout the year to assist junior members to gain hands-on experience including PCB design, CAD applications, and motor control fundamentals. The design of the rover was periodically reported in a series of design reviews such that fellow students, faculty members and industrial partners had access to the research and technologies under development.

3.2 Design Exercise

The process of designing each rover took several months, as designs were suggested, discussed, discarded, and recreated. Although less time was needed as experience was gained, the process itself is an important part of an engineering education. The overall experience was akin to any real-world industrial design process, both in content and in environment, and serves as a resume-quality reference for the participants.

Experience gained in URC 2008 encouraged the team to engineer each sub-system with sufficient margin, and to pay close attention to every aspect of the design. The team had the chance to experience a unique opportunity to design and build something larger, more complex, and more comprehensive as a group than an average student could alone. That experience was often described as "satisfying", and is also expected to be useful in any profession.

The team also valued the lessons learned about teamwork as the competition became more challenging. Appreciation of team effort in engineering education is a difficult concept to demonstrate in a classroom setting, and the University Rover Challenge presented the concept in a relatively "safe" environment with tangible rewards. Also, the opportunity to work with a self-managed, multi-disciplinary team is mind-broadening for students, and does not often occur in traditional educational streams.

3.3 Field Experience

One of the most unique aspects of this experience was the opportunity to perform engineering tasks in the field, rather than in the lab or classroom settings. We performed field tests of the rovers during development to validate and improve their engineering, and also in Utah to prepare for the URC events, such as in Figure 11. Field testing is often considered to be one of the most fun parts of the build process, as students are able to enjoy the results of their hard development and fabrication work.

This field testing and experience led to a vast number of modifications in the 2009 rover compared to the 2008 design, such as larger motors and wheels, a more controllable, lighter arm design, redundant control methods in software, more flexible design of the communications system, and a modular electronics design just to name a few. More importantly, the students were able to put their own engineering and interpersonal skills, paradigms of quality, and self-limitations to the test under real-world conditions.

4 LESSONS LEARNED

The engineering concepts learned through the rover challenge are often considered "difficult" to teach in the classroom. Practical curricula often include practical components in the form of design projects, team exercises, and laboratory training. The rover challenge offered a wide
range of lessons that included much of the above experience with little guidance in a longer term with more student participation, and allowed the application of skills and technology from within the classroom to a real-world environment.

Through two years of designing, building, and testing the rovers, we obtained valuable experience in project management, practical engineering and team-effort. Among the many lessons we learned, we consider the following to be the most significant:

1. Fund-raising and financial management aspects of a student engineering project are just as important as good engineering management practices, and are the underpinnings of successful project delivery.

2. The team should have access to experienced feedback and be able to showcase the design through media and outreach programs, so presentations and public speaking are an important skill set.

3. In a student project such as this, it is essential that simple, incremental engineering steps be planned instead of long, complex development cycles due to volatile student timetables.

4. Contingency planning for every major technical and organizational aspect of the project is essential because of frequent lack of experience on the part of students, and builds good engineering habits as well.

5. Engineering experience provided through practical challenge and competition is an effective method for teaching both "soft" and "hard" skills, and can complement a classroom education if well planned.

5 CONCLUSION

After working with a group of talented students of a variety of backgrounds, the authors (a development team lead and a faculty advisor) feel strongly that the project has been a great success in several aspects. It presented a unique and invaluable opportunity to celebrate the engineering creativity and educational benefits.

We have gained irreplaceable lessons that would have been difficult to offer in traditional classroom settings. The rovers from the 2008 and 2009 University Rover Challenge featured simple, effective design and well-built, usable components. The members of YURT built a remotely-
operated robotic platform using off-the-shelf and machined components that could effectively perform research and technical tasks in a challenging environment. They then learned, in detail, how to build on their experience to produce a more reliable, more capable, and greatly superior rover, reaping the rewards of their hard work at URC 2009.

More importantly, we learned through hands-on, in-the-field experiential education, that team effort and well-planned project management are as important as quality engineering design. We also learned through a competitive process and large-scale project that soft skills such as fund-raising and public speaking are also recognized engineering skills that may be more difficult to implement through conventional curriculum.

The York University Rover Team is proposed as a successful model of engineering and engineering-related learning that can compliment a classroom education. We, as a team, look forward to another rewarding year of competition and have initiated a design process for URC 2010.

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