The Mobile Manipulation Challenge

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In this column, we have a report on the 2010 IEEE International Conference on Robotics and Automation (ICRA) Robot Challenge, held during ICRA 2010 in Anchorage, Alaska. The challenge consisted of four events and attracted 16 teams that demonstrated state-of-the-art work in mobility and manipulation, at both human- and micro- (under 600 μm) scales, planning for industrial automation, and the application of modular robotics. The report was authored by Steve Balakirsky [National Institute of Standards and Technology (NIST)], with contributions from Matei Ciocarlie (Willow Garage), Jason Gorman (NIST), and Mark Yim (University of Pennsylvania).

The mobile manipulation challenge showed human-scale mobility and manipulation. Dynamaid, from the University of Bonn, demonstrated its ability to offer drinks and snacks to human guests, when requested by a pointing gesture or by showing the robot an empty container. Lisa, from the University of Koblenz-Landau, showed its ability to find objects on the floor and on a table and manipulate them by combining a gripper mounted at its base with its robotic arm, in addition to mapping an unknown environment. The Care-O-bot, from Frauhofer IPA and Siemens, successfully mapped and navigated an unknown environment with dynamic obstacles, recognized and grasped objects common in daily living, and transported them to desired locations. Finally, PR2 robot from Willow Garage Inc. demonstrated robust pick-and-place operations on both known and previously unseen objects, using its stereo cameras for object detection. Overall, the challenge participants succeeded in demonstrating reliable autonomous behavior in a real-life scenario while identifying a number of reusable building blocks that can be shared by future higher level applications. The team highlight sessions were very well attended, a trend we hope to continue for future editions. Discussion also focused on active research areas, such as manipulation in clutter, versatile end effectors, and safe manipulation in human environments. For future editions, the challenge is likely to center on more complex, lifelike environments such as homes or offices.

Complementing the human-scale challenge was the NIST Mobile Microrobot Challenge. An essential part of the challenge rules is that the microrobots must be untethered, and each microrobot must be smaller than 600 μm in all of its dimensions. In the 2010 event, there were three tasks, designed to highlight known technical limitations: the 2-mm dash, microassembly, and the freestyle task. In the 2-mm dash, the microrobot had to travel 2 mm and then come to a complete stop as quickly as possible, which provided a measure of the robot's maximum speed and motion repeatability. The microassembly task was based on the planar case of the classic peg-in-hole assembly problem using pegs that were approximately 100 μm wide (equivalent to the width of a human hair). The freestyle task allowed each team to select a technical demonstration of their choice. Six teams participated in the challenge, which showcased several major advances in microrobot technologies. Most impressively, a piezoelectric microrobot developed by FEMTO-ST and the Institut des Systèmes Intelligents et de Robotique in France completed the 2-mm dash in 32 ms, and a magnetic microrobot from ETH Zürich was able to complete four peg-in-hole assemblies in each of three consecutive trials without a single failure. Because of the outstanding performances in 2010, the 2011 event will see significant increases in difficulty in these two tasks. The first task will require autonomous navigation around a figure eight track to demonstrate 2-D motion control. The second task will be focused on the manipulation of microscale objects in narrow channels, as motivated by biomedical applications where objects must be transported through blood vessels for diagnostics or surgery.

The virtual manufacturing and automation challenge (VMAC) focused on simulated factory automation. This year's events were designed to focus attention on the problems of mixed-palletizing and intrafactory package delivery. Mixed palletizing is an example of the three-dimensional cutting stock problem, a variant of the combinatorial nondeterministic polynomial-time hard knapsack problem. Teams were required to generate a pallet stacking plan from a provided order file and constraints. This plan was then evaluated by NIST's emerging metrics for pallet quality, built in simulation, and then built on a 1/3 scale palletizing cell. Two teams from the Georgia Institute of Technology competed against the state-of-the art commercial solution in this event by applying both a neural network learning-based approach and a deterministic planning approach. The teams were able to create mixed pallets of goods and build the pallets on actual robotic hardware. The second event aimed to address the need for factory robots to operate in unstructured environments amongst dynamic obstacles. Teams were tasked with docking a rear-wheeled Ackerman steered robot with a conveyor system, picking up packages for transport, and then delivering these packages to unloading stations in the factory. The highlight of the event was the University of Zagreb controlling three autonomous vehicles with their automated delivery system. This system uses a layered approach with the lower layer implementing vehicle localization, waypoint tracking, docking, and undocking. At the higher layer, tasks for individual vehicles are assigned and scheduled using a version of the Banker's algorithm. The VMAC competition will continue next year with both mixed palletizing and forklift operations.

The final challenge event examined robotic planetary contingencies with an eye toward modular robotics. For this event, teams developed solutions to an emergency problem at a Mars base

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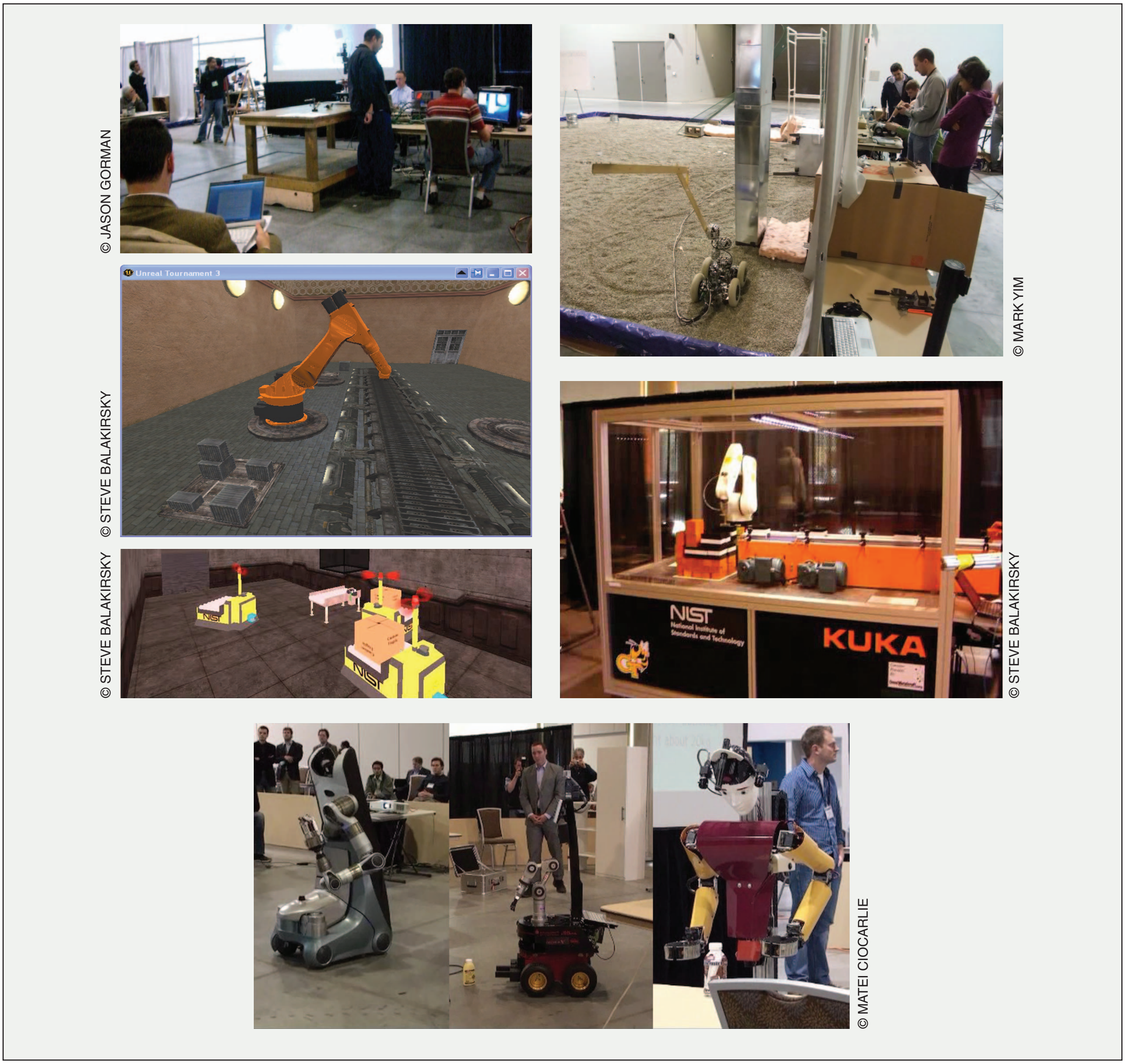

Figure 1. *Scenes from the 2010 ICRA Robot Challenge.*

station. This event simulates an unexpected problem occurring at a planetary habitat, where a robotic solution must be quickly developed and deployed, using only existing resources. The intent of this event is to develop versatile robotic systems and software that can be adapted quickly to address unexpected events. Since humans are present, a natural solution to realistic unexpected events would exploit human creativity and human–robot interaction. The competition drives not only the development of versatile robotic hardware and on-board software but also the design and development of programming and assembly tools capable of rapidly implementing a wide variety of capabilities. Since teleoperation is not precluded for this event, the development of effective user interfaces is another expected outcome. At the 2010 competition, teams from Harvard, Massachusetts Institute of Technology, University of Washington, and two teams from University of Southern Denmark participated. Teams had the option of using CKbot modules supplied by the GRASP laboratory at the University of Pennsylvania or their own hardware and software, which all of the teams did except for the two teams from Denmark. Two tasks were attempted by the teams. These tasks had a 4-h window for completion and required navigation in Martian terrain (a 10×10 m gravel bed) as well as manipulation of materials to heights of 1–3 m. In the end, the University of Southern Denmark team with their ATRON robot won the competition. They had the most robust arm and locomotion system along with clever teleoperation aids.