UltraTimTrack: a Kalman-filter-based algorithm to track muscle fascicles in ultrasound image sequences

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Summary

The biomechanics and energetics of human movement depend on skeletal muscle architecture and its changes during muscle contraction, which are difficult to assess in vivo. Changes in muscle architecture may be estimated by tracking muscle fascicles in ultrasound image sequences, but this remains a time-consuming process because existing tracking algorithms require manual drift- and/or noise corrections. We therefore developed an algorithm that tracks fascicles without drift and with low noise for a range of conditions and image acquisition settings. The algorithm performed well in comparison with state-of-the-art algorithms, as indicated by measures of noise, drift, deviation from manual tracking, and processing time.

Introduction

Brightness-mode (B-mode) ultrasound is a valuable tool to non-invasively image skeletal muscle architectural changes during movement, but automatically tracking muscle fascicles remains a major challenge. This is because existing fascicle tracking algorithms either require time-consuming drift corrections or yield noisy estimates that require further post-processing. We therefore aimed to develop an algorithm that tracks fascicles without drift and with low noise across a range of experimental conditions and image acquisition settings.

Methods

We applied a Kalman filter to combine fascicle length and fascicle angle estimates from existing and openly available UltraTrack [1] and TimTrack [2] algorithms into a hybrid algorithm called UltraTimTrack [3]. We applied this hybrid algorithm to ultrasound image sequences collected from the human medial gastrocnemius of healthy individuals (N=8, 4 women), who performed cyclical submaximal plantar flexion contractions or remained at rest during passive ankle joint rotations at given frequencies and amplitudes whilst seated on a dynamometer chair. We quantified each algorithm's tracking accuracy, noise, and drift as the respective mean, cycle-to-cycle variability, and accumulated between-contraction variability in fascicle length and fascicle angle.

Results and Discussion

The proposed algorithm yielded low-noise estimates like UltraTrack and was drift-free like TimTrack (Fig. 1) across the broad range of conditions we tested. Over 120 cyclical contractions, fascicle length and fascicle angle deviations of UltraTimTrack accumulated to 2.1 ± 1.3 mm (mean ± s.d.) and 0.8 ± 0.7 deg, respectively. This was considerably less than UltraTrack (67.0 ± 59.3 mm, 9.3 ± 8.6 deg) and similar to TimTrack (1.9 ± 2.2 mm, 0.9 ± 1.0 deg). Average cycle-to-cycle variability of UltraTimTrack was 1.4 ± 0.4 mm and 0.6 ± 0.3 deg, and was similar to UltraTrack (1.1 ± 0.3 mm, 0.5 ± 0.1 deg) and less than TimTrack (3.5 ± 1.0 mm, 1.4 ± 0.5 deg). Further, UltraTimTrack was less affected by experimental conditions and image acquisition settings than its parent algorithms. It also yielded similar or lower root-mean-square deviations from manual tracking for previously published image sequences (fascicle length: 2.3 – 2.6 mm, fascicle angle: 0.8 – 0.9 deg) compared with a recently proposed hybrid tracking algorithm [4] (4.7 mm, 0.9 deg), and the recently proposed DL_Track algorithm [5] (3.8 mm, 3.9 deg). Furthermore, UltraTimTrack's processing time (0.2 s per image, Intel Core i7-10700 CPU @ 2.90 GHz) was at least 5 times shorter than that of recently proposed algorithms (hybrid tracking: 1.0 s per image, DL_Track: 1.7 s per image).

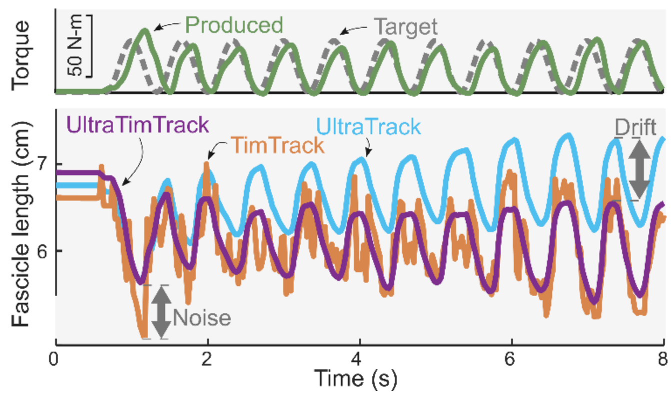

Figure 1: First 8 s of fascicle tracking for 120 cyclical contractions.

Conclusions

We developed a Kalman-filter-based algorithm to improve fascicle tracking from B-mode ultrasound image sequences. The proposed algorithm provides low-noise, drift-free estimates of muscle architectural changes that may better inform muscle function interpretations for human movement.

Acknowledgments

This work was supported by the Deutscher Akademischer Austauschdienst (DAAD, No. 57588366).

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