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Abstract:

Additive manufacturing of soft matter for robotic applications

The use of elastomeric polymer networks above their glass transition temperature provides unique mechanical and other functional properties to the fundamental elements that comprise robots: actuators, sensors, control algorithms. As a simple example, when a rubber band is loaded and stretched it stores this strain energy as the reduced configurational entropy of stretched polymer chains. When the extended polymer network is unloaded, it releases this energy when the load is removed. In this sense, a rubber band acts as a ligament when appropriately used in a robotic appendage. These elastomeric ligaments, when designed appropriately, can also be used as actuators that drive the motions of robots; therefore, they can be used simultaneously as artificial muscles and ligaments. Further, these elastomeric materials have been demonstrated with embedded electrically conductive, or optically transmissive, networks that measure strain during the deformation of the actuators—these materials can also be self-sensing. In addition to other functionalities (e.g., optical manipulation) these soft materials are easily processed as liquids, which makes them ideal for many additive manufacturing processes, such as rotational casting, replica and injection molding, as well as 3D printing.

In this talk, data from Professor Shepherd's Organic Robotics Laboratory will be presented on the additive manufacturing of actuators, sensors, and how these functional structures can be controlled for robotic applications like human-computer interfaces, and smart prosthetic hands. These multifunctional soft composites of polyurethanes, silicones, acrylates, and nanoparticles were replica molded and 3D printed into actuators that are powered via fluidic pressure. When a fluid is pumped into chambers within these composites, the pressurized elastomeric vessel changes shape based on how we designed the structure. To measure the shape change of these actuators, we embedded two types of deformation sensors into these elastomeric actuators: stretchable (i) capacitors and (ii) lightguides. These sensors are chemically and mechanically similar to the actuators themselves and thus do not alter the performance of the robot, while also providing accurate shape information for appropriate feedback control. Because we are able to mold a large number of sensors, we have also applied machine learning techniques to interpret the large amount of sensory information as deformation.

In order to create sophisticated assemblies of these polymer networks and nanoparticle-elastomer composites that provide these functions, we have adopted projection stereolithography as a 3D printing process compatible with our material systems. The most broadly useful material platform we have developed is based on a photoinitiated thiol-ene reaction of vinyl- and mercapto-

siloxanes. We will present this system and how we have applied it for directly printing fluidically pressurized elastomeric actuators, and their ability to self-heal.

Finally, this talk will end by describing our work on light emitting microparticles embedded in elastomeric networks; we have used additive manufacturing of this soft material composite to create a new capability for robots. We used these stretchable, elastomeric light emitting displays as well as texture morphing skins for soft robots.

Keywords:

Elastomer – crosslinked polymer networks above their glass transition temperature that typically have highly elastic responses at large strains. These materials are attractive because many are “stretchable” at room temperature and at low applied stresses.

Robot – a machine that can sense and respond to its environment

Actuator – a machine that does work according to a powered input

Additive manufacturing – a production process that adds material (e.g., injection molding), rather than substracts (e.g., machining).