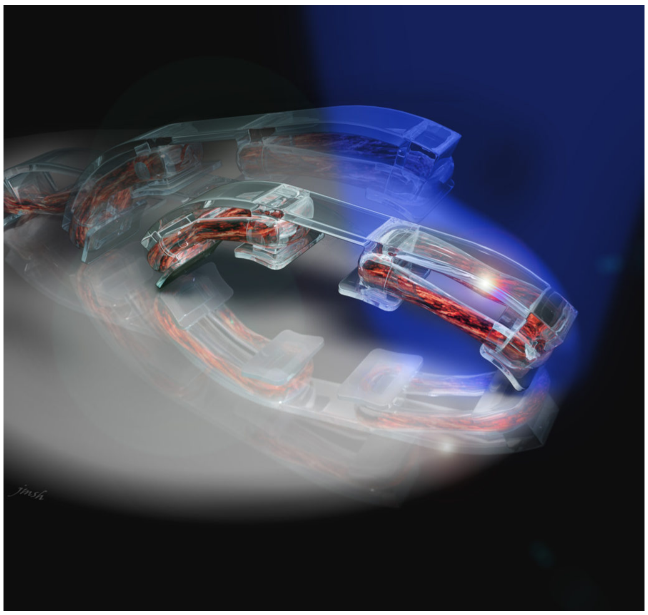
Light-controlled muscle-powered walking biological robots

For centuries, engineers have built with traditional materials, such as woods or metals, which can't dynamically respond to changes in their environment. Intuitively, we know that biological materials can do things synthetic materials cannot. For example, our skin can heal when it is damaged by a cut, and our muscles can get stronger when we exercise. This ability to dynamically adapt to changes in the environment make biological materials much "smarter" and more interesting, motivating the newest generation of engineers to learn how to "build with biology".



Schematic of a two-legged bio-bot composed of a 3D printed skeleton made of a biocompatible polymer (clear) powered by two modular muscle ring actuators (red). Stimulation with blue light leads to contraction of the muscle, leading to controlled locomotion of the bio-bot in the direction of light stimulation. Image credit: Janet Sinn-Hanlon. More information on bio-bots and how they work can be found on the following websites:
http://engineering.illinois.edu/do-the-impossible/biobots/
https://news.illinois.edu/blog/view/6367/338997#image-3

Broadly defined, a robot is a machine that can sense, process, and respond to a range of environmental signals in a controlled manner. A biological robot, or "bio-bot", is a robot that uses biological materials to do one or all of these functions. Using adaptive biological materials could help us build smarter robots that are capable of more complex functions than traditional robots, such as self-assembly or self-healing in response to damage. A bio-bot could, for example, detect a chemical toxin using specialized sensory cells, transmit and process this information through brain cells, walk towards the toxin using muscle cells, and neutralize the toxin using cell-secreted chemicals. This functionality could potentially be used to clean up public water supplies from pathogens, or even extended to medical use by targeting and neutralizing toxins in the human body. We envision that bio-bots can, in the future, be targeted at a wide variety of different applications in health, security, and the environment, and be used to improve human quality of life.

Many robotic applications require the ability to move, which is why we have focused on learning how to build bio-bots that can walk. In the body, force production and locomotion is driven by skeletal muscle. Skeletal muscle contracts when stimulated by an external signal, and contraction across joints produces motion. Taking inspiration from natural biological design, we 3D printed soft skeletons for our robots. These skeletons took the form of a flexible beam (representing a flexible joint in the body) with a stiff pillar at each end (representing tendons that anchor skeletal muscle to bone). To engineer muscle in the lab, we grew mouse skeletal muscle cells and mixed them in a gel containing proteins and biological factors that mimic the native environment of muscle in the body. This cell-gel solution was injected into a ring-shaped mold and, over time, the solution solidified into dense 3D muscle tissue shaped like a rubber band. This muscle rubber band, about 10 mm in diameter, could then be picked up and placed around the flexible 3D printed skeleton, resulting in a truly bio-integrated machine.

By using electrodes to stimulate this engineered muscle with electrical signals, similar to those muscle receives in the body, we could readily control the ability of the the muscle to generate force and visibly contract. Since using electrodes can be fairly invasive, we sought a way to control the bio-bots remotely using a non-invasive stimulus, such as light. Using the novel technique of optogenetics, we genetically engineered muscle cells that could contract in response to blue light. This enabled us to control the contraction of engineered muscle using an LED, and even drive our bio-bots to walk in one direction or another simply by moving the LED. We were also able to make our bio-bots stronger by exercising the engineered muscle using a daily light stimulation regimen. We believe that this study is a fundamental step forward in teaching the next generation of engineers how to use biological materials to build the machines and systems of the future.

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