Robust and Reliable Microtechnology Research and Education Through the Mobile Microrobotics Challenge

By Dan O. Popa

Inspired by the success of Robocup [1], the U.S. National Institute of Standards and Technology (NIST) [2] proposed a robot competition at the microscale—the Mobile Microrobotics Challenge (MMC). Microrobots for this competition utilize microelectromechanical system technology and are actuated using advanced control systems.

The first MMC competition was held in 2007 with the name Robocup Nanogram [3]. The MMC has been held at the IEEE International Conference on Robotics and Automation (ICRA) every year since 2010 and involves microrobots that must fit within a 500-µm- diameter sphere [4]. In a controlled setup under a microscope, microrobots race along a distance of 2 mm, push microparts, or slalom around obstacles.

Teams must qualify for the challenge by sending a proposal and also demonstrating basic maneuverability of their robots ahead of the competition.

In 2013, the NIST delegated responsibility for the organization of the MMC to the IEEE Robotics and Automation Society (RAS), where the IEEE-sponsored challenge was led by a committee of representatives from the RAS Micro-Nano Robotics Technical Committee. In 2014, the MMC will be held in Hong Kong at ICRA 2014 [6]. Teams must qualify for the challenge by sending a proposal and also demonstrating basic maneuverability of their robots ahead of the competition.

Digital Object Identifier 10.1109/MRA.2013.2297597
Date of publication: 10 March 2014

Microrobot Challenge 2007–2013

In the first few years of the MMC, NIST provided competitors with the arenas, as well as with the driving electronics. Early competitions took place with electrostatic actuation under a microscope for three categories of drills:

- 2-mm Dash: The microrobots race in a straight line across the playing field in a test of raw speed.
- Slalom Drill: The microrobots dart around obstacles to test their agility and controllability.
- Ball-Handling Drill: The microrobots retrieve a set of balls and dribble them across the goal line.

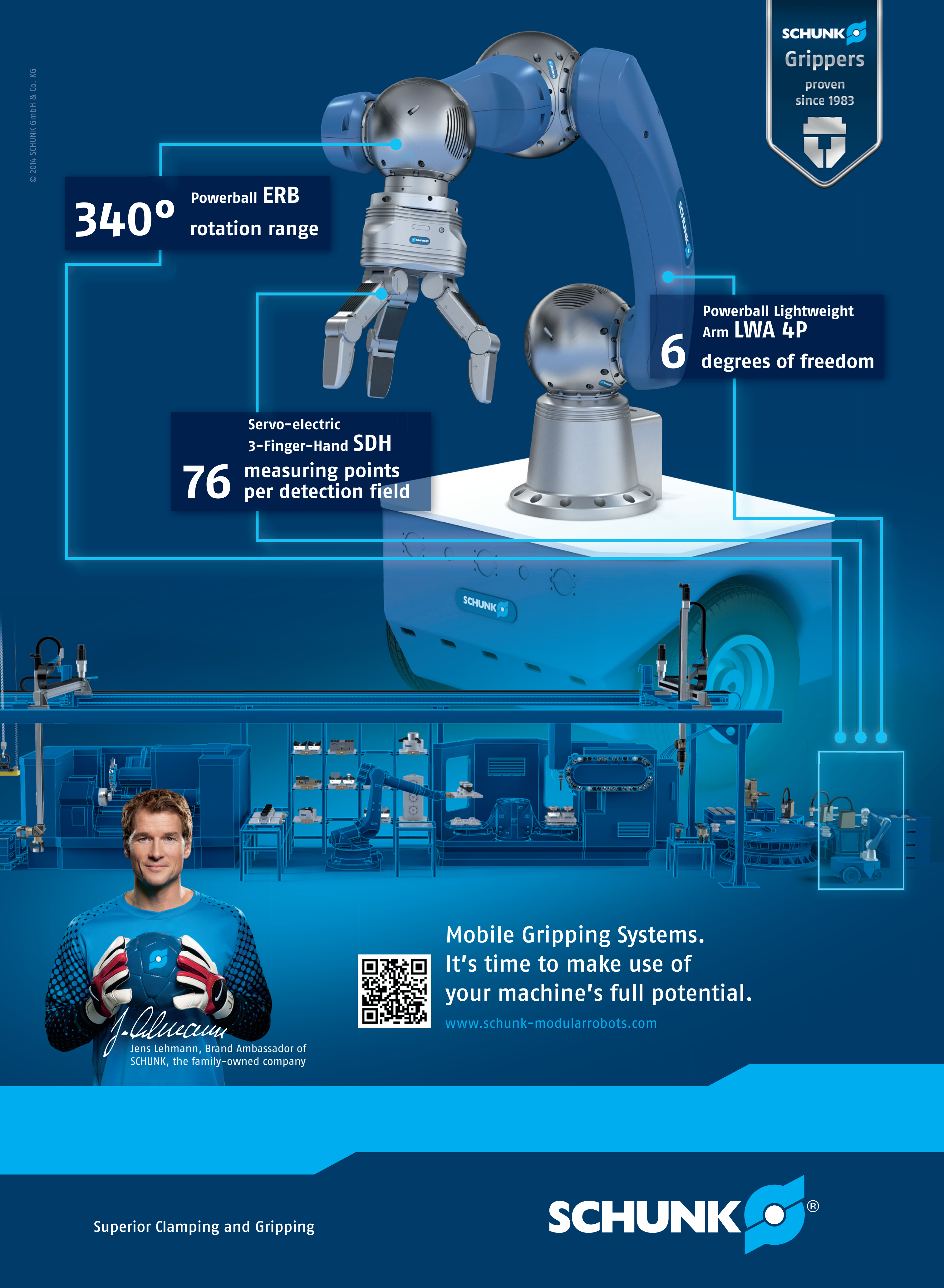
Microactuation approaches varied from [7], which discusses an electrostatic microrobot of dimensions 250 × 60 µm × 10 µm powered through a capacitive coupling with the underlying substrate, to the work [8], demonstrating a 250 µm × 130 µm × 100 µm magnetic microrobot that can operate under the excitation of an external magnetic field. One of the more successful designs was a resonant magnetic actuator composed of two paramagnetic bodies, a spring system and a metal frame. It can move forward, backward, and turn in place with a forward speed up to 12.5 mm/s [9].

In the early years, the MMC was clearly dominated by European teams, for instance, in 2010, ETH Zurich was the winner of the microassembly event with their Octomag magnetic drive [10], and the French CNRS-sponsored team was the winner of the 2-mm dash event with a hybrid magnetic/piezoelectric microrobot [11].

In later years, teams were invited to bring the microactuation technology of their choice, as long as the drive system, the arenas, and the microrobots abide by strict dimensional guidelines and can fit under the competition microscope. As the 2-mm dash and microassembly with pegs matured, and more teams successfully completed both events, new challenges were put forth, starting with the 2011 competition (Figure 1):

- the figure-eight mobility challenge, where the goal was to complete a closed path connecting four narrow gates in the shortest possible time
- a microassembly challenge, where the goal is to tightly assemble triangles into a narrow conduit by pushing them with the microrobot.

In many instances, the microrobots themselves were either passive magnetic structures or they could be micromachined to resonate at various input frequencies. And, in recent years, several North American teams [Carnegie Mellon University (CMU), University of Hawaii, Stevens Institute of Technology, and the University of Texas (UT) Arlington] have also been strong contenders. U.S. teams, in particular, have been boosted through a National Science Foundation (NSF)-sponsored grant that funded student travel to the competition venues since 2011 (grant


SCHUNK
Grippers
proven
since 1983
© 2014 SCHUNK GmbH & Co. KG
340°
Powerball ERB
rotation range
Powerball Lightweight
Arm LWA 4P
6
degrees of freedom
Servo-electric
3-Finger-Hand SDH
76
measuring points
per detection field
SCHUNK
Mobile Gripping Systems.
It's time to make use of
your machine's full potential.
www.schunk-modularrobots.com
Jens Lehmann, Brand Ambassador of
SCHUNK, the family-owned company
Superior Clamping and Gripping
SCHUNK®

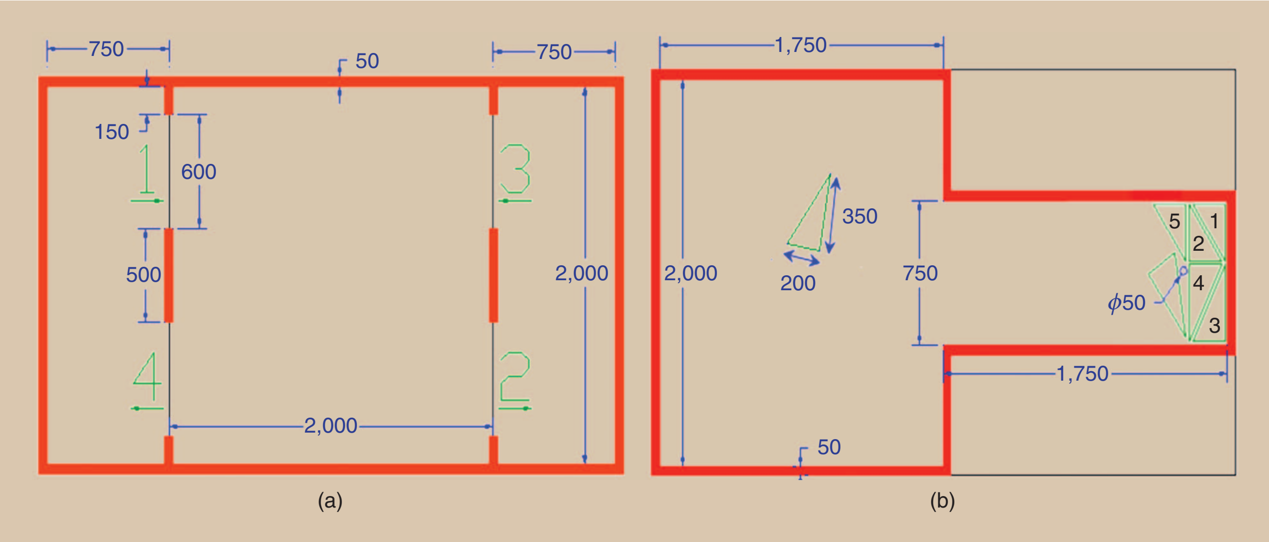


Figure 1. (a) The MMC mobility arena and (b) assembly arena with dimensions in μm.

IIS-1132487). In the 2011 competition, only one U.S. team (University of Hawaii) placed second at the Mobility Challenge. At the 2012 and 2013 competitions, however, U.S. teams fared much better, with CMU, the University of Hawaii, and UT Arlington placing first, second, or third at both events.

MMC participants in 2011–2013 included a dozen teams from North America and Europe (Figures 2 and 3). These teams traveled with their own equipment to ICRA, set it up, and competed over the period of three days. Teams also brought posters and presentations for the summative poster session at the end of the competition.

Even though magnetic actuation remains popular and reliable for most teams, in recent, years, several contenders brought alternate energy harvesting technology to the challenge, for instance, thermal gradients [12], electro-wetting [13], vibration [14], and laser [15]. At MMC 2013, the top three teams completed the Mobility Challenge considerably faster and more consistently than in 2011. As a result, the 2014 challenge will no longer emphasize completion time on a predefined course. Rather, teams will be given arbitrary courses and asked to program trajectory-following behaviors at the event. Therefore, the teams with maximum programming, planning, and control infrastructure should be favorites to win in the future.

Another MMC event is the Microassembly Challenge, in which points scored indicate triangles successfully assembled. This event favors microrobot controllability and triangle stiction mitigation, which matter more than speed. This event is still fraught with considerable challenges even after three competition years.

Conclusions

From a programmatic standpoint, after six years of competition, the MMC has already achieved its stated goals: 1) motivate researchers to accelerate microrobot development, 2) reveal the most

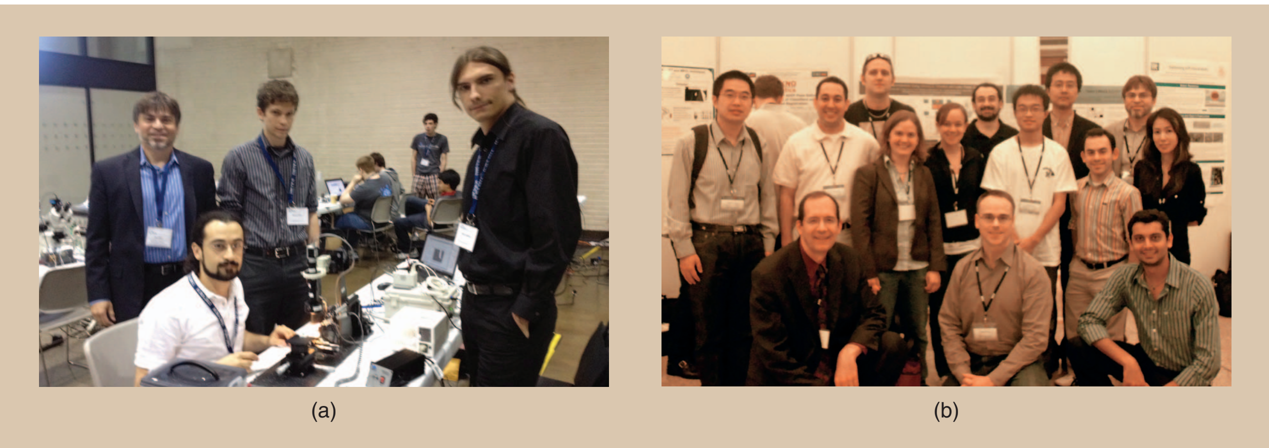


Figure 2. (a) The 2012 UT Arlington Microrobotics Team competing at IEEE ICRA in St. Paul, Minnesota. (b) The U.S. participants in the 2011 MMC in Shanghai, China, including ten students from the University of Hawaii, the University of Maryland, Stevens Institute of Technology, and UT Arlington, four faculty members, and two NIST organizers. The travel expenses for all ten U.S.-based students were supported by the U.S. NSF through grant IIS-1132487.

Figure 3. Students, faculty, and the organizers of the 2013 MMC gather in Karlsruhe, Germany.

pressing technical challenges, and 3) evaluate the most successful methods for locomotion and manipulation at the microscale (e.g., actuation techniques for crawling). The participants directly credit the MMC for channeling their research efforts toward demonstrable and robust microrobotic technology, as opposed to impractical lab curiosities.

A microassembly challenge, where the goal is to tightly assemble triangles into a narrow conduit by pushing them with the microrobot.

The MMC has also proven to be an excellent vehicle for student education by introducing engineering problems at the micro and nanoscales. The MMC brings students from all engineering disciplines closer to the micro/nano world through an exciting type of competition, which requires both theoretical and practical know how in microfabrication, metrology, control, robotics, and system integration.

The 2014 MMC organizing committee includes Dan Popa of the UT Arlington, David Cappelleri of Purdue University, and Igor Paprotny of the University of Illinois at Chicago. In a year when ICRA will be held in Asia, the organizers wish to take this opportunity to publicize and expand the list of MMC participants outside Europe and North America.

References

[1] Robocup History. [Online]. Available: http://www.robocup.org/about-robocup/ a-brief-history-of-robocup/

[2] Wikipedia: NIST. [Online]. Available: www.wikipedia.org, search word NIST

[3] C. McCraig, F. Arai, A. Jacoff, S. Tadokoro, and M. Gaitan. (2007). RoboCupSoccer—Nanogram competition. White Paper, NIST. [Online]. Available: http://www.eeel.nist.gov/812/nanogram/white_paper.pdf

[4] C. McCraig and J. Gorman, (2010, May 2–6). NIST mobile microrobotics challenge, presented at IEEE Int. Conf. Robotics Automation. Anchorage, Alaska. [Online]. Available: http://www.nist.gov/pml/semiconductor/robots_042710_program.cfm

[5] (2012). NIST mobile microrobotics challenge rules. [Online]. Available: http://www.nist.gov/pml/semiconductor/mmc/

[6] (2014). IEEE RAS MMC competition rules. [Online]. Available: http://www.uta.edu/ee/ngs/mmc

[7] B. R. Donald, C. G. Levey, C. D. McGray, I. Paprotny, and D. Rus, "An untethered, electrostatic, globally controllable MEMS micro-robot," *J. Microelectromech. Syst.*, vol. 15, no. 1, pp. 1–15, Feb. 2006.

[8] S. Floyd, C. Pawashe, and M. Sitti, "An untethered magnetically actuated micro-robot capable of motion on arbitrary surfaces,"in *Proc. IEEE Int. Conf. Robotics Automation*, May 2008, pp. 419–424.

[9] K. Vollmers, D. R. Frutiger, B. E. Kratochvil, and B. J. Nelson, "Wireless resonant magnetic microactuator for untethered mobile microrobots," *Appl. Phys. Lett.*, vol. 92, no. 14, pp. 144103–144103-3, 2008.

[10] M. P. Kummer, J. J. Abbott, B. E. Kratochvil, R. Borer, A. Sengul, and B. J. Nelson, "OctoMag: An electromagnetic system for 5-DOF wireless micromanipulation," *IEEE Trans. Robot.*, vol. 26, no. 6, pp. 1006–1017, Dec. 2010.

[11] I. Ivan, G. Hwang, J. Agnus, N. Chaillet, and S. Regnier, "NIST and IEEE challenge for MagPieR: The fastest mobile microrobots in the world," *IEEE Robot. Automat. Mag.*, vol. 20, no. 2, pp. 63–70, June 2013.

[12] W. Hu, K. S. Ishii, and A. T. Ohta, "Microassembly using optically controlled bubble microrobots," *Appl. Phys. Lett.*, vol. 99, no. 9, p. 094103, 2011.

[13] E. Schaler, M. Tellers, A. Gerratt, I. Penskiy, and S. Bergbreiter, "Toward fluidic microrobots using electrowetting," in *Proc. IEEE Int. Conf. Robotics Automation*, May 14–18, 2012, pp. 3461–3466.

[14] M. R. Pac, K. Rathatha, B. Rukavina, and J. Weir. (2011, Aug.). Development of microrobotics control system—UT Arlington microrobotics team. [Online]. Available: https://decibel.ni.com/content/docs/DOC-16574

[15] M. R. Pac and D. O. Popa, "3-DOF untethered microrobot powered by a single laser beam based on differential thermal dynamics," in *Proc. IEEE Int. Conf. Robotics Automation*, Shanghai, China, May 2011, pp. 121–127.