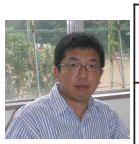
【Grant-in-Aid for Scientific Research (S)】

# Dynamically reconfigurable wet robotics powered by self organization of molecular artificial muscle

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## Purpose and Background of the Research

Microrobots as small as a human hair, ants, microbes have been on demand in a various kinds of application. It is expected to be valuable in narrow spaces where people and conventional robots cannot enter, such as a diagnosis application inside a human body and environmental agricultural monitoring. However, due to a small body structure, it is difficult to integrate and assemble various mechanical parts such as actuators, batteries, and sensors into a small body. In the conventional method, the components of microrobots, such as mechanical structures, actuators, batteries, sensors, etc., are manufactured in different locations and then assembled one by one. This method causes time-consuming and labor-intensive manipulation task and has many limitations. So far, Morishima, has developed a microrobot that uses chemical energy as an energy source without the need for an electrical power source, equipped with a muscle cell-driven bioactuator, based on the idea of using the contractile ability of muscle cells. [(1)] However, it takes several days to culture the muscle cells that work as bioactuators, and assembly is difficult. Therefore, we will fundamentally review the design theory of bioactuators and microrobots so far, more precisely control, more reproducable self-organization process of biomolecular proteins, and architect biological design rules of emergence of structures and functions in nature, and simple manufacturing and production. We have come up with an idea that integrating assembly methods is an important challenge and breakthrough in the development of a small scale robotics field. Our design of architecture in an in vitro environment is based on the processes occurring inside the cells, such as the fusion and differentiation of muscle cells, the self-organization of sarcomere, and the formation of contractile muscle tissue. How can we create a mechanism that generates such a large force on a millimeter scale as a driving source? It would be possible to realize a group of dynamically reconfigurable microrobots based on the design rules for biomolecular motor protein powered artificial muscles using a multiscale microflow process (Fig. 1).

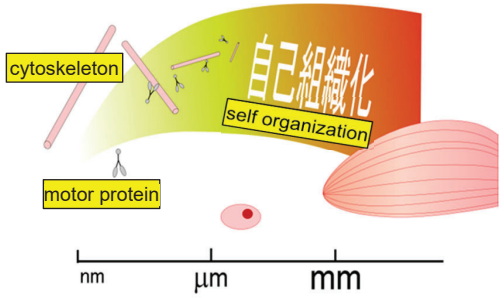


Figure 1. Concept of multiscale self organization of ATP driven bioactuator

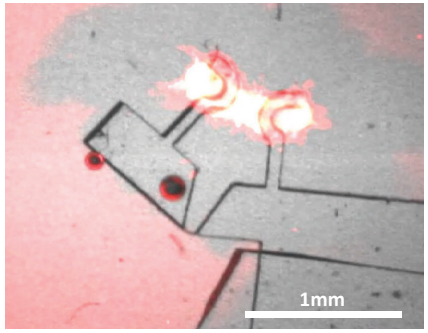


Figure 2. A microscopic photo of contraction of molecular artificial muscle during UV exposure

At the same time, an fundamental "question" was raised up to explore the underlying mechanisms of multi-scale self-organization processes spanning from the molecular scale to the millimeter-scale level, as well as various mechanical motor functions, self-assembly, and self-repair abilities. We have started joint research with the Hiratsuka (research co-investigator) and Nitta (research co-investigator) groups. In this study, inspired by the self-organization process of in vivo systems in nature, based on the biomolecular motor protein that consist of printable biomolecular motors[(2)] that we have researched and developed so far, we will print a muscle from proteins as an actuator and assemble on a body structure from a soft biocompatible gel. We will develop a method for in situ manufacturing microrobots by processing and assembling various component parts in one place. The proposed in-situ assembly method is expected to rapidly produce microrobots one after another.


1. “Atmospheric-operable bioactuator powered by insect muscle packaged with medium, Yoshitake Akiyama, Toru Sakuma, Kei Funakoshi, Takayuki Hoshino, Kikuo Iwabuchi and Keisuke Morishima, *Lab Chip*, 13, 4870-4880,(2013).
2. “A printable active network actuator built from an engineered biomolecular motor”, Takahiro Nitta, Yingzhe Wang, Zhao Du, Keisuke Morishima & Yuichi Hiratsuka, *Nature Materials* vol.20, pp.1149–1155 (2021)


## Expected Research Achievements

The bioactuators that have been realized not only by our group but also by other groups around the world are all driven by ATP chemical energy, but, they use the muscle contraction function of cells, which are the smallest unit of living organisms. However, a millimeter-scale hybrid device in which the precise mechanism generated by the mechanical interaction of biomolecular motors generated inside cells has been integrated and controlled on a large scale in vitro has not yet been realized. In this study, the assembly process itself was artificially controlled in vitro by the concept of 3D printing by microfluidic manipulation and stereolithography. Figure 3 shows a conceptual diagram of in situ flexible production system for dynamically reconfigurable microrobots, which can continuously manufacture a large variety of microrobots in small quantities and integrate and assemble actuators in one place. Understanding the mechanism of the self-assembly process help us mass-produce motor proteins as driving components with high efficiency, and freely assemble them with micro-components, large-scale self-assembled molecular motors. In the future, 3D-printable microrobots made of biocompatible gel with various functions and biomolecular protein motor muscle will be able to stay in the body for long periods of time for sensing and diagnosis, and could provide us advanced health and medical technology. In addition to medical applications, it can be expected to develop innovative energy-saving new principle devices that are fundamentally different from conventional energy-consuming manufacturing.

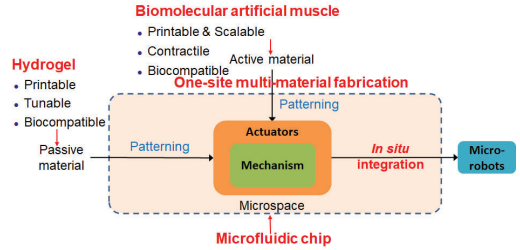


Figure 3. In situ micro robot assembly and integration based on microfluidic lithography and printable biomolecular motor protein artificial muscle


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