Making 330 lbs of electronics, metal and hydraulics move like an athlete —

Team MIT takes on the DARPA Robotics Challenge

"Our dream is to build machines that go where they're told and do what they're told."

Professor Seth Teller and co-lead Professor Russ Tedrake are developing machines in pursuit of this dream, as part of the MIT team they are leading in the DARPA Robotics Challenge (DRC). Teller is enthusiastic about the progress that Team MIT has made in the first two major rounds of this Department of Defense-sponsored competition, in which researchers from around the world strive to develop and operate robots that could save lives and prevent or mitigate devastation in future disasters.

Since March 2012, Teller, Tedrake and about 20 others from across MIT including faculty, staff, postdocs, PhD students, Masters students, and UROPs from EECS and the Department of Mechanical Engineering, the Center for Ocean Engineering, and the Department of Aeronautics and Astronautics, have focused their talents and drive on developing a humanoid robot that will meet (and, they hope, surpass) DARPA's requirements.

Like many other competing teams, Team MIT members chose to program a DARPA-supplied humanoid robot called Atlas, rather than build their own hardware. The team wanted to capitalize on its relative strength in algorithms and software systems, rather than expend significant effort on hardware design and development. This choice made particular sense for MIT, as the Atlas robot is manufactured by the local firm Boston Dynamics, co-founded by former EECS Professor and Artificial Intelligence Laboratory member Marc Raibert. After qualifying in June, MIT received its Atlas robot, with a listed value of $2 million, in August 2013.

Why humanoid?

Teller says: "For many task domains, humanoid robots are the future. If they are to work in a world of humans, negotiate our stairs, fit through our doors, and use our tools and appliances, a roughly human form will serve them well."

Atlas cuts an impressive figure, standing six feet two inches tall and weighing more than 330 pounds. Its black metal frame includes chrome caging surrounding its flexible torso, to which are attached two arms, two legs and a head. Its backpack compressor, driving 28 hydraulically-actuated joints, creates a loud droning sound, and multiple lights including a yellow beacon on its head signal bystanders to pay attention. Despite its connection by a flexible tether to electric power, cooling fluid, and external computers, Atlas looks relatively independent.

After successful completion of DARPA's Virtual Robotics Competition, held in simulation in June 2013, sixteen teams from various universities, industries and institutes competed in December 2013 in the first of two "Trials" to be held over the multi-year DRC competition. Teams demonstrated robots with both humanoid and non-humanoid forms attempting a series of tasks set by DARPA that include walking on uneven terrain, turning valves, handling and operating tools, dragging and hooking up firehoses, opening doors, climbing ladders and driving cars – with minimal input from remote human operators. MIT was one of the top eight finishers in December, earning a competition berth in the DRC Finals, expected to occur in mid-2015. The single top-scoring team at the Finals will take home a $2 million prize.

Teller and Tedrake anticipate that their approach, which combines high-level perception and decision-making by the human operators with low-level motion planning and controlled execution by the robot, will do well in the final stage of the competition. This confidence stems in part from the experi-

The goal is for greater speed and more fluid motion — the answer is to build more autonomy

ence and infrastructure the team developed as part of the 2007-8 DARPA Urban Challenge, the goal of which was the development of a vehicle that could drive unoccupied, with no remote assistance, through an urban-like road network. Teller notes that "work from the labs of Professors John Leonard, Jon How, and Emilio Frazzoli not only paved the way for the current effort, but continues to help other robotics groups all over the world through their use of software tools that came out of MIT."

Nevertheless, there were challenging moments at the December trials.

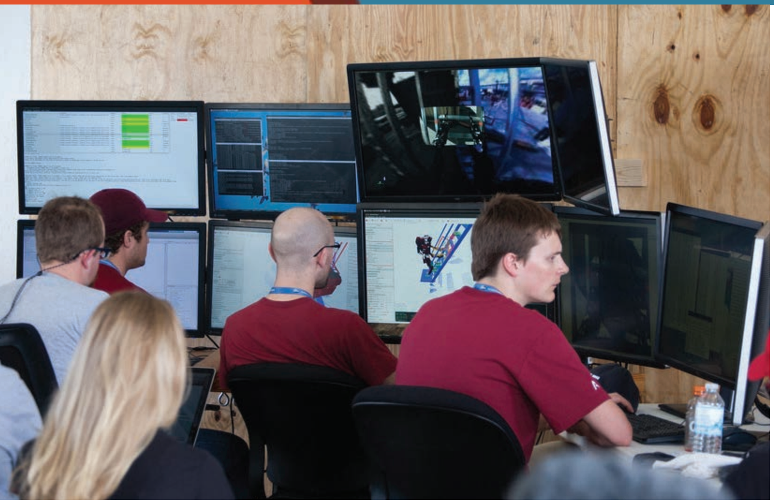
EECS PhD graduate student Robin Deits, a student in Tedrake's Robot Locomotion Group says that the lowest and highest points of the December trial happened during the rough terrain-walking task. Besides glitches in the DARPA-supplied network infrastructure the day before competition began – for which DARPA asked MIT Team member and networking expert Toby Schneider to troubleshoot, later awarding him a medal for doing so – strong winds brought other challenges. After months of developing software and piloting the robot through the walking task, Team MIT members were dismayed when the robot fell over due to either sudden winds, or problems with the robot's tether. DARPA allowed the team to continue the run (after sacrificing one point, of the maximum four possible, due to the need for human intervention), and the MIT team piloted its Atlas over the finish line – something only two other teams managed to do.

Tedrake notes that the robot's third-party hands and head are clearly things to avoid breaking in a robot fall. But Teller notes, "One of the big lessons we learned in December was that we can give up on perfection, and still get a really useful robot. What we care most about is not autonomy, but real-world utility." He agrees with Tedrake's metaphor about the robots' current slow speeds – "though our robot moves like a statue now, it is moving more like a dancer or an athlete every day."

The DRC goal is for greater speed and more fluid motion, and the answer to that challenge is to build more independence into the robot's behavior. MIT Research Scientist Maurice Fallon, who is the perception and infrastructure lead on the team, says that as the robot embodies greater autonomy, it will be more responsive in unexpected situations. "It's almost a philosophical thing," he suggests. "Can the robot make a decision? If the robot pulls on a door, and it doesn't open, will the robot figure that out – and adjust its behavior accordingly – or will it try to walk through anyway?"

Using the data collected by Atlas's cameras, laser range scanners, joint encoders, and inertial sensor, the operators can monitor the status of the machine and its surroundings as they command it to walk, climb and handle objects. While Fallon works on figuring out exactly where the robot is and how it's moving through space, Pat Marion, robotics software engineer and soon a first-year PhD candidate in the EECS Department at

Team MIT takes on the DARPA Robotics Challenge, *continued*



MIT, has taken the lead on using the data to semi-automatically fit object models, transmit the data and convert it to height maps used to help the robot place its feet.

Atlas interprets its surroundings through its perception system, but it truly engages the world as it is operated under a planning and control system that can be applied from the lowest levels – commanding each of the 28 joints – to the more basic but wider control of the upper body. Scott Kuindersma, postdoctoral associate working with Prof. Tedrake, is the planning and control lead for the MIT DRC team.

"Once the human operator has interpreted the robot's surroundings from available sensor data," Kuindersma, says, "the planning software works with the operations goal – such as walking to a door, for example. From there the controller, which runs on the robot, is responsible for actually carrying out the motions produced by the planner." If it sounds like he is overworked, part of Kuindersma's job is to organize the efforts of the large group of graduate students working on the planning and control aspects of the system. He notes, "That part is easy, because the students are all extremely talented and self-motivated."

Overall, Teller notes that the DRC has motivated Team MIT to incorporate their research advances into the DARPA tasks to achieve real-world utility. He is pleased that he and his students, whose previous focus had not been on human-like motion, are engaging in an intensive collaboration: "It's wonderful to work with and learn from Russ and his group."

Equally impressed with the power of collaboration, Russ Tedrake notes about the DRC experience: "It's a big commitment; the people who really contribute are giving their lives for this. It's a big deal." The dedication of the MIT team is highlighted by the fact that it was competing with teams from NASA and Lockheed Martin – while many of MIT's members were taking final exams!

Teller and Tedrake agree that the DRC has been a fantastic driver for robotics research. Tedrake says: "We are getting a really good litmus test of what we can and can't do in order to compare ourselves with the rest of the world. It's good for [upcoming] research and it's good for communicating our research to others." In the meantime, students from both of their labs end up working for or starting robotics companies that are in the news.

As robotics plays a bigger role in manufacturing, medicine and as yet only fantasized roles in society, Teller and Tedrake hope that the strides the MIT DRC players have made will lead to large scale alliances to sustain longer-term collaborations. Teller says, "The capabilities that we and other DRC teams are developing are bringing us closer to the day when these machines will do useful work in our public spaces, our workplaces, and our homes."

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