Educating the Global Robotics Engineer

Prof. Michael A. Gennert, Worcester Polytechnic Institute

Prof. Michael A. Gennert is Director of the Robotics Engineering Program at Worcester Polytechnic Institute, where he is Professor of Computer Science and Professor of Electrical and Computer Engineering. He has worked at the University of Massachusetts Medical Center, Worcester, MA, the University of California/Riverside, General Electric Ordnance Systems, Pittsfield, MA and PAR Technology Corporation, New Hartford, NY. He received the S.B. in Computer Science, S.B. in Electrical Engineering, and S.M. in Electrical Engineering in 1980 and the Sc.D. in Electrical Engineering in 1987 from the Massachusetts Institute of Technology. Dr. Gennert is interested in Computer Vision, Image Processing, Scientific Databases, and Programming Languages, with ongoing projects in biomedical image processing, robotics, and stereo and motion vision. He is author or co-author of over 100 papers. He is a member of Sigma Xi, NDIA Robotics Division, and the Massachusetts Technology Leadership Council Robotics Cluster, and a senior member of IEEE and ACM.

Prof. Gretar Tryggvason, University of Notre Dame

Gretar Tryggvason is the Viola D. Hank Professor of Aerospace and Mechanical Engineering Department at the University of Notre Dame. He moved from the Worcester Polytechnic Institute, where he was the Head of the Department of Mechanical Engineering, in 2010. Tryggvason received his doctorate from Brown University in 1985 and spent a year as a postdoctoral researcher at the Courant Institute. After fifteen years as a professor of Mechanical Engineering and Applied Mechanics at the University of Michigan, he moved to WPI in 2000. He has also held short term visiting positions at Caltech, NASA Lewis Engineering Research Center, University of Marseilles, and University of Paris VI. Professor Tryggvason is well known for his research on numerical simulations of multiphase and free-surface flows, vortex flows, and flows with phase changes. He is an active member of several professional societies, a fellow of the American Physical Society and the American Society of Mechanical Engineers, and the editor-in-chief of the Journal of Computational Physics.

Educating the Global Robotics Engineer

Abstract: Robotics Engineering as a distinct discipline is an idea whose time has come. Traditionally, engineers working in the robotics industry have been mostly trained in a single science or engineering discipline, such as computer engineering (CE), computer science (CS), electrical engineering (EE), mechanical engineering (ME), or software engineering (SE). However, as an inherently multidisciplinary activity, no single discipline provides the breadth demanded by robotics in the future. Realizing this, universities are now starting to offer undergraduate and graduate degrees in robotics. Worldwide, there are now approximately 10 undergraduate programs and an equal number of graduate programs in robotics. Note that the intellectual basis for Robotics Engineering is *integration* – it is fundamentally a systems engineering major that is grounded in CE, CS, EE, ME and SE. As such, it is well-positioned to educate the "entrepreneurial/enterprising engineer" of the 21st century, the engineer who 1) knows everything, 2) can do anything, 3) collaborates, and 4) innovates. The entrepreneurial/enterprising engineer needs a global perspective and the globalization of robotics brings several implications for robotics engineers, including manufacturing, food production, defense, and telepresence.

Thus, the globalization of robotics carries many potentially disruptive societal impacts. Destruction of existing jobs / creation of new jobs. Enhanced security / reduced individual liberty. Longer lifespan / quality of life. Telepresence / never quite being present. Because of the disruptive potential of their craft, Robotics Engineers bear a special responsibility to humankind, embodied in a Code of Ethics for Robotics Engineers. We conclude that in addition to a broad and rigorous technological education, they must be well educated in economic, ethical, societal, and global issues. This education happens formally, through course, project, and off-campus experiences, and informally, through international robotics events. Taken together, these formal and informal activities and programs can give robotics engineers the global mindset demanded of the modern engineer.

1. Introduction

Robotics—the combination of sensing, computation and actuation in the real world—as a distinct field is an idea whose time has come [1]. Traditionally, engineers working in the robotics industry have been mostly trained in a single science or engineering discipline. Typically, those are computer engineering (CE), computer science (CS), electrical engineering (EE), mechanical engineering (ME), or software engineering (SE). However, as an inherently multidisciplinary activity, no single discipline provides the breadth demanded by robotics in the future. Realizing this, universities are now starting to offer undergraduate and graduate degrees in robotics. Worldwide, there are now approximately 10 undergraduate programs and an equal number of graduate programs in robotics. Roughly half of each are in the United States; the other half are distributed globally.

Beyond the broad technical education required of robotics engineers, to be an effective robotics engineer also requires an awareness of social and societal issues. These issues are global in scope. This leads to our main theses: 1) Robotics engineering is a global profession, 2) Robotics engineering education offers many opportunities for globalization, and 3) Informal robotics education can play an equally large role in globalization. Taken together, these formal and informal activities give robotics engineers the global mindset demanded of the modern engineer.

2. ROBOTICS ENGINEERING: A GLOBAL PROFESSION

The intellectual basis for Robotics Engineering is *integration* – it is fundamentally a systems engineering major that is grounded in CE, CS, EE, ME and SE. Thus, robotics engineers must be broadly educated in the supporting disciplines to understand and practice integrated thinking. As an integrated discipline, the field is well-positioned to educate the "entrepreneurial/enterprising engineer" of the 21st century who

- "**Knows everything**—can find information about anything quickly and knows how to evaluate and use the information. The entrepreneurial engineer has the ability to transform information into knowledge." [2]

  Thanks to the Internet, information sources are located globally, accessible globally, and available continually. Maintaining high precision and high recall is one differentiating capability of the effective engineer, especially robotics engineers who are expected to assimilate a wealth of information.

- "**Can do anything**—understands the engineering basics to the degree that he or she can quickly assess what needs to be done, can acquire the tools needed, and can use these tools proficiently." [2]

  Robotics engineering returns practitioners to good old-fashioned engineering marked by the absence disciplinary boundaries or silos. When confronted with a new challenge, it is never, "Not my job." [3]

- "**Works with anybody anywhere**—has the communication skills, team skills, and understanding of global and current issues necessary to work effectively with other people." [2]

  Robotics is a global enterprise; robotic systems may incorporate motors, sensors, circuits, hardware, and software from global suppliers.

- "**Imagines and can make the imagination a reality**—has the entrepreneurial spirit, the imagination, and the managerial skills to identify needs, come up with new solutions, and see them through." [2]

  Robotics addresses many of the global issues identified as NAE Grand Challenges [4].

The globalization of robotics brings several implications for robotics engineers. We list several:

Manufacturing: Robots in manufacturing enables the migration of production away from low-wage locations to low-cost-to-move-materials-locations. Capabilities and cost are the big drivers, dominated by workforce availability (including engineers) and the costs of obtaining and transporting raw materials, energy, and transport to the consumer or other end-user. Consequently, one can expect manufacturing to locate nearer consumers and reduce the pressure to off-shore operations.

Food production: Automation has affected virtually all aspects of food production, from self-driving agricultural vehicles [5] to automated fruit picking [6]. As the available arable land reaches its carrying capacity, it may become necessary to derive more food form the oceans, tended by robots [8].

Defense: Drones and other autonomous vehicles extend military presence to wherever they can be fielded, not restricted to where personnel can be deployed. Persistent tracking and privacy implications, national sovereignty, human-in-the-loop (or not!), and responsibility for inadvertent causalities are just a few of the issues raised.

Telepresence: Telepresence robots are a growing market, allowing people to "be" anywhere anytime. Schoolchildren who are unable to physically attend classes due to illness may now attend virtually. Likewise, doctors may be able to virtually meet with patients who cannot travel to their offices. Surgical robots separate surgeon from patient, although the surgeon remains in the operating room. Future surgeons will operate from anywhere in the world, not necessarily the operating room or hospital.

Thus, the globalization of robotics carries many potentially disruptive societal impacts: destruction of existing jobs / creation of new jobs, enhanced security / reduced individual liberty, longer lifespan / quality of life, telepresence / never quite being present.

3. ROBOTICS ENGINEERING EDUCATION: OPPORTUNITIES FOR GLOBALIZATION

The social implications of robotics makes it all the more important that an engineer's education address ABET Program Outcome (h) "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [7]. There are many opportunities to incorporate global concepts into robotics engineering educations. Naturally, these are not necessarily specific to robotics; nonetheless, robotics provides ample examples.

Product case studies with global implications – Unmanned Aerial Vehicles / Systems (UAV/UAS) and Unmanned Underwater Vehicles can cross national boundaries, presenting opportunities to discuss global issues in classroom activities and in-class projects, or in stand-alone capstone and other required projects. See, for example, [8] which examines robotics in ocean-based farming and the effect of the Law of the Seas Treaty.

Code of Ethics – Many engineering programs require coursework on ethics. The proposed Robotics Engineering Code of Ethics [9] can be a valuable resource. It touches on global issues, such as the responsibility to protect the global environment, respect for diverse cultures, and awareness of international laws.

Off-campus projects – Some capstone design projects are performed at industrial sites and government laboratories, including geographically diverse locations.

Geographically distributed capstone project teams – Geographically distributed design projects offers the opportunity to engage as students in the kinds of global engineering activities that are expected of practicing engineers. The challenges and some methods to optimize idea generation in distributed settings are described in [10].

Institutional exchange programs – Many institutions of higher education have exchange programs in place whereby students from one university spend a semester or year at another university, and vice verse. A recent twist involved a robot as an exchange student [11].

Degree programs that cross borders – A particularly noteworthy program is the European Masters on Advanced Robotics [12], which partners three European and three Asian universities.

These examples illustrate the range of opportunities for including globalization concepts and activities in robotics engineering education, varying in scale from classroom activities to entire degree programs. Although we are not aware of any studies quantifying the long-term effects of these efforts, it seems plausible that early and frequent exposure to global education activities will result in more globally aware engineers.

4. Informal robotics engineering education and globalization

We see that there are many opportunities for globalization in formal robotics engineering education, although these are often available to other engineering disciplines. However, there are also significant opportunities in informal education. Chief among them is robotics competitions. At this writing, the Robot Contests and Competitions FAQ lists 122 (!) different events worldwide [13]. Among the best-known competitions are FIRST, BotBall, RoboCup, RoboOlympics, DARPA Challenges, NASA Centennial Challenges, Sumo, AUVSI, IEEE MicroMouse, and various combat robot contests.

At the K-12 level, robotics competitions have proven an effective way to increase student interest in STEM fields generally. FIRST has the largest impact; its four leagues are expected to reach over 300,000 students from 60+ countries in 2013 [14].

At the university- and above-level, many competitions are explicitly international, including the AUVSI (Association for Unmanned Vehicle Systems International) ground, underwater, surface, and aerial robotic competitions [15], RoboCup soccer world cup [16], and European robotics events European Land Robot Trial (ELROB) [17] and Eurobot [18].

At any level, the interaction with like-minded participants from different countries and cultures is bound to open students' minds to global concerns. The presence of so many international robotics events at all levels suggests not only that the field is global in extent, but also that participants are exposed to globalization early and often. We believe that this preparation can reinforce the more formal globalization in robotics engineering education.

5. Conclusions

Because of the disruptive potential of their craft, robotics engineers bear a special responsibility to humankind. We conclude that in addition to a broad and rigorous technological education, they must be well educated in economic, ethical, societal, and global issues. This education happens formally, through course, project, and off-campus experiences, and informally, through international robotics events. Taken together, these formal and informal activities and programs can give robotics engineers the global mindset demanded of the modern engineer.

Bibliography

[1] M.A. Gennert, G. Tryggvason, “Robotics Engineering: A Discipline Whose Time Has Come”, IEEE Robotics & Automation Magazine, pp. 18-20, June 2009.

[2] G. Tryggvason and D. Apelian. “Re-Engineering Engineering Education for the Challenges of the 21st Century.” Commentary in JOM: The Member Journal of TMS, Oct. 2006.

[3] M. Taylor, “It is never 'not my job'.” IEEE Spectrum Blog/Automation, http://spectru.ieee.org/automaton/robotics/robotics-software/its_never_not_my_job_robotics_engineering_at_wpi, Jul. 2008.

[4] National Academies of Engineering, “NAE Grand Challenges for Engineering”, http://www.engineeringchallenges.org/.

[5] F. Rovira-Mas, H. Shufeng, J.F. Reid, “Evaluation of automatically steered agricultural vehicles," *IEEE/ION Position, Location and Navigation Symp*, pp. 473-478, May 2008.

[6] C. Aloisio, *et.al.,* “Next generation image guided citrus fruit picker,” *IEEE Int. Conf. Technologies for Practical Robot Applications,* pp. 37-41, Apr. 2012.

[7] ABET, “Criteria for Accrediting Engineering Programs“, http://www.abet.org/, Oct. 2012.

[8] S. Batchelder *et.al.,* “An Analysis of Future Sustainable Aquatic Farming”, Interactive Qualifying Project Report, Worcester Polytechnic Institute, http://www.wpi.edu/Pubs/E-project/Available/E-project-031212-191226/unrestricted/Final_Paper.pdf, Mar. 2012.

[9] B. Ingram *et.al.*, "A code of ethics for robotics engineers," *ACM/IEEE Int. Conf. Human-Robot Interaction*, pp.103-104, Mar. 2010.

[10] M. Glier *et.al.,* “Distributed Ideation: Idea Generation in Distributed Capstone Engineering Design Teams”, *International Journal of Engineering Education,* Vol. 27, No. 6, pp. 1281-1294, 2011.

[11] J. Falconer, “Japanese elementary school enrolls robot exchange student”, Gizmag, http://www.gizmag.com/atr-robovie-robot-elementary-school/26177/, Feb. 2013.

[12] EMARO, European Masters on Advanced Robotics, http://emaro.irccyn.ec-nantes.fr/.

[13] Robots.net, “Robot Competitions”, http://robots.net/rcfaq.html, Mar. 2013.

[14] US FIRST, “FIRST at a glance”, http://www.usfirst.org/aboutus/first-at-a-glance, Jan. 2013.

[15] AUVSI Foundation, “Competition Central”, http://www.auvsifoundation.org/Competitions/CompetitionCentral, 2013.

[16] RoboCup, http://www.robocup.org/, 2013.

[17] ELROB, “European Land Robotics Trial”, http://www.elrob.org/, 2013.

[18] Eurobot, http://www.eurobot.org/, 2013.