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EDITORIAL

Growing the Soft Robotics Community Through Knowledge-Sharing Initiatives

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In relatively new fields of science and technology, where protocols and know-how have not been established over decades, significant effort must be dedicated to sharing knowledge between researchers, engineers, designers, and students. This is especially true in cases of technological uncertainty, where scientists and engineers are optimistic about the future of a technology but are uncertain as to how it will develop.[1] One effective method for this knowledge sharing is researcher mobility; the movement of workers between different labs helps dissemination of information and advances the field as a whole. Another important factor is the establishment of knowledge-sharing communities and networks.

As a relatively young area of science and technology, soft robotics faces significant technological uncertainty. Best practices in terms of design, fabrication, and characterization have yet to be established. Building and growing a community of soft robotics researchers is a prerequisite for solving many of the open challenges. In the past decade, an interdisciplinary, international soft robotics community has emerged. This journal has contributed significantly to the formation of this community, as have a variety of networks and events. One such network was the RoboSoft Coordination Action Network (www.robosoftca.eu), which was funded under the European Union's Seventh Framework Programme for Research and Technological Development from 2013 to 2016. RoboSoft established a scientific research community focused on soft robotics and served as a knowledge transfer and promotion vehicle through workshops, summer schools, competitions, and other events, as well as publication of research articles, working papers, and a book of proceedings. Another network is the IEEE Robotics and Automation Society Technical Committee on Soft Robotics (www.softrobotics.org), which runs an international mailing list that connects scientists and engineers from a broad range of disciplines.

The growth of the soft robotics research community has led to a large output in publications. In addition to this journal, recent years have seen special issues on soft robotics in the *IEEE Robotics and Automation Magazine* and the *Journal of Micromechanics and Microengineering*, as well as a dedicated soft robotics section of *Frontiers in Robotics and AI*. Next year will see soft robotics special issues in journals including *Biomimentics* and *Micromachines*. Soft robotics technical sessions and workshops have been held at multiple international robotics conferences, including the *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, the *IEEE International Conference on Robotics and Automation (ICRA)*, the *IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics*, *Robotics: Science and Systems*, and the *Materials Research Society (MRS) Conference*. In addition, the first *IEEE International Conference on Soft Robotics* will be held in April 2018.

Initiatives such as these are essential to the success of soft robotics research. However, at this stage in the field's development, it is also desirable to have mechanisms for sharing more detailed information than is typically possible through a journal, conference, or mailing list. Throughout history, there are multiple examples of new technologies, from airplanes to personal computers, being developed through periods of ''collective invention'' in which scientists and engineers share detailed design documentation and testing protocols. Recently, this type of community-based development activity has been used in the open source movement in software and electronic hardware. In this editorial, we wish to discuss community-building through one resource intended to facilitate the sharing of knowledge between researchers, designers, and students: the Soft Robotics Toolkit.

The Soft Robotics Toolkit

In 2014, we announced the launch of the Soft Robotics Toolkit (www.softroboticstoolkit.com) in this journal.[2] The toolkit is an open-access Web site containing detailed information about the design, fabrication, and characterization of soft actuator and sensor component technologies. The Web site is an intellectual rather than physical toolkit and contains design documentation, downloadable resources, tutorials, and case studies submitted by an international community of soft robotics researchers and designers. The intent in creating the toolkit was to support the emerging soft

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robotics community by serving as a means for researchers and designers to share detailed information. Since its launch in September 2014, the toolkit has grown considerably. The Web site is visited by 350 people per day on average. at the time of writing, its pages have been viewed 1.5 million times by >197,000 people from 195 countries. The toolkit now hosts contributions from 19 research groups, as well as multiple individual students and designers. Design files shared by these community members have been downloaded >27,000 times. It has a mailing list of 1,536 people and an online forum that allows users to ask questions and discuss soft robotics topics with each other.

An unexpected result of launching the toolkit was the level of interest we received from middle- and high-school students. Over the past 3 years, we have organized talks and workshops with hundreds of younger students. Based on our experiences in these workshops, we produced a collection of instructional materials suitable for use by teachers in K-12 classrooms, and now have a section on the toolkit Web site dedicated to materials for educators. We have also created an online community of educators interested in teaching soft robotics. This allows educators to share their experiences in the same way that the toolkit enables researchers to learn from each other's work. An important aspect of community building is attracting and training the next generation of community members. The toolkit supports this activity by serving as a hub for both experienced robotics researchers and novice students interested in pursuing robotics careers.

Building Community Through Competitions

In the early days of the toolkit, we faced difficulties in attracting contributions from other research groups. In the first 6 months following its launch, the toolkit was visited by >36,000 users. However, during that time, only one external research group contributed material to the Web site. To become a true community resource, rather than just a Web site where we shared our own work, we needed to encourage robotics researchers to share their work in the toolkit. We also needed to learn about how people were using the soft robotics information shared on the site. Competitions can be an effective way to build community, encourage sharing of knowledge, and advance a field of technology. Soft robotics competitions, such as the RoboSoft Grand Challenge in 2016 and the ICRA Soft Materials Robot Challenge in 2017, have shown the benefits of contests as community-building activities. In 2015, we decided to organize a series of competitions through the Soft Robotics Toolkit to encourage students and researchers to share their work and to promote and reward advances in the field.

The first competitions that took place in 2015 consisted of a design category and a research category. The design category was aimed at a general audience and asked participants to use the materials on the Web site to design a novel device for the application area of their choice and to document their results for inclusion in the toolkit. The aim of the design category was to encourage use of the resource and to produce a collection of case studies describing soft robotic systems based on the component technologies documented on the toolkit. The research award was intended to incentivize research groups to contribute new soft robotics content. It rewarded the most significant recent contribution to soft robotics research documented on the toolkit Web site, as determined by an international panel of experts recruited from leading soft robotics research groups. For both categories, cash prizes were offered, and the judging of entries was based entirely on documentation submitted to the Web site.

The first year of the competitions saw 82 projects submitted by 243 participants. Entries to the design category included work completed by undergraduate students as part of robotics classes, projects undertaken by high school students for science fairs, and low-cost robotic systems designed by and for hobbyists. Applications included assistive devices, functional apparel, children's toys, architectural features, locomotion, and electro-pneumatic control hardware. The winning entry described the design and fabrication of an untethered pneumatic wheel robot (Cornell University, NY). Entries for the research award included new approaches for modeling and controlling soft actuators, new manufacturing methods, and novel designs for soft sensors and actuators. The winning entry consisted of a self-sensing technique for pneumatic artificial muscles (Robotics and Motion Laboratory, University of Michigan).

During the second year of the competitions, the categories were modified to reflect better the level of interest from younger students. While some of the most interesting competition entries in the first year came from high-school students, it seemed unfair to force these students to compete with older participants who had more experience and access to facilities. The 2016 competitions therefore consisted of three categories: a design category for high-school students, a college-level design category for undergraduates and hobbyists, and a research award, which again aimed to attract contributions from robotics labs.

The second year of competitions attracted 96 entries from 228 participants. The winning high-school project documented a novel locomotive robot (Robbinsville High School, NJ). The winning entry in the college-level competition described the design of a bioinspired manta ray robot (Worcester Polytechnic Institute, MA). The winners of the research award presented a new soft, biomimetic, tactile sensor (Bristol Robotics Lab, Bristol, United Kingdom). The paper by Ward-Cherrier et al. in this issue describes a family of devices based on this tactile sensor, which has itself been made available to the community as an open source design. This is an excellent example of using multiple channels to disseminate knowledge that can advance the soft robotics field as a whole: the authors have shared their research through traditional conferences and journals, soft robotics competitions, and open licensing models.

The recently completed third year of the competitions saw a total of 83 projects from 186 participants. Entries included a modeling and design tool for soft pneumatic actuators, a DEA-powered robotic ball, and a 3D-printed soft gripper that uses passive particle jamming to modulate stiffness. The winning entry in the high-school competition used candy to create edible soft pneumatic actuators (The Haverford School, PA). This project is an example of younger students innovating in a manner similar to leading research groups[3] to create their own novel contributions. The winners of the college competition described a soft pneumatic hand with embedded 3D printed soft electronics (Massachusetts Institute of Technology, MA). The winning research entry was

by the Organic Robotics Lab at Cornell University, and described soft pneumatic actuators composed of an open-celled elastomer foam surrounded by an outer layer of nonporous elastomer.

Conclusion

A huge number of soft robotics researchers, educators, and students have contributed to building a global soft robotics community over the past decade. Through the international networks such as RoboSoft, the conferences and events such as Soft Robotics Week, and the resources such as the Soft Robotics Toolkit, we have seen the potential for individuals to pool their efforts in the interests of scientific and technological progress. We believe that continued community-building activities are essential to the growth of this field and to the solution of technical challenges that serve as obstacles to broader adoption of soft robotics. We call on all readers to contribute to these efforts by joining existing networks or starting new ones, by running outreach events and workshops with younger students, by organizing and entering soft robotics competitions, and by leveraging existing resources such as the Soft Robotics Toolkit. Our intention has always been for the Soft Robotics Toolkit to become a resource grown and curated by the community. Over the next year, we are keen to establish an international board of advisors who can guide the continued evolution of the toolkit so that it can best support the soft robotics community and inspire younger students to become involved in this field and STEM fields in general. We encourage readers to contact us with ideas for the Soft Robotics Toolkit and tell us how they would like to get involved. This is an exciting time for the soft robotics community. We look forward to continued growth and collaboration in the coming years.

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