AC 2009-328: NASA SUMMER ROBOTICS INTERNS PERFORM SIMULATION OF ROBOTICS TECHNOLOGY

Kenneth Fernandez, NASA Marshall Space Flight Center

Richard Fischer, NASA Marshall Space Flight Center

Amir Mobasher, Alabama A&M University

Paul Drews, Missouri University of Science and Technology

Maegan Grady, Saint Mary's College, University of Notre Dame

Robert Rucker, Vanderbilt University

Jessica Tham, Louisiana Tech University

Thomas Bierbower, Randolph High School

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ABSTRACT

This paper provides an overview of the NASA Robotics Academy and highlights the accomplishments of one of three robotics teams that participated in the summer robotics workshop in 2008. The program which is administered by NASA's Office of Education places student teams at several NASA Centers engaged in robotics work. Robotics Team 1 at the Marshall Space Flight Center located in Huntsville, Alabama was assigned to the Self-Aware Surface Networks (SASN) project. The SASN project is studies the use of networks to gather data from scientific instruments and to control robotic vehicles in scenarios similar to those anticipated when NASA returns to the moon or beyond. SASN project has a fleet of eight (8) small MARCbot robots acquired from the U.S. Army which have been modified with a prototype communications network. The project also has a larger robotic system, the iRobot/John Deere R-Gator capable of carrying large instrument payloads and robotic arms. During the 10 week tenure of the team the students developed computer graphics-based simulations of a lunar surface operational scenario in which satellite imagery is used to identify the location of a target of interest. Small scout robots are deployed to examine the target and a larger vehicle equipped with proximity sensors is used to retrieve the target. The simulations represent actual hardware demonstrations that have been performed or are planned for implementation in the near future. Their project required the students developed graphic models of all vehicles and to developed the control algorithms needed to execute the robotic scenarios. This work was completed early by the student team which volunteered for an additional assignment. This last assignment consisted of simulating a fleet of four (4) robots equipped with acoustic sensors positioned in a dispersed pattern. Upon detecting the initial arrival of a sound e.g., a gunshot and recording the time of arrival, a published algorithm was used to identify the point of origin. The students also performed sensitivity studies to identify error caused by tolerances in system components.

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Introduction:

This paper presents the results of collaboration between NASA, Industry and three educational institutions through NASA Robotics Academy and highlights the accomplishments of one of three robotics teams that participated in the summer robotics workshop in 2008. The program which is administered by NASA's Office of Education places student teams at several NASA Centers engaged in robotics work. One of the goals of this program is to introduce and involve the students with “real-life” projects that NASA is involved with and introduce the students to applications of their engineering courses to engineering problems. It is also intended to familiarize the students to concepts of team building, interdisciplinary work, concurrent engineering and systems approach to problems solving to name a few.

The objective of this paper is to present the engineering tasks given to engineering students and corresponding results of the work done by the collaboration between NASA, Industry and Educational Institutions. It will also present an overview of the benefits of such collaboration for all three organizations.

Overview of the NASA Robotics Academy

The NASA Robotics Academy is a educational outreach initiative implemented by the agency to provide an opportunity for junior and senior level engineering students to gain knowledge of robotics activities at NASA. The program is a 10 week residency program held at a NASA Center. In 2008 the participating NASA Centers included the AMES Research Center (ARC) in Sunnyvale, CA, the Goddard Space Flight Center (GSFC) located in Greenbelt, MD, and the Marshall Space Flight Center in Huntsville, AL. The Robotics Academy is administered by the Goddard Space Flight Center which collects applications from across the country. Additional information on the program can be obtained at http://robotics.gsfc.nasa.gov/. Weekly seminars presented by NASA and industry engineers and scientists were provided as well as three field trips. In 2008 MSFC teams toured the GM Saturn plant in Tennessee, the AMES Research Center, and iRobot Corporation in Boston, MA. The twelve students participating in the Robotics Academy at MSFC were divided into three teams. Team 1 was assigned to the Surface Mobility Systems project within Science and Mission Systems Office; Team 2 worked with the Automated Rendezvous and Capture project while Team 3 worked with the robotics team at the University of Alabama in Huntsville. The remainder of this paper describes the experience and accomplishments of Team 1 and concludes with a summary of outcomes resulting from this program.

Description of Tasks for each group

Robotics Team 1 at the Marshall Space Flight Center located in Huntsville, Alabama was assigned to the Self-Aware Surface Networks (SASN) project (Figure 1). The SASN projects is studying the use of networks to gather data from scientific instruments and to control robotic vehicles in scenarios similar to those anticipated when NASA returns to the moon or beyond. SASN project has a fleet of eight (8) small MARCbot robots acquired from the U.S. Army which have been modified with a prototype communications network. The project also has a larger robotic system, the iRobot/John Deere R-Gator capable of carrying large instrument payloads and robotic arms. During the 10 week tenure of the team the students developed computer graphics-based simulations of a lunar surface operational scenario in which satellite imagery is used to identify the location of a target of interest. Small scout robots are deployed to examine the target and a larger vehicle equipped with proximity sensors is used to retrieve the target. The simulations represent actual hardware demonstrations that have been performed or are planned for implementation in the near future. Their project required (Task 1) the students developed graphic models of all vehicles and to developed the control algorithms needed to execute the robotic scenarios. This work was completed early by the student team which volunteered for an additional assignment. This last assignment (Task 2) consisted of simulating a fleet of four (4) robots equipped with acoustic sensors positioned in a dispersed pattern. Upon detecting the initial arrival of a sound e.g., a gunshot and recording the time of arrival, a published algorithm was used to identify the point of origin. The students also performed sensitivity studies to identify error caused by tolerances in system components.

Figure 1. Several participants pictured with R-Gator system include: Dr. Fernandez, Maegan Grady, Paul Drews, Robert Rucker and Jessica Tham

Description of the Robotic Systems

Task 1: Lunar Surface Simulation

As stated above, the Marshall Space Flight Center has utilized two types of robotic vehicles in its research on self-aware surface networks. The first vehicle shown in figure 2 below is an R-GATOR system manufactured by a collaboration between iRobot and the John Deere Corporation. The vehicle is built on the John Deere M-GATOR which is a light-weight utility vehicle used widely by the gardening and landscaping industry. The R-GATOR variant retains the basic chasis with modifications to include a GPS navigation system and servo-motors to control vehicle motion and braking commands. The R-GATOR is capable of being driven like a conventional vehicle, but can also be teleoperated from a remote operator control unit via an 802.11 link. The R-GATOR is also capable of automated waypoint navigation and is equipped with LIDAR and RF sensors for hazard avoidance. Figure 2 below shows the R-GATOR system used by the Self-Aware Systems Network project at MSFC. The R-GATOR is used as an analog of rovers that will be used to carry astronauts and equipment on future missions

Figure 2 - R-Gator used at MSFC to simulate large surface vehicle

A second robotic system is also used by the project at MSFC. It is based on the MARCbot (Multi-function Agile Remote Control robot) developed by the U.S. Army to facilitate remote inspection of suspected improvised explosive devices (IED's). This original system was built around a radio-controlled hobby vehicle, but was modified by NASA to include 802.11 digital control. Other enhancements added GPS and near-infrared digital cameras. The modified MARCbot includes automated way-point navigation and depicts the robots location as an icon superimposed onto a Google Earth map. This updated robot designated the MARCbot-N (for NASA) more fully supported the research goals of the NASA SASN project. The robot was also adopted by the U.S. Army and is currently being deployed as a replacement to the original MARCbot system. Figure 3, below depicts the MARCbot-N which has a wheel base of approximately 18 inches. The MARCbot-N simulates smaller automated rovers that would be used to carry instrumentation and sensors to explore the lunar surface and return data to the lunar base.

Figure 3. MARCbot-N small robot vehicle with 18" wheel base

The task that the students were given required them to develop graphical and kinematic models of both the R-GATOR and MARCbot-N robot systems and to develop a simulation of the following scenario. A satellite system orbiting the moon detects and relays the location of a target-of-interest. In this case the target is a cargo trailer. A small robot simulated by the MARCbot is sent to examine the target to determine its status. The target may represent an autonomous rover that has broken-down or is in need of servicing. Once the examination is performed a larger vehicle simulated by the R-Gator is deployed to retrieve the Target and return it to the lunar base for servicing. A sensor system on-board the R-Gator would be used to determine the relative position of the two vehicles and guide the control system to the point at which a trailer latching mechanism would engage. Figure 4 depicts the back of the R-Gator and the latching mechanism. The cone shaped receiver helps compensate for any misalignment errors during the final latching operation.

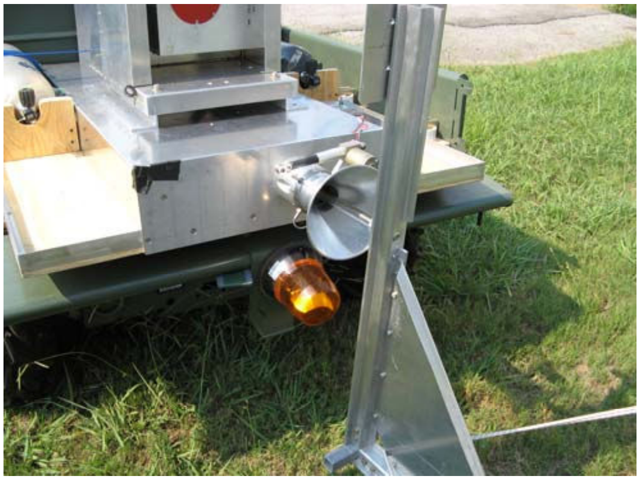

Figure 4 Rear of R-GATOR with sensor pallet and cone-shaped trailer hitch

Based on this configuration, a simplified tricycle model of the vehicles steering mechanism was developed. The kinematics of this system allowed the team to specify the vehicle's turning radius, R, as a function of the steering angle, α. This relationship is shown in figure 5.

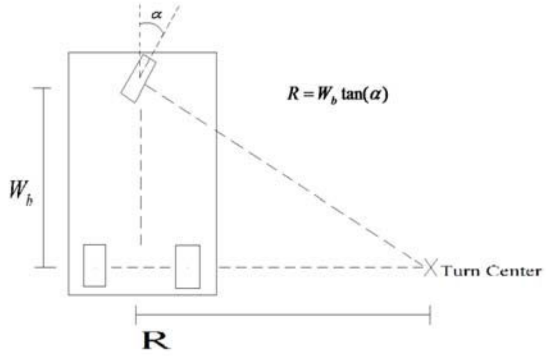

Figure 5. Kinematic Model of the Robot.

The team incorporated the kinematic model of the R-Gator and the MARCbot-N into their graphics based simulation which utilized ROBOSIM, a graphics-based robot simulation software package developed by NASA [1]. This resulted in simulated vehicles that followed trajectories that accurately modeled the actual vehicle systems. The students developed a set of steering laws that translated operator "joystick" commands into commands to the vehicle steering and drive mechanism which allowed them to simulate remote or teleoperated control of their simulation.

Automated way-point navigation was simulated by the development of a control law that would provide a command to the simulated vehicle causing it to traverse between each way-point at a specified velocity. Such control algorithms are widely used by unmanned vehicles. Figure 6, below, depicts the velocity profile of a simulated vehicle which was commanded to traverse at a speed of 100 inches per second. A fixed acceleration rate governs the start-up velocity profile while a linear profile based on position error controls the terminal phase when the vehicle is within 500 inches of the target way-point.

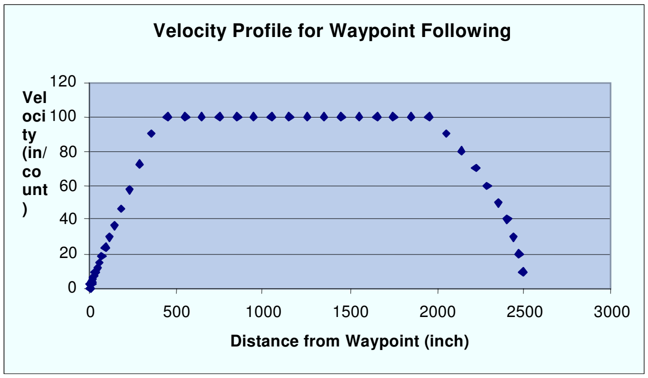

Figure 6. waypoint following algorithm velocity profile

The simulations of the different scenarios were performed using the ROBOSIM simulation package. Figure 7 depicts a lunar base where an array of R-Gators are performing specific tasks such as docking to a supply trailer, exploration of the surface, or collecting the soil sample and carrying it to specific locations.

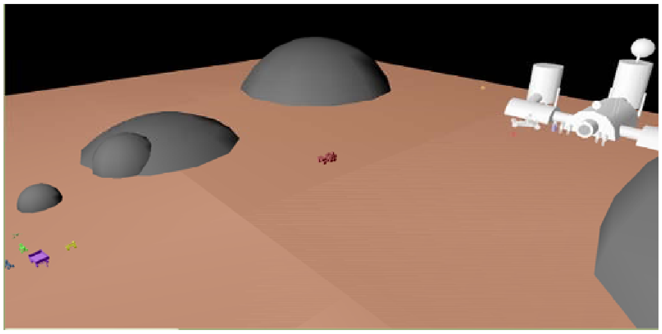

Figure 7. Trailer (left in purple), MARCbot-N's (left in green),
R-Gator (center in red), Lunar Base (right in white)

TASK 2 "Gunshot Localization"

A second task was assigned to the student team as a result of their completing task 1 seven weeks into the ten week program. Since the NASA team has worked closely with the U.S. Army in development of the MARCbot-N system the task chosen related to a military scenario in which three or more robots equipped with acoustic sensors are deployed in a pattern to monitor and detect the origin of sounds that are detected by at least three of the sensors. Systems of this type have been deployed in urban areas within the U.S. and by the military in combat zones. To simulate this scenario the students modified their simulation in Task 1 to depict the scenario. Although graphic simulation was not required to solve and demonstrate the "Gunshot Localization" problem it proved to be a useful tool in demonstrating the results and for investigating the underlying geometric relationships between sensors particularly for sensor displacement patterns that resulted in localization ambiguity.

In this simulation scenario known positions of the robots and their acoustic sensors were used to compute the actual time of arrival of the initial sonic wavefront due to a gunshot. In the actual system only the time of arrival and the estimated position of the robot/sensor would be known. An algorithm [2,3] was used to estimate the initial position and time of the gunshot. Once the implementation of this algorithms was verified through a series of simulation runs with the robots in a variety of placement patterns another set of runs were made to study the relationship of the estimated "shooter" location when random errors are introduced into the timing signals and sensor location measurements. In practice such simulation runs would be useful in determining the tolerance requirements for system components to achieve a specified level of accuracy or to use in conjunction with signal estimator algorithms or Kalman filters. However the length of this program did not permit those additional studies.

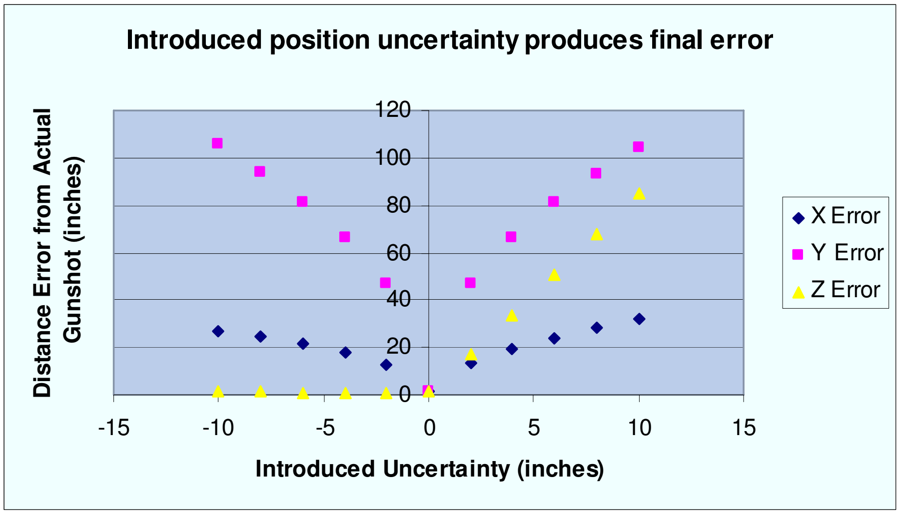

Figure 8. Relationship of "shooter" position error to sensor position error

In Figure 8, above, the relationship between the position error associated with sensor location to the resulting error in the "shooter's" location are depicted. While Figure 9, below, shows the "shooter's" position error as function of the accuracy of the clock used to log the incidence of the acoustic wave.

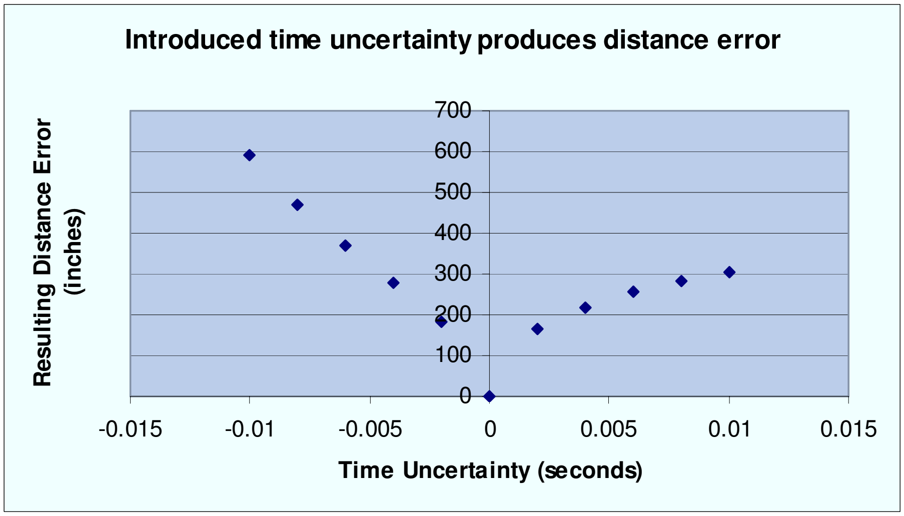

Figure 9. Relation of "Shooter" location error to clock uncertainty

Conclusions and Outcomes:

This project achieved several goals and objectives oulined in the following paragraph:

a. Collaboration and partnership between NASA and educational institutions: This project increased the collaboration between educational institutions and NASA. It helped the faculty to involve in research related to Robotics and Autonomous systems within NASA and in turn contribute to those goals in a positive manner.
b. Increase inter-disciplanry work within engineering programs- Since the proposed robotic system involved integration of different units form different disciplines, the inter-disciplanry component of this proposal was strong. The effort involved one faculty form the Mechanical Engineering program and one from the Electrical Engineering program with participation of students from the corresponding departments. This effort involved research in both Electrical and Mechanical engineering programs.
c. Retention and recruiting- The students were involved in real world engineering problems of relevance to NASA. Students had hands-on exposure to projects that were directly aligned with the work done withing NASA;consequently, this had potential for recruiting new students to the engineering programs. More importantly, involvement of students with the real world engineering programs, helped in retention of students. Some of the students involved in this project participated in hands-on experience through their capstone design projects enabling them to apply their knowledge of engineering and mathematics. The vehicle was displayed at important university events such as Highschool Day and Engineering day and through this vehicle missions of NASA and AAMU were exposed to the potential engineering students.
d. Familiarity with NASA goals and missions- the research project provided an avenue for the students to become familiar with the vision and mission of NASA.
e. Increase research thrust within the engineering programs- the resarch provided the opprtunity for the faculty and students to synthesize the knowledge towards development of new and innovative products that is critical to NASA's mission.
f. Following the summer program one student joined a local engineering company and is continuing in a graduate program; three sudents have entered graduate school on a full-time basis; and the high school student has changed his future college program to engineering.

References

1. Springfield, Jr., James F., and George E. Cook. Robot Simulation. Nashville: Vanderbilt University School of Engineering.

2. Bucher, Ralph, and D. Misra. "A Synthesizable VHDL Model of the Exact Solution for Three-dimensional Hyperbolic Positioning System." VLSI Design 15.2 (2002): 507-520.

3. Williams, Nathan. “Seismic.” Geophysics. 2007. Cornell University. 5 August 2008. <http://www.people.cornell.edu/pages/nrw22/astro/seismics.htm>.