Frog Cyborg Driven by Biological Muscle Actuators That Packaged Physiological Solution

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1 Introduction

Locomotion of an animal is generated through interactions among the nervous system, the musculo-skeletal system and the environment. We particularly focus on bio-machine hybrid systems in order to understand dynamics of these interactions. We can modify balances of the interactions by bio-machine hybrid systems. In this study, we intend to deal with a frog cyborg driven by biological muscles.

Recently, a frog cyborg which enables us quantitative measurement of dynamics of interactions in the aquatic environment was developed to understand the roles of the musculoskeletal system. Richards et al. developed a platform that reproduced foot rotations of an aquatic frog (X. laevis) and mimicked swimming velocity [1,2]. A robotic platform that reproduce a whole motion of an animals is necessary to understand the roles of the interactions between musculoskeletal system and environment [3].

Thus, we focused on coordinated motions of the frog ' s whole leg when the hip, knee, and ankle angle extend simultaneously during swimming. So far, we have developed a frog cyborg Xenopus-noid [4] driven by biological muscles isolated from a *Xenopus laevis*. And, the biological muscles are activated by the electrical stimulations based on the traditional approach [5]. Based on this Xenopus-noid, we have successfully observed frog-like swimming motion by bio-machine hybrid systems approach. However, the biological muscle as a driving source was available under a physiological solution environment only.

Based on above consideration, this study aims at development of a Xenopus-noid driven by biological muscle actuators that packaged physiological solution. Here, the biological muscle actuator consists of a muscle issue, electrodes, physiological solution inside a silicone pack. As experimental results, we observed a new Xenopus-noid can locomote under not only a physiological solution environment but also a natural environment in the air.

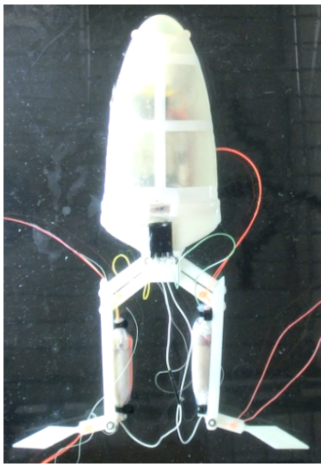


Figure 1: Xenopus-noid developed. This frog cyborg consists a body trunk include electric circuits for control, skeletal structure of legs, and biological muscle actuators.

2 Xenopus-noid Equipped with Packaged Actuator

We developed a frog cyborg Xenopus-noid driven by biological muscle actuators. Figure 1 shows the whole system of Xenopus-noid, which compose a control system, and a musculo-skeletal system. The control system was mounted as micro-controller unit (Edison, Intel), and embedded into a body trunk built with a 3D printer (Connex260, Stratasys). The musculo-skeletal system consists of both legs mechanical structure and biological muscle actuators. Figure 2 indicates the mechanical structure of each leg. We designed the knee mechanical structure as four-link mechanisms so that the leg can kick backward appropriately based on the preliminary observation of a frog swimming (which is not shown in this article). The biological muscle actuator is equipped with a bi-articular muscle of an islolated tissue of plantaris longus muscle, which is known as a muscle produces the most propulsion in swimming of a Xenopus laevis [6, 7]. By contraction of the biological muscle actuator, Xenopus-noid generate kick motion like Fig. 2. The biological muscle actuator (Fig. 3) packaged a muscle tissue, electrodes, physiological solution (Ringer solution) inside a

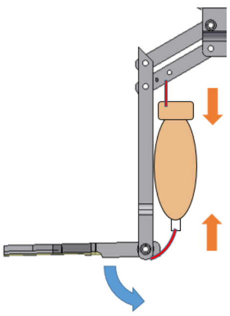


Figure 2: Mechanical structure of each leg. The orange-colored arrow shows contraction of a biological muscle actuator. The blue-colored arrow shows kick motion of a foot.

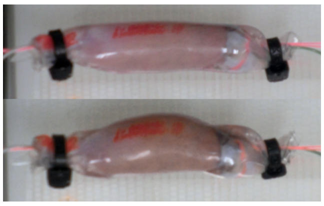


Figure 3: A biological muscle actuator which packaged physiological solution developed. Upper figure shows the natural state of the actuator. And the lower figure shows tetanic contraction by electrical stimulation.

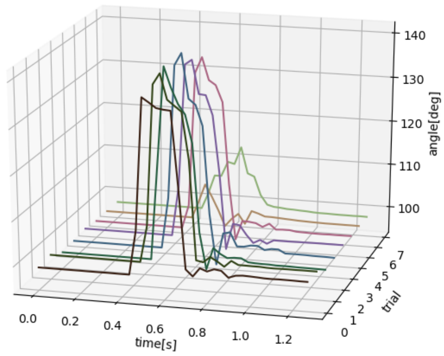
PDMS silicone (Silpot184, Dow corning toray) pack. As in the fig. 3, this biological muscle actuator contract by electrical stimulations.

3 Experimental Results

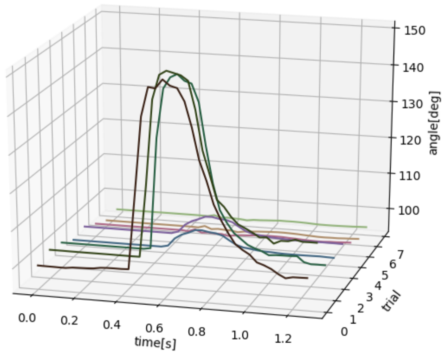
Figure. 4 shows the experimental result which verify the lifetime of the biological muscle actuator that packaged physiological solution. Here, at first, we mount the biological muscle actuator onto the Xenopus-noid body. Secondly, this Xenopus-noid was placed in the air environment. Next, we applied electrical stimulation to the actuators at intervals of 5 minutes. Then, we compared the lifetimes between (a) with-pack and (b) without-pack conditions. Time axis shows time development of each trial. Trial axis shows the trial number of electrical stimulations. As in the figure 4, the lifetime significantly increases in the case of with-pack condition.

4 Conclusion

In this study, we developed a Xenopus-noid driven by biological muscle actuators that packaged physiological solution. As the experimental results mentioned above, we found that the biological muscle actuator with pack increase the lifetime in the air environment. Moreover, we observed a new Xenopus-noid can locomote under not only a physiological solution environment but also a natural environment in the air (not indicated in this article). At the conference, we are planning to conduct demonstration of Xenopus-noid swimming on site.



(a)with-pack condition



(b)without-pack condition

Figure 4: Lifetime of the biological muscle actuator that packaged physiological solution. (a) and (b) show with-pack and without-pack conditions respectively.

Ackowledgment

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