Soft Robotics

By Erico Guizzo

In this issue, Erico Guizzo (EG) interviews Rolf Pfeifer (RP), professor of computer science and director of the Artificial Intelligence Laboratory at the University of Zurich, Switzerland, about the promises and challenges of soft robotics.

EG: **You've been working and giving talks on soft robots lately. What do you mean by "soft robotics" and why is it important?**

RP: The term is a bit metaphorical; it's soft at various levels. It starts with the notion of soft to touch, which means relying on soft and deformable materials. A soft robot would also have to be soft in the way it moves, which requires using elastic compliant materials for muscles and tendons or variable-compliance actuators as well as exploiting passive dynamics, so that you can have movements that are more natural, more humanlike rather than robotlike. Finally, there's the idea that robots should interact with people in a soft way, with movements and behaviors that are friendly and natural. The reason why soft robotics is important is that it has the potential to lead to robots that are more adaptable and capable, as well as safer, than existing robots, especially in situations where they closely interact with people in unstructured environments such as homes, offices, and public places.

EG: **In a talk last year, you said that soft robotics could lead to a "new industrial revolution," with soft robots being the key to new factory automation technology.**

RP: This is all, at this point in time, speculation . . .

EG: **I love speculation. People in robotics are too cautious. We need dreamers.**

RP: (Laughs.) Yes, I see huge potential for soft robots to help with the next-generation factory automation. Companies in the United States and Europe outsourced manufacturing because some tasks were too hard to automate using current manufacturing technologies, and labor was cheap abroad. However, now things are starting to change, with labor costs in Asia increasing compared with what they used to be. So we're reaching a point when, if more capable automation machineries and tools were available, companies could begin to think about bringing their manufacturing operations back home. I think that it's these sorts of soft robots that could make that possible. Robots with compliant technology could potentially achieve manipulation skills that current robots don't have. One example would be the ability to grasp small, delicate objects with fingertips that adapt to the shape of the object without the need to precisely preprogram the robot to do so. It's important to note that these new robots will not replace traditional factory robots; it's a complementary technology that will do other things. However, I do think that if some breakthroughs on manipulation technologies using these compliant systems are made, this could have a big impact on the future of manufacturing.

Figure 1. The ECCE robot, a European Union (EU)-funded project that involves the University of Sussex, the University of Zurich, the Univerzitet u Beogradu, Technische Universität München, and The Robot Studio. (Photo courtesy of Patrick Knab/University of Zurich AI Laboratory.)

EG: **You and several collaborators have been working on an anthropomimetic robot called *ECCE* (Figure 1). I have to say it's quite a sight. What are the goals for this project?**

RP: ECCE stands for embodied cognition in a compliantly engineered robot [1]. The goal is to develop a robot that, as you noted, is anthropomimetic, which means it copies not only the shape of a human body but also the inner

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Figure 11. The QB telepresence robot by Anybots. (Photo courtesy of Randi Klett/*IEEE Spectrum*.)

will be roaming around offices—a place where robots were nonexistent—all over the world. It's a first in robot history. In 2012, a new entrant promises to make this market even more competitive; it's likely that Suitable Technologies, a Willow Garage spin-off, will introduce its much-awaited remote presence system as well. So expect to see more telepresence robots near you—if you don't become one yourself.

12) Bionics: The Line Between Humans and Machines Gets Blurry

Cyborgs and other man–machine hybrids have long captured people's imaginations. We're still far from the technology envisioned in science fiction shows such as "The Six Million Dollar Man" and "Robocop," but researchers have made significant progress in the past two years. Areas such as robotic prostheses and brain–machine interfaces seem to be building lots of momentum, and we expect to see some promising milestones in 2012. In particular, exoskeletons are literally strutting out of the laboratory. This year, Ekso Bionics (formerly Berkeley Bionics) will begin selling its robotic suit first to rehab clinics in the United States and Europe, hoping to have a model ready for at-home physical therapy by the middle of 2012 (Figure 12). At the same time, a DARPA-sponsored project by Johns Hopkins University and the University of Pittsburgh has been testing a brain implant that allows patients to control an advance robotic arm with their thoughts alone. Many other groups are also working on technologies that promise to blur the line between humans and machines; it won't happen overnight, but now the promise is not just science fiction anymore—it's real.

Figure 12. A test pilot tries the exoskeleton created by Ekso Bionics. (Photo courtesy of Ekso Bionics.)

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Turning Point

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structures and mechanisms, such as bones, joints, muscles, and tendons. We've already built two robots, and now we want to figure out how to control them and give them humanlike cognitive features.

EG: **Is ECCE going to assemble my next iPhone?**

RP: ECCE is a research platform. It uses cables with a certain degree of elasticity as tendons. There are 45 motors embedded in its body that pull on the cables to make the body move. As for your future iPhone, I don't think it makes sense to put humanoid robots in factories. The next-generation factory robots could be just a pair of arms or hands, or other kinds of manipulators, which don't even have to look humanlike. However, maybe it could be an ECCE hand.

EG: **How do you control ECCE's movements? How many degrees of freedom does it have?**

RP: Too many. That's one of the biggest challenges. For example, when the robot lifts one arm, the torso and the other arm wiggle a bit. It's very biological and realistic in how it works, but it doesn't make control easy. Lifting the arm requires the actuation of multiple muscles that need to be coordinated, actuated to varying degrees. The way the body and muscles interact is difficult to model using classical control methods. There are lots of nonlinear behaviors, the tendons have static and dynamic friction, and the mechanics are not precise. This is where learning becomes critical. The robot needs to figure things out by itself, at least some things. To be able to do that, we

Figure 2. Paro, a therapeutic baby seal robot. (Photo courtesy of Randi Klett.)

need to understand—and exploit—the notion of embodiment [2], [3]. One of the basic principles of embodiment is that every action has a consequence in terms of patterns of sensory stimulation: when I turn my head, the visual input changes; when I stretch out my arm, I can feel its weight through proprioceptive sensors; when I grasp a cup, I can sense it in my hand and fingers. Our plan is to let the robot, which is equipped with many sensors, explore and learn on its own. To grasp an object, for instance, it has to reach and figure out if it has actually reached the object. Then the sensors can be used to give the robot an idea of how effective its motor signals were for that particular movement. It's related to motor babling, a term used in developmental science. It will have a certain degree of randomness. However, even if the motor signals are random, the robot's movements will be constrained by the morphological and material characteristics of the system. So we're exploiting the biomechanical constraints, just as biological systems evolved to do. Then from the feedback it gets, the robot can figure out its own dynamics.

Figure 3. A robotic arm driven by McKibben pneumatic muscles and hand with flexible skin developed by Koh Hosoda and colleagues at Osaka University, Japan. (Photo courtesy of Koh Hosoda.)

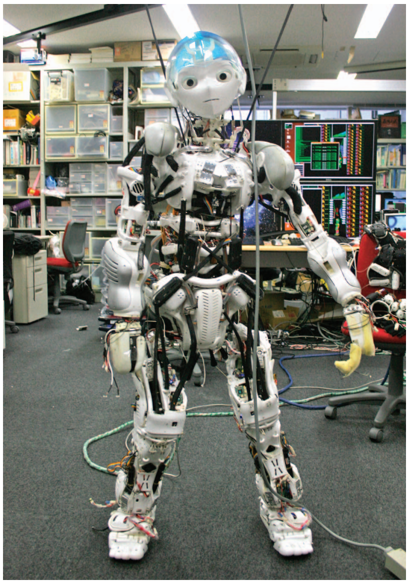

Figure 4. Kojiro, an anthropomorphic humanoid developed at the University of Tokyo. (Photo courtesy of Erico Guizzo.)

EG: **Are researchers trying to build soft robots or robots that use soft, compliant parts?**

RP: Again, the notion of soft varies widely here. You can have a robot that is soft to touch, as you see in robot pets such as Paro (Figure 2). Some groups are building robotic systems that have deformable tissue on the surface, such as the Hosoda hand (Figure 3). Others are building full-body robots using pneumatics, tendons, or other humanlike actuation systems, such as our own robot ECCE and the humanoid Kojiro from the University of Tokyo (Figure 4). There are also groups that are trying to design novel types of actuators using new materials and mechanisms that can dynamically change their properties. Another group is building a robot that mimics an octopus (Figure 5), an animal consisting almost exclusively of soft materials, the tentacles don't really have a segmental structure but are continuous [4]. Here, the challenge is how to control a system with potentially infinite degrees of freedom. Rather than trying to control every detail of the movement, the goal is to search for global parameters, for example, stiffness, which can be changed on the fly, and to leave the details to the morphological and material properties. So exploring this range of soft technologies is a big part of soft robotics.

EG: **You mentioned embodiment. Can you explain why it's important?**

RP: The classical approach, where you design a control system that takes care of everything the robot does, will not be sufficient here. That approach worked well for things such as factory robots operating in structured environments, but we need to go beyond that when we have environments that are constantly changing and interactions that are unpredictable. The system best suited for these environments is one that has properties similar to our own bodies. In other words, it is

Figure 5. The Octopus project. (Photo courtesy of Massimo Brega/The Lighthouse.)

compliant, reactive, and has control distributed throughout its subsystems rather than in a centralized fashion. To build robots that have these features we need to understand embodiment. For example, as soon as you have compliant materials with springlike characteristics in a walking robot, the elasticity of the muscle-tendon system and the shape of the leg will automatically, without control, cope with small unevenness on the ground. When grasping a hard object, a cup, I don't need to know its exact shape; it's enough to apply a certain force. My fingers will automatically wrap around the cup and the soft tissue on the fingers and in the hand will deform passively, without central control, and adapt to the shape of the cup. In this way, achieving a stable grasp is easy. We also talk about the power of materials. Another example is a robot that walks on two legs using passive dynamics [5], [6] rather than the classical zero moment point method, in which you have to plan how to actuate each joint. Because it optimally exploits the passive dynamics, it can walk very long distances on one battery charge. Here, again, part of the control is outsourced to the physical dynamics of the robot. In other words, there isn't a clear separation anymore between control and the controlled—the plant. So we actually need a new notion of control—I prefer to use the term orchestration rather than control. We need to figure out how the robot's anatomical characteristics, material properties, and location of sensors and actuators, among other things, fit with the information processing performed by the controller [7]. That's a big research challenge.

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