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CHARACTERIZATION OF ANIMAL MUSCLES AS ACTUATORS FOR BIO-MECHATRONIC SYSTEMS

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SUMMARY

Electrically stimulated tibialis anterior muscles from Wistar Albino rats are characterized, i.e., contraction forces are measured for different voltage magnitudes and signal frequencies. Characterization experiments will also be run for muscle plantarus longus of Rana Pipien frogs. A mathematical model will be fit to the findings. The aim of the project is to use these mathematical models to design a live-muscle-actuated mechanical/ mechatronic hybrid system.

INTRODUCTION

Biologically inspired design of mechatronic systems is a promising method of solving complex engineering problems, which may involve developing soft muscle-like actuators [1]. Various materials have been proposed as muscle-inspired actuator systems, although modeling, design, manufacturing, and control of such soft/compliant systems remain a significant challenge. Such synthetic materials should provide high performance and robust service with limited power consumption [1].

On the other hand, integration of biological and mechanical components into hybrid systems is likely to open up remarkable new possibilities. A live muscle used as an actuator may eliminate the need to develop high performance synthetic soft materials in some cases, though in other cases synthetic actuators may be preferable once suitable materials are developed. Hybrid systems, if successful enough, may be the system of choice in solving certain health problems as well as in some energy-efficient engineering systems.

A swimming robot actuated by two frog muscles was built and tested in [2]. The robot remained active for up to 42 hours during which time it performed basic swimming maneuvers. However, significant engineering problems wait to be solved for such systems.

Muscles can be stimulated electrically and chemically though the former seems to be the preferred method for research purposes. The ultimate goal of the present study is to couple live muscles with a mechanical system wherein the engineering problems in question are solved. The interim goal is to compare the performances of the electrical and chemical methods of muscle stimulation. The constraint in the performance study will be that bio-actuation will be part of a mobile bio-mechatronic system not connected to any source. The prerequisite to such an endeavor is to understand and characterize muscles fully. The present paper and the related presentation at the conference will report characterization test results on rat and frog muscles. Findings may also be reported on a novel design of a small mobile bioreactor aimed to keep muscles alive.

METHODS

In the part of the ongoing project reported here, force and velocity characterization of tibialis anterior muscles from Wistar Albino rats under electric stimulation is presented. All muscles were duly extracted under the approval of Yeditepe University Ethics Committee. An apparatus was designed similar to that in [3] for muscle characterization with varying square wave stimulator signal properties such as voltage, frequency and duty cycle. The apparatus allows force measurements for both isometric and isotonic contractions under in-vivo culture conditions.

The present work involves development of a mathematical correlation between stimulation variables such as voltage magnitude and frequency and muscle force. Velocity response of a muscle is also a critical issue governing the design of a muscle-actuated mechanical system. The results will be presented at the congress. Mathematical functions were proposed for muscle behavior in [4].

RESULTS AND DISCUSSION

Table 1 shows three experiments in each of which the indicated voltage is applied four times with a time gap of 22 s in between consecutive applications. The first column gives the number of the contraction. F is the muscle force response in Newtons and F_n is the force normalized with respect to the value of F in the first contraction for each experiment.

Table 1: Muscle forces in N in consecutive stimulations

	6 volt, 90 Hz		2.5 volt, 90 Hz		6 volt, 60 Hz	
contr	F	F_n	F	F_n	F	F_n
1	3,57	1,00	1,26	1,00	0,71	1,00
2	3,33	0,93	1,15	0,91	0,66	0,93
3	2,89	0,81	1,04	0,83	0,59	0,83
4	2,48	0,69	1,01	0,80	0,49	0,69

The table indicates that a higher voltage at a given frequency induces a larger muscle force but causes more fatigue in the muscle. (At 6 V, the muscle force drops to 69 % of its initial value after the fourth contraction while at 2.5 V it drops only by 20 %.) On the other hand, a higher frequency at a given voltage induces a larger muscle force while the muscle gets fatigued to the same level at both frequencies.

It is of interest to determine muscle response to non-uniform voltage stimulation in a single run. Figure 1 shows the results of a run where 2.5 V, 7.5 V and 2.5 V signals are applied for durations of 2 s each, one after the other. Each two-second duration has a rectangular pulse train of 10 % duty cycle at a frequency of 60 Hz. The dense plot shows the excitation signal whereas the single curve shows the muscle response in N. It is observed that the muscle steadily gets fatigued within a fixed-voltage period. The muscle force jumps up or down in parallel with the change in the excitation voltage but the upward change is weaker indicating the limited capacity of a muscle to respond to positive stimulation once fatigued.

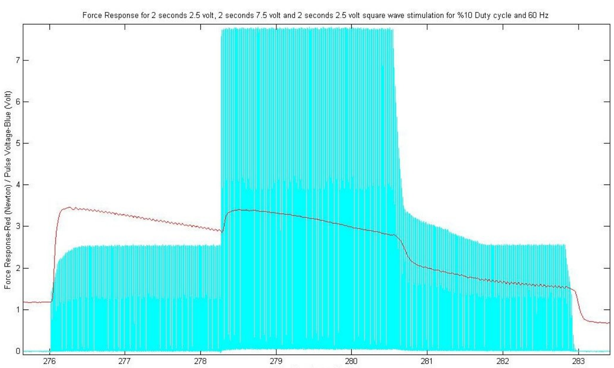

Figure 1: Muscle response to varying voltage stimulation applied consecutively.

CONCLUSIONS

Force response of Wistar Albino rats to electrical stimulation is determined. The same will be done for Rana Pipien frogs. It is found that frequency of the excitation signal affects the force induced in the animal.

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