Programmable Matter: A Microscale, Self-Reconfigurable, Modular Robotic Metamaterial

Patel, Sohi (School: College Park High School)

Material fabrication is an inherently irreversible process, with only a limited number of elements available for use and finite reservoirs of these elements on Earth. Programmable matter, an intelligent material able to assume a variety of structural properties on command, has been made feasible by the recent, rapid microscaling of electronics in industry and is a key contender in the digitalization of fabrication. A modular robotic material, comprising a swarm of identical cubic modules driven by internal circuitry and supported by six electropermanent face magnets each, was designed at the micrometer scale. 50 modules were fabricated by electrodepositing hundreds of layers of copper wires, iron nodes, and cobalt-platinum magnets onto a steel substrate. Each layer was planarized with an epoxy resin dielectric; the wafer was singulated into individual solid-state modules and separated from the substrate for testing. The system exhibited high speed of connection (avg time: 0.12 sec) which scaled proportionally with module amount ($p < 0.00001$). Each module was found to hold 1,000 times its own weight through a magnetic pull procedure. Circuitry was fast and reliable, transferring power and data pulses between modules uninterruptedly and within milliseconds of connection. Self-reconfigurability and route optimization skills were aided by assembly planning algorithms, which were tested in the physical system with 50 modules and in simulations with up to 50,000 modules, exhibiting little deadlocking and zero noncompliance. Programmable matter may contribute impressively to aerospace, military, and industry applications, evolving through future generations of metamaterials into a universal tool.