Programmable Matter II: Optimizing Logical Topology and Automating Manufacture of a Microscale, Self-Reconfigurable Swarm Robotic System

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Millions of application-specific materials are currently in circulation, each with unique extraction, refinement, and synthesis requirements incurring severe environmental and economic costs. Programmable matter, an intelligent material able to assume a variety of structural properties on command, allows for the immediate assembly and reconfiguration of any material or mechanical device from a fixed feedstock input. A modular swarm of microrobots, each supported by electropermanent magnet actuators, was designed and manufactured by electrodepositing layers of copper, iron, and cobalt-platinum through high-precision elastomeric masks with a stepped 3-axis gantry crane. Integrated circuits were designed, testbenched, and fabricated using photolithography and ion implantation. Microrobots exhibited high strength and speed; each held 1,000 times its weight ($p < 0.0001$) and high delay datapaths were allowably removed. Occupying just 1 mm^2 of die space and transferring power and data within milliseconds of connection, circuitry was architecturally optimal and compliant. Application software was programmed to translate 3D CAD models into configuration data and simulate large-scale swarm interactions. In forms of varying size and complexity, less than 0.5% deadlocking and 0% premature energy dissipation was identified ($p < 0.00001$). Self-reconfiguration and route optimization techniques were informed by assembly planning algorithms, which sustained 50 physical microrobots and 100,000 in simulation. The developed programmable matter system boasts high functionality, data-efficient algorithms, and a robust, scalable fabrication process flow; it can contribute impressively to issues in aerospace, defense, and infrastructure as an instrument of instant and autonomous conception.

Awards Won:
Air Force Research Laboratory on behalf of the United States Air Force: Glass trophy and USAF medal for each recipient
Air Force Research Laboratory on behalf of the United States Air Force: First Award of $750 in each Regeneron ISEF Category, FOR 2023 ONLY: EBED WILL HAVE TWO