Learning Robotics through Participation in National Design Contests

Ahad S. Nasab, Walter W. Boles, Rick Taylor, Travis Martin, Thomas Klutts, Jason Ray, Keith Melton, Chase McGrady, and Kevin Redington[1]

Abstract

Every two years students from many academic institutions gather in Albuquerque, New Mexico to participate in a NASA sponsored robotics contest. This contest that is held in conjunction with the Space and Robotics Conference, challenges students to apply their engineering and technology skills towards solution of space based technical problems. This year, a team from the Middle Tennessee State University (MTSU) participated in this contest. The students in this team designed and built two robots to accomplish the task. One robot called the Locator was designed to locate the buried lava tube (a box) by poking the sand with 16 pins with independent suspensions. Once located, the Locator robot marks the area for the second robot to approach the area, drill through the sand and the buried box, and install an airlock. The robots were remotely manipulated by the students from another room using cameras mounted on the robots to simulate control of such vehicles on the moon from the earth. Students accomplished many of the required tasks successfully due to the methodical utilization of their design and project management skills.

Introduction

The senior design or capstone projects are designed to provide an environment for engineering and technology students to harness the knowledge gathered in many upper division technical courses and use them in a complex design and production process. These activities are also categorized as project-based learning. Many renown institutions across the nation promote such activities at various educational levels[1, 2]. The subject of the design varies depending on the major field of study. There are, however, many areas in the engineering and engineering technology fields that specialty knowledge in one field of engineering would not be sufficient in successful execution of the project. One particular example of such projects is activities involving industrial or mobile robots. The field of robotics is a truly multidisciplinary field in that knowledge and skills in many areas such as mechanical, electrical, manufacturing, materials and controls are practiced. Additionally, when such projects are performed by teams of students and with the further constraint of a national design contest, other skills such as project management, budgeting, fund raising and written/oral presentations become indispensable.

One important objective of a senior design project is teaching the students how to utilize diversified human resources to the benefit of the project. The teamwork environment is one of the more challenging activities of a complex project since it involves diverse personalities and behavior issues, which are rarely addressed in the technical curriculum contents.

Managing a project with limited funding and human resources as well as actual size, weight, shape, and date constraints requires some levels of sophistication in project management[3]. The reasonable in addition,

---

[1] All authors at Middle Tennessee State University., Murfreesboro, TN 37132.

practical management of such activities need to be emphasized early in the formation of the team and needs to be a vital assessment tool for project progress.

This paper explains the experiences of the Middle Tennessee State University senior design project team, which designed two robots to compete in the biannual NASA-Robotics[4] contest held in Albuquerque, NM. It covers issues such the technical design, construction, logistics, and project management.

Project Definition

NASA is establishing the first permanent base on the Moon. Constructing a habitat is the first priority. Construction will take place remotely with robots controlled from the Earth. Previous missions have detected lava tubes just under the lunar surface. The task assignment for the contest is to locate a subsurface lava tube, excavate to expose the tube, drill a hole in the tube for a 4-foot diameter (scales to 4 inches) entry/exit airlock, install an airlock, and demonstrate that the airlock is airtight. For purposes of the contest, it is assumed the lava tube is capable of pressurization (up to one psi). A panel of judges evaluates the teams based on the quality of their technical report, engineering design and analysis, budgeting, oral presentation, and performance demonstrations of the proposed prototype.

The oral presentations are scheduled in the evening before the first day of the biannual Space and Robotics conference. On the next day, teams are randomly selected to demonstrate the performance of their proposed remote-controlled robotic systems. The competing teams have the option of repairing and fine-tuning their robots and competing again on the following day.

A 12-foot square box filled with sand to simulate regolith represents the surface of the Moon. One lava tube made of half-inch thick gypsum board is buried at a random location up to four inches below the surface. The depth of the sandbox is approximately ten inches. The box simulating the lava tube has dimensions of 4 by 10 by 16 inches.

Each team is allowed to manually place their robots in the sandbox and then leave the area to another location so that they can control their robots using wireless camera systems only. The tasks include locating the underground box, finding its approximate center, installation of an airlock system and disengagement and clearing of the area. All power and other resources must be placed onboard. No visual or physical attachment to the robots is allowed. This requirement simulates the control of such robots from Earth. Extra points are awarded for teams who incorporate a simulated three-second delay in the video transmission to mimic such signal transmission delays from the moon to the earth. All methods must be lunar viable, meaning techniques using acoustical wave reflections would not be acceptable. All hardware is to be designed to fit in the Dynamic Payload Envelope of the lunar rocket at the scale of one inch representing one foot in the actual rocket payload area.

Team Composition

Senior design projects often require skills in many technical and non-technical disciplines. It is imperative that teams be composed of students with diverse backgrounds and interests. The NASAelectromechanical engineering technology majors, one design engineering technology major and one engineering technology graduate student. The graduate student was selected into the team because of his extensive machining background. Figure 1 shows the MTSU NASA-Robotics team members.

Figure 1: The MTSU NASA-Robotics Design Team

Technical Activities

Conceptual design - One of the most challenging parts of this project was deciding on a feasible system that would meet all the constraints of the competition. Since all the initial proposed designs were equally complex, it was decided that two of the most feasible designs be selected and worked on simultaneously while other concepts were to be revisited on a regular basis to determine if they seemed more feasible in light of team's accumulated experiences. Since many tasks were to be performed remotely by the robotic system, it was decided that a system comprising two simpler robots would have many advantages. Each system not only would be specialized in their hardware and tasks, but each robot could also act as a very versatile vision system for the other. Furthermore, it was decided that designing a system which would be able to drill and install an airlock without the need for clearing the sand would simplify the hardware, even though it would add more complexity to the airlock module.

Locomotion - Movement of the proposed robotic Moon rovers on the soft and often moist sand presented a unique challenge since ordinary wheels and tires could not be used in such environments. Most tire designs include groove patterns that supposedly add to the wheel traction, but such designs become very ineffective after few inches of travel in the soft and sticky sand. One of hardest tasks for all the participating teams was easy moving and maneuvering in the sand. Realizing this difficulty in the early stages of the design, our team assigned two team members to investigate various wheel and tire configurations. The wheel design that was proposed was a custom-built wheel made of 1/8 inch thick acrylic sheets organized in a radial array and separated by about 1/2 inch on the outer rim. See Figure 2.

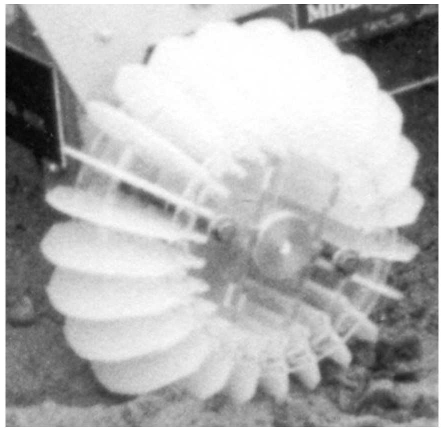

Figure 2: The final design of the robot wheels

For the combination of rpm and torque required for this robot, the MTSU team's design calculations led to the selection of 12 VDC motors attached directly to a gearbox, which provided 25 rpm under no-load conditions. This combination worked well for the locomotion tasks. During the competition, the MTSU robots were the only ones that easily traversed the rough sandy terrain of the sandbox and encountered no difficulty in moving forward and backward as well as turning in any direction.

Locating scheme - One of the required tasks to be performed in the NASA-Robotics competition is finding the buried lava tube or in this case the gypsum board box. Several intrusive and non-intrusive schemes may be employed for this task. Obviously, the non-intrusive options present a faster solution, leaving time for other tasks to be accomplished within the allotted 45 minutes for each team. The non-intrusive techniques include radar and sonar waves. Sonar waves are not lunar viable, since they rely on an intervening medium such as air for transmission of the acoustic waves. The radar systems, which employ electromagnetic waves are lunar viable; however, these systems require large power supplies and relatively expensive hardware for transmission and detection of radar signals. The minimum cost of such systems is approximately $10,000, which was not feasible for this competition where the cost was supposed to be contained within one or two thousand US dollars. Of the intrusive techniques, typically a rod or blade is inserted continuously or intermittently into the sand to detect the box. Such encounters are then detected either visually using the on-board cameras or by a sensor system.

Inserting a rod or blade in the sand at a depth of at least 5 inches presents a significant drain on the torque furnished by the motors and wheels. Blades offer the least resistance, but deform easily when the vehicle makes turns. It should also be noted that a 12' by 12' area has to be monitored and a box with only a 10" by 16" top surface area be detected. This constraint requires that an efficient scheme to be devised to perform this task within 15 to 20 minutes. Most participants in this competition forfeit the points for this task and request that the information about the coordinates of the buried box be furnished to them. This task, however, is one of the more intriguing and challenging activities of this project and our team decided that they would spend as much time and skill resources on locating the box as they would on airlock installation and pressurization tasks.

After many design trials and technical evaluation of each, the MTSU team decided on a small vehicle that would include an elevator platform with sixteen pins around its peripheries. This locator vehicle would start at a random corner of the box, move two feet in a certain direction, and then stop and lower the pins to detect the box. If a box was not detected, the pins would be retracted and the vehicle would move another two feet to a new location. The vehicle speed as well as the lowering and raising of the pins were designed so that the entire sandbox could be examined within 15 minutes. See Figure 3.

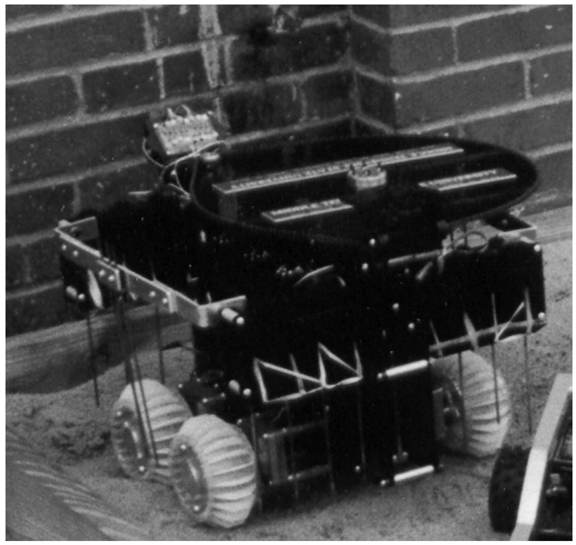

Figure 3: The locator robot with locating pins on the elevator platform

The pins had individual suspension systems and were each individually attached to simple limit switches that would power onboard LEDs. An onboard camera kept a constant view of the circuit board that housed the LEDs. This way, the human controllers could get detailed information about the detection of the box by any of the pins and be able to locate the box and its center within two inches. The other vehicle designed for drilling and installation of the airlock provided an off-base view of the locator robot while box detection task was underway.

A particularly difficult question to answer in these series of design activities was how the location of a detected box would be given to the human operators so that they could maneuver the drilling robot to that location. In other words, once the box is detected and the locator robot is moved out of that location, the area where the box was detected would be practically unmarked and the information about the box location would be lost. After many trials, our team decided on a scheme where the locator robot would turn in place three times to mark the area with a circle having the diameter approximately equal to that of the locator robot's wheelbase. This scheme worked well for this task.

Materials and Manufacturing: - For minimizing the total weight of the system and the torque burden on the motors, the robot chassis was made of one-inch aluminum angle stock. The rest of the vehicle including all the platforms was made of 1/8-inch thick acrylic sheets. The plastic pieces were designed using AutoCAD software and the files transmitted to a X-30 Universal Laser Systems 50 W CO_2 laser cutting system where they were cut and later manually assembled. This system gave the team a remarkable advantage on the design trials of the wheels and locator robot's elevator system.

About seventy percent of the design time was spent on the design of a self-contained drilling, airlock, and pressurization head. This one-piece system was supposed to comprise a drilling head, a sealing interface, pressurized capsules, and a pressure indicator; moreover, it was supposed to be automatically disengaged when the task was accomplished.

Many prototypes were assembled to check the functionality of the drilling module. After some modifications of the design, the final module was designed using AutoDesk Mechanical Desktop and manufactured using a Stratasys FDM (fused deposition modeling) 3000 rapid prototyping machine, which uses ABS plastic material along with a bonding agent to convert AutoCAD STL files into physical models. See Figure 4. The cutting tools were embedded into the module during the manufacturing process. The drill module was the hallmark of this design team. It took very intense and sophisticated design practices to successfully manufacture this part.

Figure 4: The one-piece drill/airlock/pressurization module

Remote Vision system: - The vision system mounted on the two robots comprised three wireless X10 cameras with pan and tilt capabilities. These cameras as well as a multitude of other motors and equipment were all operated by remote controls performed by two students from another location. The MTSU team had a slight advantage over some of the other participating teams in this area, since they had some, albeit limited, experience with controlling devices and motion using camera systems. Ideally, one team member needs to be proficient in controlling the robots using the camera vision system. An unforeseen phenomenon that interfered with efficient remote control of devices and video reception was the presence of many spectators around the competition arena and the fact that many of the audience carried video cameras and other EM transmitting devices. Figure 5 shows the drilling robot with all the equipment onboard.

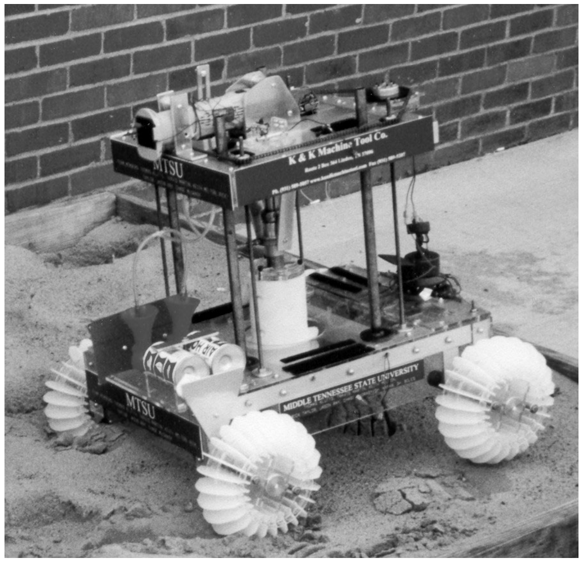

Figure 5: The drill robot showing the drill motor, cameras, and air canisters

Project Management

Project management is seen by some[5] as a critical area for technology students who are increasingly likely to encounter project teams and may serve as project managers. Management of student design projects can help the progress of such projects when done correctly[6]. Project management needs to rely on sound management principles to help expand the range of experiences as well as to keep the projects true to their time, human resources, and budget limitations and deadlines. Students at MTSU are required to work in teams in many of their junior and senior level courses. Such experiences have helped students to manage capstone projects with fewer difficulties. Human interaction and time/budget limitations are among the less familiar concepts that typical engineering and technology students deal with. Successful projects need to require skills such as communications, organization, team building, leadership, and consensus building[7]. Even though there was a constant drift toward project execution by the students, the team managed to address other issues such as scheduling, planning, budgeting, and design evaluation.

Results and Conclusions

Many aspects of the NASA-Robotics project described above fall into two major categories; namely, qualitative measures and quantitative gains. Experiences gained through 12 months of teamwork, project management, fund raising, and various communications are qualitative gains, which enhance the student educational experience in ways that no formal classroom activity can do. Projects that are tied to national or international level contests bring a very tangible component to the project assignment and give a new meaning to the objectives of the project. Moreover, it places the work of the students in a national ranking system that adds to the credibility and significance of such accomplishments. The MTSU team placed third nationally in the NASA-Robotics competition, which was held in April 2002 in Albuquerque, NM.

More quantitative goals of the project, such as conceptual design, performance calculations, prototyping, manufacturing, testing, and evaluation, were accomplished and were indispensable requirements of the project. The budget and size constraints of the project were very real and were frequently checked for compliance.

One of the ancillary benefits of using robots in senior design projects is that it attracts and requires multi-disciplinary activities. Students must address the interfaces between electrical, controls, mechanical, and manufacturing systems. Such projects readily satisfy the ABET requirements that curricula should include cross-disciplinary and project-based learning.

In a capstone project, the use of basic project management techniques introduces students to project planning rather than execution-only activities. It also helps students identify the weaknesses of the project and maximizes the efficiency of resource management.

References

1. Jahan, K., R. A. Desseau, R. P. Hesketh, A. J. Marchese, R. P. Ramachanandran, S. A. Mandayam and J. L. Schmalzel, Engineering Measurements in the freshman engineering Clinic at Rowan University, 1998 ASEE Annual conference and Exposition, Seattle, WA, June 28 – July 1, 1998, Session 1326.

2. Marchese, A. J., J. A. Newel, R. P. Ramachanandran, B. Sukumaran, J. L. Schmalzel, and J. Marriappan, The Sophomore engineering Clinic: An Introduction to the Design Process Through a Series of Open ended Projects, 1999 ASEE Annual conference and Exposition, Charlotte, NC, June 20 – 23, 1999, Session 2225.

3. Heitman, G. K., and R. Manseur, Organization of a Capstone Design Course, 30th ASEE/IEEE frontiers in Education Conference, October 18 –21, 2000, Kansas City, MO, session F1C.

4. Official Web site of the Space and Robotics biannual Conference., http://www.spaceandrobotics.org

5. Vavreck, A. N., Project Management Applied to Student design Projects, 2002 ASEE Annual conference and Exposition, Montreal, Quebec, June 16-19, 2002, Session 2642.

6. Smith, I., Teaching Project Management Skills using Project Management – A True Hands-On Experience. 1998 ASEE Annual conference and Exposition, Seattle, WA, June 28 – July 1, 1998, Session 3448

7. Smith, K. A. Strategies for Developing Engineering Student's Teamwork and Project Management Skills, 2000 ASEE Annual conference and Exposition, St. Louis. MO, June 18-21, 2000, Session 1630.

Ahad S. Nasab

Dr. Nasab is a Professor in the Engineering Technology and Industrial Studies Department. He is presently the coordinator for the Electro-mechanical engineering technology program. Dr. Nasab received his B.S. degree in Engineering from California State University, Northridge. He received his M.S. and Ph.D. degrees in Mechanical Engineering from the Georgia Institute of Technology. He later joined the Center of Excellence for Laser Applications of the University of Tennessee Space Institute as a research associate. While there he conducted research on electromagnetic launchers (railguns), arcjet thrusters for spacecraft propulsion, free electron lasers for laser propulsion, and various aspects of laser welding technology. He has published several technical papers in various scientific engineering and physics journals and has presented papers in many national and international conferences on high- energy systems engineering. His activities at MTSU include robotics and automation as well as thermal sciences. Dr. Nasab is registered as a Professional Engineer in the State of Tennessee and a member of ASEE, AIAA, and ASME.

Walter W. Boles

Dr. Boles is Professor and Chairman of the Engineering Technology and Industrial Studies Department. He earned an A.S. Degree in Pre-Engineering from Danville Community College, Danville, Virginia, and B.S. /M.S. degrees in Civil Engineering from Virginia Tech. Dr. Boles then worked nine years in the construction industry where he held positions such as project engineer, subcontracts manager, project manager, and sales manager. Dr. Boles then attended the University of Texas at Austin where he received a Doctor of Philosophy degree in Civil Engineering, specializing in Construction Engineering and Management. Dr. Boles' teaching and research interest include the areas of construction management, construction operations on the Moon and Mars, automation in construction, construction materials, and methods. Dr. Boles has authored over 30 publications and recently completed a NASA-ASEE Summer Faculty Fellowship at Johnson Space Center in Houston, Texas. Dr. Boles has taught at Texas A&M University and Eastern Kentucky University. He is a proud recipient of the 2001 Excellence in Teaching Award from Eastern Kentucky University's National Alumni Association. Dr. Boles is very active in the American Society of Civil Engineers and is a member of the American Society of Engineering Education and the American Concrete Institute. He is also a reviewer for several scholarly journals.

Rick Taylor, Travis Martin, Thomas Klutts, Jason Ray, Keith Melton, Chase McGrady, and Kevin Redington

All students of various engineering technology programs at Middle Tennessee State