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Pulse Modulation in Braided Pneumatic Actuators Mimics Contractile Behavior of Biological Muscles

Portland State UNIVERSITY

AGILE & ADAPTIVE ROBOTICS LABORATORY

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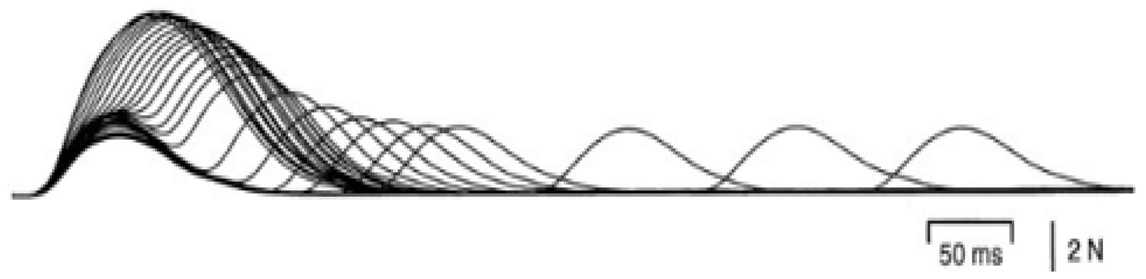
Abstract

Advancements in robotics and bioengineering have steered toward the emulation of biological muscle systems with robotic actuators to achieve a synthesis of mechanical strength and biological adaptability. One area that has been the subject of relatively few investigations, however, is mimicking the pulse-like control of muscles. Muscles contract in response to action potentials generated in motoneurons. Previous investigations have found that muscle contractile force is highly dependent on the timing between action potentials. This study investigates the influence of pulse lengths and the inter-pulse gap on the performance of braided pneumatic actuators (BPAs), devices characterized by their nonlinearity and dynamic response akin to biological muscles. Our research hypothesizes that pulse-based control strategies used in artificial muscles will closely resemble the same force dependence on inter-pulse intervals that is seen on biological muscles. We present an analysis of the maximum force output of BPAs as a function of pulse length and pulse timing, illustrating a discernible pattern of force augmentation related to pulse durations and inter-pulse gap. The pulse length tested were 10, 15, 20, 25, 30, 35, and 40 ms, In these tests, two pulses were provided to the artificial muscles with varying inter-pulse intervals, ranging from 1 ms to 500 ms. The force and pressure in the muscles was recorded during the pulses. The corresponding max recorded forces were 71, 105, 136, 158, 182, 204, and 205 N. When these max forces were normalized by the force the muscle produced under one pulse, The max forces were 3.55, 3.38, 3.16, 2.63, 2.52, 2.41, and 2.2 , respectively. Our findings suggest that using artificial muscles with a bioinspired pulse-based control scheme may provide increased biomimetic capabilities when compared to other control schemes, with the maximum force being recorded with a pulse gap interval of approximately 27 ms, regardless of the pulse duration.

Introduction

In nature, muscles contract when they receive signals from the nervous system that cause their fibers to shorten, pulling on bones and creating movement. In the study by Griffin et al. , they explored how electrical pulses can be used to stimulate muscle contractions, specifically in muscles that are paralyzed due to spinal cord injuries. They discovered that a specific pattern of quick pulses of electricity followed by short pauses maximized the force of muscle contractions.



50 ms 2-pulse train force results from a paralyzed thenar muscle.

Braided Pneumatic Actuator

Recent advancements in the field have underscored the potential of human muscle activation patterns to enhance the functionality of braided pneumatic actuators (BPAs). These actuators, noted for their nonlinearity, hysteresis, and time-varying behaviors, necessitate sophisticated control strategies that can emulate the adaptability and precision of biological muscles

References

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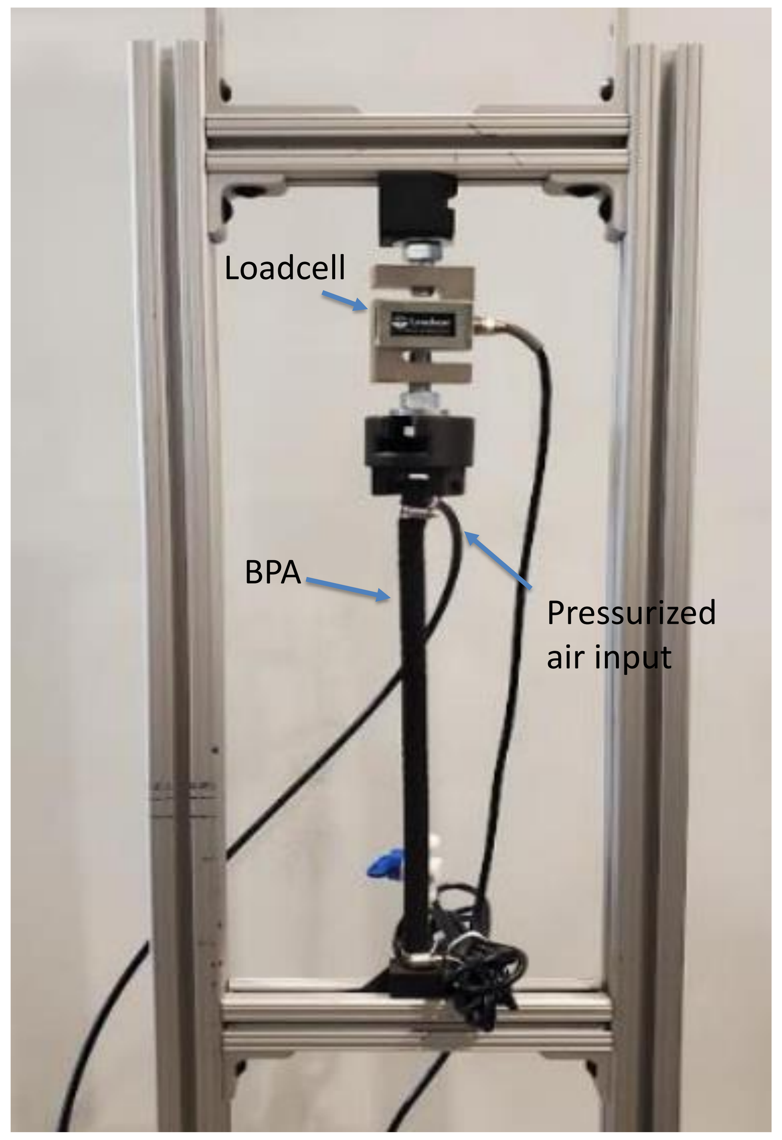
Experiment

The experimental apparatus consisted of braided pneumatic actuators (BPAs) connected to a controlled air supply that could vary the pulse length and inter-pulse gap. Loadstar RAS1 S-beam force sensors were attached to the BPAs to measure the output force in Newtons (N). Pressure sensors were placed parallel to the BPA to confirm pulse pressure. The structure, as shown in Figure 2, consists of T-slot bars holding a S-beam load cell connected to one end of the BPA. The sensor readings and control of the valves were implemented with the use of an Elegoo Uno R3 board and Arduino coding, and the data processing was implemented with the use of MATLAB. The load cell data was calibrated to be zero force while the setup was at rest, and all reported force values are in reference to this no-load force.

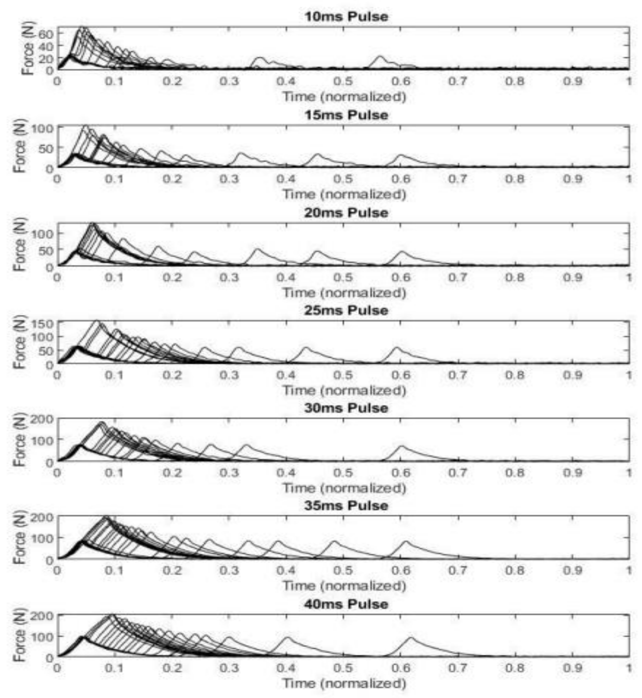


Testing structure holding the BPA. The artificial muscle, long tube in black, is secured using 3D printed parts to the bottom of the frame and an S-shaped load cell for force data collection.

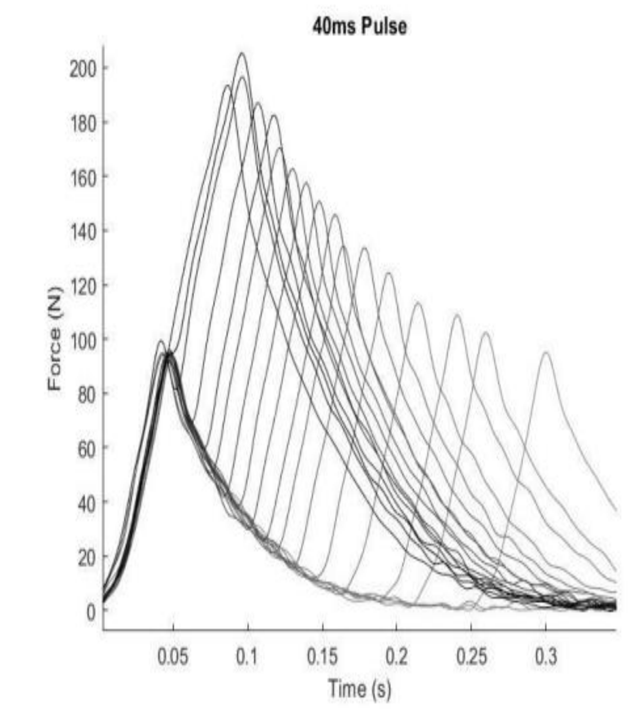
The braided pneumatic actuators (BPAs) were subjected to air pulses of varying lengths: 10, 15, 20, 25, 30, 35, and 40 ms

Results

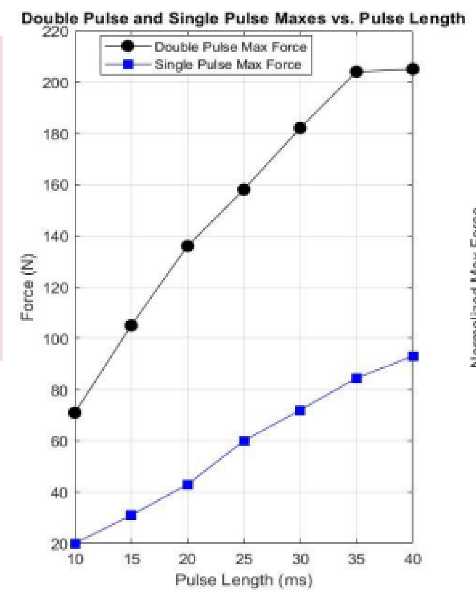
For the pulse lengths of 10, 15, 20, 25, 30, 35, and 40 ms, the corresponding max recorded forces were 71, 105, 136, 158, 182, 204, and 205 N. When these max forces were normalized by the force the muscle produced under a single pulse, The max forces were 3.55, 3.38, 3.16, 2.63, 2.52, 2.41, and 2.2, respectively.



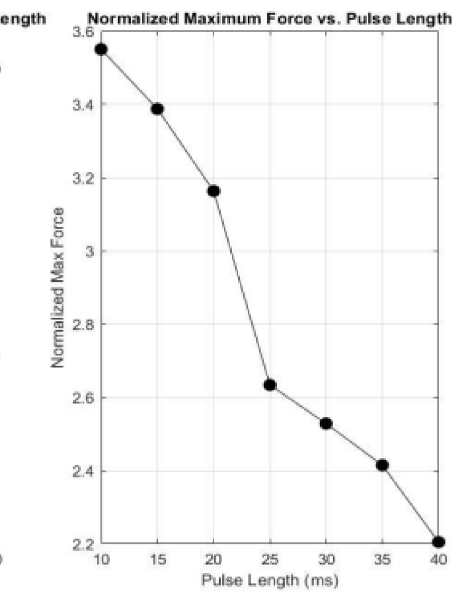
Force vs. time graph following the decreasing length of time between pulses for all pulse lengths



Close up of the force vs time graph of the 40ms pulse lengths



Single pulse and double pulse maximum outputs vs pulse length.



Normalized maximum force output vs corresponding pulse length

Conclusion

In conclusion, our study underscores the potential of bio-inspired pulse modulation in advancing the design and functionality of pneumatic actuators. As we continue to bridge the gap between biological inspiration and robotic application, the insights from this research will undoubtedly play a role in shaping the future of soft robotics, paving the way for more adaptive, efficient, and capable robotic systems