Modeling and Control of Modular Actuator Arrays

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WHERE DISCOVERIES BEGIN
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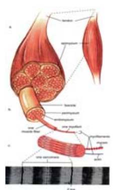
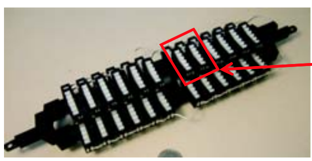
Introduction

Human muscles are composed of thousands of contractile fibers, called sarcomeres. The number of axons in a given muscle group varies, but there are many inputs that correspond to a given degree of freedom. We call this redundant actuation. The cellular actuator is an actuator for robotic applications that is conceptually similar. Bundles of cellular actuators move robotic devices by deforming their own structure and have multiple inputs per degree of freedom.

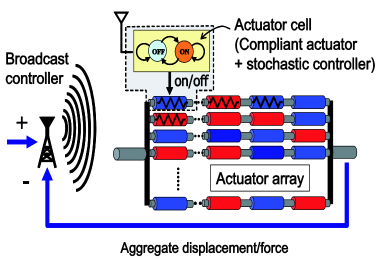

Human muscle


Stochastic Actuator Array

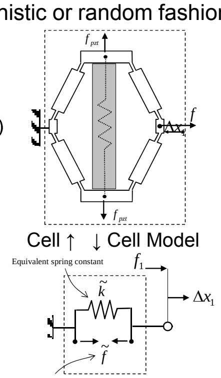

Individual Cells

Modular Actuators

The actuator arrays are built from small actuator cells with structural elasticity. These cells are controlled in a bistable manner. The ON-OFF control approach overcomes hysteresis problems in actuator materials by pushing the state towards either fully contracted (ON) or relaxed (OFF) state. The structural elasticity allows the cells to be combined into complex arrays and for the resultant array to appropriately interact with the environment. Recruitment of actuator units can be performed either in a deterministic or random fashion.



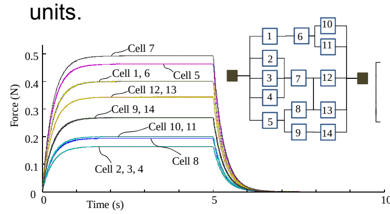
Stochastic Recruitment Technique



Cell ↑ ↓ Cell Model

Array Dynamics

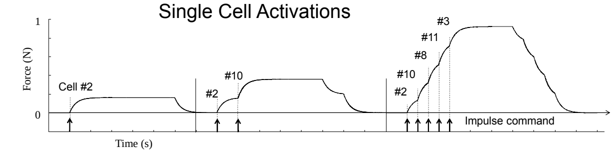
Biological muscles are non-continuous and non-uniform; muscles consist of several types of muscle tissues with different levels of contractile speed and fatigability . Actuator cells can be arranged into complex topologies giving a wide range of strength, displacement, and robustness characteristics. A non-uniform actuator array can generate different levels of force by non-uniformly connecting actuator units.



Single Cell Activations

&1	&1	&E	&10	&1	&6	&8	&1F
5	1	1	2	2	2	1	-1
0	0	0	0	0	0	0	-1

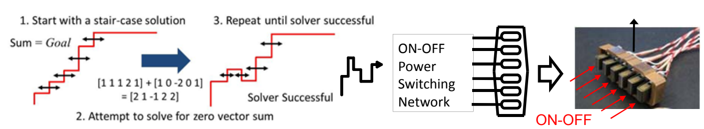
Actuator Array Fingerprint [1]



Twitch to tetanus: a series of stimuli closely spaced results in developing a larger force

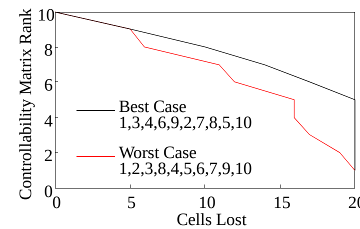
ON-OFF Command Timing Modulation

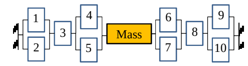
Minimum-switching discrete-switching vibration suppression shown [2] is an open loop technique for point to point motion for quantized systems that results in reduced residual vibration. The initial results showed that an appropriate modulation of switch timings provides better controllability of modular actuator arrays with quantized inputs than by using un-modulated inputs. The intersample quantization combines a discrete time closed loop controller with a mapping from a continuously variable control signal to a switching signal between neighboring discrete values.



Controllability/Robustness

The robustness of a dynamic array can be analyzed by studying the controllability of the array as cells become unusable. The order of cell loss affects the controllability, however the best, worst, and mean cases can be used to compare array profiles.

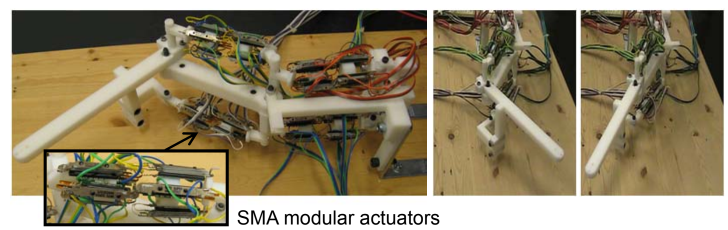




Agonist Antagonist

2-Joint Robotic Arm

A two-degree-of-freedom robot arm driven by antagonist modular adulator arrays has been developed. The arm is to reproduce movements in the horizontal plane created by the shoulder and elbow joints. Nano Muscle (® MIGA Motors Company) SMA actuators were adopted. A single array, an array of 8 cells, is configured to have 4 pairs of cells in series. Analog MOSFET drivers restricted to be either ON or OFF control the SMA actuators to realize the bistable control.


SMA modular actuators

References

[1] MacNair, D. and Ueda, J. David MacNair and Jun Ueda, A Fingerprint Method for Variability and Robustness Analysis of Stochastically Controlled Cellular Actuator Arrays, *The International Journal of Robotics Research*, Volume 30, Issue 5, pp. 536 - 555, April 2011.
[2] Schultz J.and Ueda, J. Experimental Verification of Discrete Switching Vibration Suppression, *IEEE/ASME Transactions on Mechatronics*, in Press.



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