Soft Robotics: Challenges and Perspectives

MANOJ ASHOK BHILKAR

Department of Information Technology (Msc.IT Part 1)

MSC IT Department, Model College (Dombivli), University Of Mumbai, India

ABSTRACT :

There has been an increasing interest in the use of unconventional materials and morphologies in robotic systems because the underlying mechanical properties (such as body shapes, elasticity, viscosity, softness, density and stickiness) are crucial research topics for our in-depth understanding of embodied intelligence. The detailed investigations of physical system-environment interactions are particularly important for systematic development of technologies and theories of emergent adaptive behaviors. Based on the presentations and discussion in the Future Emerging Technology (fet11) conference, this article introduces the recent technological development in the field of soft robotics, and speculates about the implications and challenges in the robotics and embodied intelligence research.

KEYWORDS

Soft robotics ,Bio-inspired robotics, Smart materials Adaptive and autonomous robot control.

I. INTRODUCTION

Although robotic systems are usually made of rigid materials such as steel and aluminum, biological systems are rarely composed of rigid mechanical components, but they generally make use of soft, elastic, and flexible materials in order to survive in complex unstructured environments. Animals' bodies are, for example, composed of soft skins and hairs, elastic muscles and tendons, and various wobbly organs. Control architectures are also very different by reflecting the differences in underlying material properties. For example, while the conventional robotic systems usually rely on the pre-programed motion patterns, biological systems usually update their neural circuitry continuously to adapt to the dramatic changes of body structures.

Given such salient differences in constituent systems, there has been an increasing interest in the studies of "softness" in the context of embodied intelligence research, for which the field of soft robotics is emerging. While the field is still young and not very well defined, there are a few distinctive research directions which share a similar motivation. For example, a number of researchers have been investigating unconventional materials for robotic systems, in which soft materials such as polymer based materials are examined for novel sensory devices and actuators. The newly developed smart materials, sensors and actuators were then integrated into micro-robots of various kinds . Also the flexible body structures of animals were replicated in the reconfigurable robots .

The main goal of this article is to provide a concise overview of this young yet stimulating field with some introductions of enabling technologies and conceptual issues. In particular, we attempt to identify the important development and challenges of enabling technologies of soft robotics, on top of which we argue the implications and perspectives toward the future.

The backbone of this article was developed in the process of organizing the session "Soft Robotics: Theories and Technologies" in the Future Emerging Technology (fet11) conference held in Budapest, Hungary, May 2011. In this session, we invited Hod Lipson from Cornell University as a plenary speaker, and additional three technical presentations given by Dario Floreano, Cecila Laschi, and Liyu Wang. At the end of this 90 minute session, we also organized a panel discussion together with Rolf Pfeifer, Paolo Dario, and Josh Bongard as panelists.

II. CONTROL OF SOFT MOTIONS

Throughout the history of robotics research, we have been exploring a number of different materials to be used in robotic systems. Mostly they are made of the metal-based rigid materials, many soft, deformable, and elastic materials were also employed, including springs, dampers, and impact-absorbing rubbers. A simple case study of such soft robots could be a legged robot that has passive springs in the knee or ankle joints, or a finger robot driven by elastic tendons. These robots are generally capable of using the elasticity in the joints to achieve dynamic locomotion and grasping tasks. Even in these relatively simple examples, we could already observe the significant benefit from soft material properties. For example, if compared to robots that are fully actuated by many bulky motors, the passivity based legged or finger robots can have lighter bodies and exhibit more dynamic and energetically efficient motion control. In addition, because the passive joints of legs and fingers are not fully controlled by motors, the robots exploit "mechanical self-stabilization" - utilizing mechanical passive dynamics for achieving desired behaviors - which substantially decreases the complexity in control architectures.

A more radical approach could be to design the entire robot body by using soft and deformable materials, just like elephant trunks or octopus arms. Here we find many challenges that we have not considered in conventional robotics research: the body plans can no longer be viewed as the chains of rigid links with rotational or sliding joints as typically explained in classical mechanics, but they are all continuous and deformable; and it is not clear how to represent the state variables of body posture of the systems because the dimensions of design parameters are dramatically changing depending on the body postures. Obviously these fundamental changes in mechanics introduce additional complexity in actuation (how to generate force and torque), sensing (how to sense the physical parameters of mechanical body structures), and control (how to plan goal directed behaviors) because conventional technologies such as electric motors and joint angle sensors cannot be easily transferred.

One of the main challenges in this research direction is the technologies to make actuators and sensors smaller, softer, and deformable. Some of the ongoing research activities include the use of unconventional actuator materials such as shape memory alloy (SMA) and piezoelectric crystal that can dramatically miniatualize actuation components. The use of deformable materials also accelerates the development of novel actuators and sensors for soft robotics .

III. TOWARD-AUTONOMOUS MORPHING

Animals often need to change their body shapes to achieve many different tasks, as we make a fist to knock on a door and stretch a finger to touch an object. Generally speaking, a robot is capable of more variations of tasks if it can reconfigure its morphology. While the soft motion control discussed in the previous section involves dynamic changes of morphologies, another important aspect that we focus on here is the "plastic changes" of morphologies, i.e. the changes of body shapes and dynamics in a relatively longer period of time. By analogy, the plastic changes of morphologies can be exemplified by the growth of body structures and strength in the animals' developmental processes, in contrast to the soft motion control that refers to the body posture changes by the muscle forces, for example.

The plastic changes of morphology were previously investigated in the context of reconfigurable robots. Typically a reconfigurable robot consists of a number of smaller modules, and each module is capable of autonomously connecting and disconnecting to each other. The connection mechanisms generally employ mechanical grippers or electromagnetic adhesion, and with these mechanisms, a reconfigurable robot is able to change its shape from a snake-like locomotion robot to a legged robot, for example. The main lesson that we learned from the studies of reconfigurable robots is that modularity and connectivity are the key components for autonomous plastic changes of robot morphologies: when a robot consists of small-sized modules which are capable of flexibly connecting and disconnecting to each other, it is able to perform considerably more variations of tasks.

Biological systems take advantage of similar mechanisms for their growth processes: animals' body structures consist of many cells and they are able to flexibly connect to each other. Compared to the biological cells, however, our reconfigurable robots have only very basic capabilities of autonomous morphing, and there are many questions to be tackled. For example, we still do not know how we can build more flexible connection mechanisms in each module such that each cell could connect to many other modules? How can these modules vary their mechanical properties (more elastic, more stiff, or softer)? How can they self-repair? How can they replicate themselves for physical growth?

From this perspective, the recent technical progress in soft robotics proposed a few novel approaches that could potentially contribute to these challenges in the reconfigurable robot research. For example, the exploration of unconventional materials has led to several adhesion mechanisms such as a universal gripper based on granular materials, electro adhesives, and chemical adhesives. The use of Hot Melt Adhesive materials, in particular, has shown its capability to attach to many different materials while maintaining very strong connection forces. We expect that these investigations on new connectivity and adhesion mechanisms of soft robotics would eventually scale up the reconfigurable robot research to more general solutions for autonomous morphing.

IV. SIMULATING SOFT ROBOTS AND BODY-CONTROL CO-DEVELOPMENT

Besides the handling techniques of physical materials, modeling and simulation tools are required for a systematic development of this research field. In particular, new methodologies for modeling and simulating soft bodies and materials seem to be necessary because the conventional solutions do not characterize many behaviors of our soft robots very well. For example, one of the underlying problems lies in the fact that, as we make use of more soft materials in our robots, it is necessary to simulate more continuous models in addition to discrete ones represented by mechanical links and joints. Also our soft robots usually make use of more decentralized control architectures on top of centralized ones.
The simulation techniques allow us to explore significantly more complex processes in soft robotics. Complexity can be, for example, enhanced in the variations of soft body structures (e.g. different sizes and various viscous-elastic properties), and their influences to intricate sensory-motor processes. Such an approach could essentially be used for the body-control co-optimization as has been partially demonstrated in the past. In addition, simulating plastic changes of morphologies and material properties seems to be one of the significant challenges in soft robotics. With the models of plastic morphological changes, we will be able to simulate optimization in different time scales, which could be a process similar to ontogenetic development.

V. CONCLUSION

The soft robotics research has many "faces": soft robotics is a research field that investigates unconventional materials and morphologies of autonomous systems; it explains the relation between morphologies and functionalities; it tackles the challenging problems on self-organization, self-stability, and self-assembly with concrete engineering terms; and it also envisions the real-world developmental and evolutionary robotics. The research field is still in a nascent stage, and the main efforts are currently invested onto the exploration of unconventional materials and their implementation in robotic systems. Soft robotics is, however, also providing novel scientific concepts and methodologies which contribute to our in-depth understanding of embodied intelligence.
Most of the research platforms were developed for the sake of scientific explorations so far, but we also expect considerable impacts in practical applications. The use of unconventional materials can, for example, be used for miniatulizing mechatronics applications such as micro-aerial vehicles, interacting with sensitive objects, and unconventional sensing devices (e.g. deformable tactile sensors and optics). In particular, soft robotics will provide a significant impact in human-oriented robotic devices including medical and educational applications such as prosthetic and rehabilitation devices.

VI. REFERENCES

1. Trivedi D., Rahn C.D., Kier W.M., Walker I.D.**Soft robotics: Biological inspiration, state of the art, and future research.**

2. Ilievski F., Mazzeo A.D., Shepherd R.F., Chen X., W hitesides G.M.**Soft robotics for chemists, Angew** Chem. Int. Ed., 50 (2011), pp. 1890-1895.

3. Hara F., Pfeifer R. (Eds.), Morpho-functional machines: The new species: Designing embodied intelligence, Springer (2003)

4. Yim M., Shen W.M., Salemi B., Rus D., Moll M., Li pson H., Klavins E., Chirikjian G.S.**Modular self-reconfigurable robot systems: Challenges and opportunities for the future** IEEE Robotics and Automation Magazine (2007), pp. 43-52.

5. Albu-Schaffer A., Eiberger O., Grebenstein M., Haddadin S., Ott C., Wimbock T., Wolf S., Hirzinger G.**Soft robotics** IEEE Robotics & Automation Magazine, 15 (3) (2008), pp. 20-30