Evolutionary Flowing Robots with Switchable Surface Activity of Liquid Metal

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***Abstract*— Recently, it has been shown that the interfacial tension of a liquid alloy of gallium can be controlled via surface oxidation using a very low voltage. It enables shape-reconfigurable metallic components reversibly [1]. This newly identified electrohydrodynamic phenomena can push the frontiers of soft robotics by making robots evolve and flow to new shapes and locations.**

I. Introduction

Soft robot uses both its morphology and material property for locomotion, integration with other modules, and manipulation to perform tasks. We plan to develop soft robots, which are functionalized, first, by equipping them with a set of devices necessary for a particular task, second, by inducing a certain function, for example, increased surface friction or affinity to water or surface tension, through material reassembly at nano/micro scales. This project will develop techniques not only to actuate the motion of the surface or body to create configuration changes at macro scale, but also to change the topology through chemical/physical interaction of materials at nano/micro scales. Eventually, we aim to achieve morphology change triggered by sensor signals. This paper summarizes the first three projects: (1) slime mold robots, (2) variable-stiffness robots, grippers, actuators, and (3) further applications. We plan to pursue all of these ideas and more to draw out the full potential of thisinteresting phenomena of switchable surface tension of liquid metal.

II. Slime Mold Robots

A. Slime Mold Robots I : Polymer

Cellular slime mold, *Dictyostelium discoideum*, has a unique series of developmental events. The cells associate, forming streams of migrating cells that merge in an aggregate for mutual benefit and survival. We have begun the development of a biologically-inspired cellular slime mold robot (SMR), the first soft modular robot to the best of our knowledge [2]. The slime mold robot is a reconfigurable robot with remarkable flexibility, shape change, and integration capability. Its body is made of a flexible polymer with shape memory alloy wire springs embedded inside as muscles. The viscoelastic body helps physical connection with other slime mold modules. By actuating different sections of the springs, several different shapes from the same module can be created and the size of each individual SMR module can also be controlled. Having similar folding characteristics as the DNA origami, these basic unit shapes can facilitate versatile assemblies with other SMR module and enable the design of intricate shapes. The individual SMR module has a flat, flexible body with mobility. Unlike most modular robots, each SMR has dual modes of locomotion. It can crawl and swim. Experiments have successfully shown its ability to crawl and grasp.

B. Slime Mold Robots II : Liquid Metal

Dictyostelium discoideum changes surface tension to aggregate and migrate. The first slime mold robot made of polymer has limitations. We propose to develop continuum modular robots by changing surface tension to better imitate the behaviour of cellular slime mold. Liquid metal eutectic gallium indium (EGaIn) initially in a spherical shape in electrolyte flattens and spreads without bound upon application of an oxidative potential. We can make EGaIn continuously flow and disperse at a low voltage. As it disperses, it loses contact with electrode and surface tension becomes high again. Then, it quickly forms a spherical shape. When an oxidation potential is applied, the liquid metal flows again and spreads to touch adjacent liquid metal drops, causing them flow together. By moving the electrode touching the flowing liquid metal, we can make the aggregated drops flow/travel together. This phenomenon can be used to transport particles *borne in* liquid metal, to pass through narrow openings, to camouflage by wrapping an object, and to clean by carrying/moving debris. Also, by exciting a different electrode node at capillary channels, liquid metal flows into a different path.

III. Variable-Stiffness Robots, Gripper, Actuator

By changing the surface tension of EGaIn, we can change stiffness. One method I propose is to *interlace* solid layers with a soft capillary channel. When it is not filled with EGaIn, it is a stack of solid sheets on top of one another with a thin channel between them. The channel connects the cathode at the bottom of the stack and the anode at the top of the stack. Upon application of oxidation potential, EGaIn flows into the capillary channel inflating the channel layer by layer. The height of the stack can be controlled by the amount of EGaIn in the channel and determines its stiffness. Another way to control stiffness is by changing the electric potential applied to the liquid metal inside a flexible tube. The stiffness changes with surface tension. We can use the unique rheological behaviour of EGaIn to achieve variable stiffness in many different ways.

IV. Further Applications

- Because it is observed that disturbance induced distortion of EGaIn can be restored at certain potential, we can use well-controlled liquid metal

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drop as a micro gripper to grasp a variety of objects by varying the potential.

- We can also use it to pump or rotate gears in water by oscillating the liquid metal inside a capillary channel.
- We can also use the flowing liquid metal to manufacture wires through a complex shape.

References

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