# Toward Biorobotic Systems with Muscle Cell Actuators

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**Abstract:** The authors aim to develop muscle cell actuators driven by a photostimulation. Recently, bioactuators that exhibit self-organization have been attracting a lot of attention, because biological devices are expected to have significant abilities such as self-reproduction, self-repair, self-assembly. Based on this consideration, we have developed a myofilament-actuator, where we have utilized effects of a mechanical stimulation to construct the mechanical structure of such a bio-actuator. More specifically, we found that induction of differentiation into myofilament-like cells from a cultured myoblasts C2C12 is promoted under the mechanical stimulation. Under above circumstances, the next step is to find an appropriate method for driving the bio-actuators. To do so, we introduce channelrhodopsin-2(ChR2) which works as both a photoreceptor and an ion channel. Based on the above, we cultured muscle cells embedded with the gene of this protein. Then, we observed that the muscle cell actuator is contracted by a blue light stimulation.

**Keywords:** Biorobotic system, Muscle cell actuator, Mechanical stimulation, Channelrhodopsin-2.

## 1. INTRODUCTION

Living organisms change their bones, muscles and neurons by self-organization in order to adapt to their environment[1]. This process occurs not only at the level of the individual, but also on a cellular level, as prominent functions such as self-reproduction, self-repair and self-assembly. In Cell Biology, Engler *et al.*[2] found that ES cells recognize the mechanical strength of the substrate to which they adhere and in response to the stiffness of the scaffolding, differentiate into bones, muscles or neurons.

However, most state-of-the-art robots are made of metals and semiconductors which are unable to dynamically change physical and chemical characteristics during operation so it is not possible to show the adaptive functionality of structural changes in the body itself. Because of this, to implement a robot with the adaptive functionality of a living organism derived from a mechanical system, robotics and control system technologies need to be combined to achieve a flexible intelligent mechanical system like that of a living organism[3][4][5].

Hence, this study will attempt the creation of a biorobot which expresses the inherent superior characteristics of a living organism with less invasive control method. To do so, we resulted in creation of the structure of muscle cell actuators as an initial stage of development of a biological device for a bio-robot. Using mechanical stimulations that promotes cell differentiation, the design and construction of muscle actuators through self-organization became possible. Then, as the next step, we dealt with how to make the constructed actuators perform movements. In this study, by introducing "photostimulation" and "genetic engineering technology", the construction of muscle cell actuators that allow the drive control at a specific site and with specific timing is attempted in such a way that cell damage is minimized. Specifically, the method of driving the actuators is the protein ChR2, which functions as light-gated ion channel[6] and is introduced into cultured myoblasts so cells can be synchronized to the stimulus pulse of blue light. Thus, unlike the existing technique for creating an electric field, this method drives more than just one particular region and it is expected that the continued operation of the minimally invasive actuator does less damage to cells.

The purpose of this study is development of a muscle cell actuator toward biorobotic systems driven by photostimulations. More specifically, we here report on the deeply interesting experimental results as follows: (1) Creating the muscle actuator; (2) Driving the muscle actuator. The former of which is done by utilizing self-organization induced by mechanical stimulations. In the latter of which, the movement of the channelrhodepsin-2 gene-induced cultured muscle cells were synchronized to the light pulse.

## 2. CREATING THE MUSCLE ACTUATOR

This study intend to deal with a muscle cell actuator, which is made from cultured myoblasts by culturing and differentiating by exploiting mechanical stimulus re-

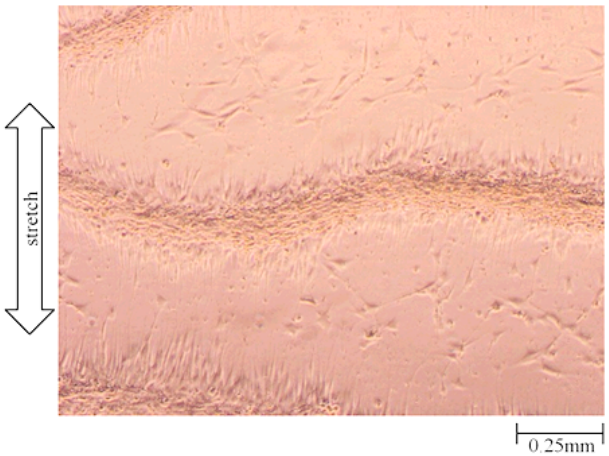


Fig. 1 : Photo of the C2C12 visualized by the microscope. As in the photo, large myofilament-like cells are indicated. This cells are cultured with mechanical stimulations.

sponse of muscle cells. In Cell Biology, recently, it is found that induction of differentiation into myofilament cells from a cultured myoblasts cells(*i.e.*, C2C12). Based on this knowledge, we create the muscle actuator by fully exploiting self-organization induced by mechanical stimulations(see Fig.1).

## 3. DRIVING THE MUSCLE ACTUATOR

Here, the next step is how to drive the muscle cell actuator. To do so, here, we investigated a photostimulation as a driving method. The results of the muscle cell photostimulation application experiment are shown in Fig 2. The distance between two points is shown with time development. The blue band represents when photostimulation was performed. This result indicates that muscle contraction occurred at the times corresponding to the light pulses. In addition, it was confirmed from the chart that around 7% contraction occurred.

## 4. CONCLUSIONS

The main contribution of this paper is development of a muscle cell actuator toward biorobotic systems driven by photostimulations. Utilizing biological devices in real-world situations remains challenging. For example, cells are only capable of surviving in cell culture medium, hence it is necessary to maintain this state by changing the cell culture medium regularly. Also, the current cell culture is 2 dimensional, therefore, for 3 dimensions it is still necessary to consider how to blanket the cells with nutrients and to consider how the individual parts can move in 3D space. For future works, it will be necessary to combine the current actuators with gel or PDMS in 3 dimensions and to also use optical fiber to create a device that can be controlled by pinpoint photostimulation. In the future, not only muscle cells as well as neurons will be used as circuits in biological devices and interaction between muscle cell actuaors and neurons can be verified.

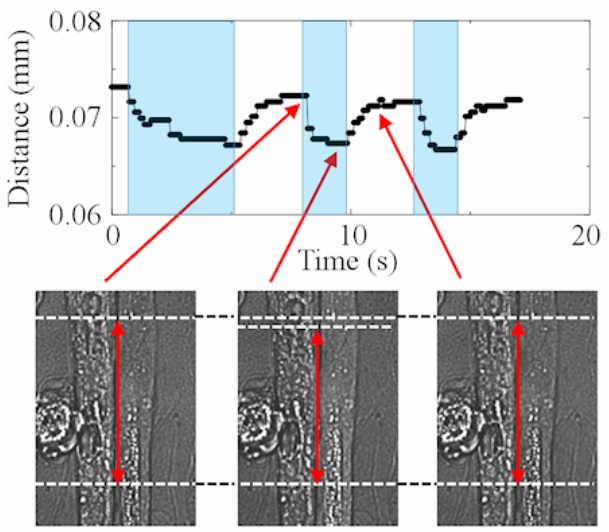


Fig. 2 Time course of a typical contraction of a muscle cell during the photostimulation. The muscle cell is contracting in the vertical direction.

## 5. ACKNOWLEDGMENTS

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