DEVELOPING A ROBOTIC MUSCLE SPINDLE FOR BIOROBOTICS AND BASIC SCIENCE RESEARCH

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http://rcs.ee.washington.edu/brl/devices/spindle

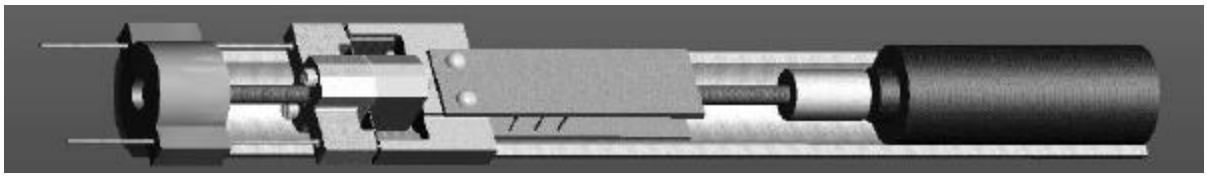

Figure 1: CAD Drawing of the robotic muscle spindle

Introduction

Researchers in biorobotics are developing structural models of biological systems on robotic hardware. These models offer the potential for gaining insight into biological mechanisms through the process of physically implementing biological theories in hardware. Further, such devices offer novel technologies for the fields of prosthetics and engineering. Extending work by Pierre-Henry Marbot[6], we present such a sensor based on the muscle spindle, a mechanoreceptor which transduces the length and velocity of an extrafusal muscle. Our objectives are:

1. To develop engineering hardware with performance sufficient to match the experimentally observed behavior of the core components of the muscle spindle, and
2. To create an integrated robotic model capable of reproducing the muscle spindle behavior.

Methodology

Based on experimental data from the muscle spindle literature[2,3], we developed performance specifications for each of the three core components of the muscle spindle: mechanical position filtering, transduction from stretch to voltage, and encoding of voltage as a frequency modulated spike train. We designed and built robotic hardware, Fig. 1, to meet each of these specifications: a lead screw based linear actuator, a two-thousandths thick strain gaged cantilever, and a Voltage Controlled Oscillator circuit[5].

Aspects of the muscle spindle's behavior not captured in the mechanical and electrical properties of the robotic hardware were added in control software[4], including an intrafusal muscle model from the Schaafsma muscle spindle model[7].

Model parameters were tuned against five metrics from the biological muscle spindle literature describing muscle spindle response to ramp and hold inputs: mean, peak, dynamic index, time domain response[1] and sensory region displacement[2]. Parameters were tuned only when justified based on experimental evidence from the biological literature or redundancy between software and hardware parameters.

The completed model was validated against an additional five experiments obtained from the muscle spindle literature. Validation experiment protocols included position inputs (ramp and holds and sinusoids) and gamma motorneuron inputs.

Results

Engineering Components: The mechanical filter exhibits the desired step response, Fig. 2, with a 26 msec rise time, 54 msec settling time, 9.2% overshoot, and 6.8×10^{-3} in steady state error. The combined transducer and encoder systems possess

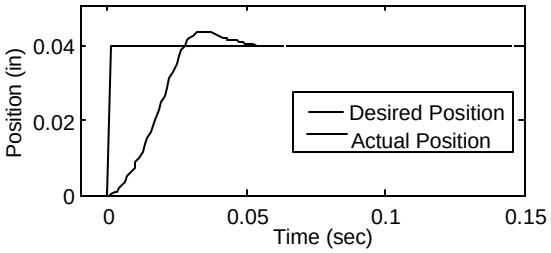

Figure 2: Step response of linear actuator

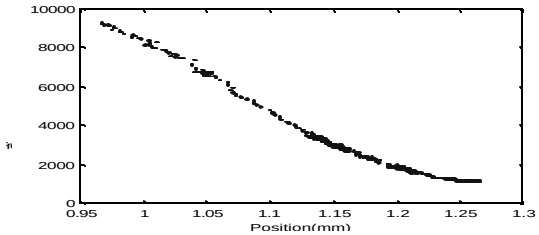

Figure 3: Transducer length-frequency response

the desired linear response to all but extreme displacements with a linear sensitivity of 34nm/Hz and maximum resolution of 0.66μm. The encoder maps the millivolt potential to a 1150Hz to 12.5kHz frequency range.

Biological Model: Figure 4 shows the results of tuning the robotic muscle spindle behavior against the biological muscle spindle's time domain response to a ramp and hold position input. The robotic data (black) closely corresponds to the biological data (gray) under all levels of gamma motorneuron stimulation. Note that in the biological data from the muscle spindle literature the x-sweep rate of the recording oscilloscope was a function of position during the ramp (black bar).

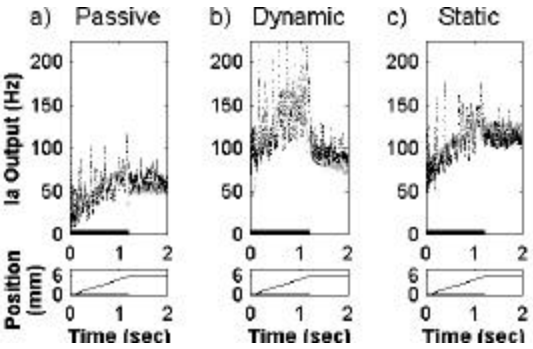

Figure 4: Comparison of Ia responses (top graph) during ramp and hold input (bottom graph). Robotic muscle spindle response (black) very closely reproduces cat soleus muscle spindle response (gray, Crowe et al. 1964[7]) under varying γmn levels ((a) 0 Hz dynamic, 0 Hz static (b) 70 Hz dynamic, 0 Hz static (c) 0 dynamic, 70 Hz static).

Hence the time scaling only applies to the hold region. We have replicated this in plotting the robotic data to allow direct comparison of the results. Major features of muscle spindle behavior reproduced include (a) position gain, evident in the ramp's slope as well as the hold magnitude, and (b) velocity gain, evident in the size of the offset during the ramp.

Discussion

We have successfully met both objectives in developing a biorobotic model of the muscle spindle. First of all, our robotic subsystems reproduced the performance requirements of the three major components of the mammalian muscle spindle in robotic hardware. Secondly, the integrated muscle spindle model captured the major elements of the behavior of the mammalian muscle spindle. Applications for this biorobotic model include addressing basic science questions in motor control as well as investigating the potential for such an actuated sensor in prosthetics and engineering applications.

References

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Acknowledgements

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