Automatic Real-Time Tracking of Soleus Muscle Fascicles

By Connor Williams, Dr. Leia Stirling, Dr. Paul Pridham

ENGINEERING
HONORS PROGRAM
UNIVERSITY OF MICHIGAN

Introduction

- Ankle exoskeletons (Fig. 1) can support walking and running in people, but multi-use control algorithms haven't been perfected.
- Energy usage in calf muscle cells can be modeled with muscle fascicle length and velocity information and can be used to control ankle exoskeletons, potentially in multiple scenarios [1].
- In ultrasound image sequences, fascicles appear as dark spaces parallel to light diagonal lines that terminate at aponeuroses (Fig. 2).
- These images are very difficult to process because of noise, differences across leg architecture, and differences in image quality.
- Previous fascicle tracking attempts feature either heuristics [2], affine optical flow [3], or deep learning [4].
- These approaches each have their own limitations which prevent their use in real-time applications such as processing rate, drift, and image quality sensitivity.
- This project explores combining approaches and assesses their performance.

Fig. 1: Ankle exoskeleton [5]

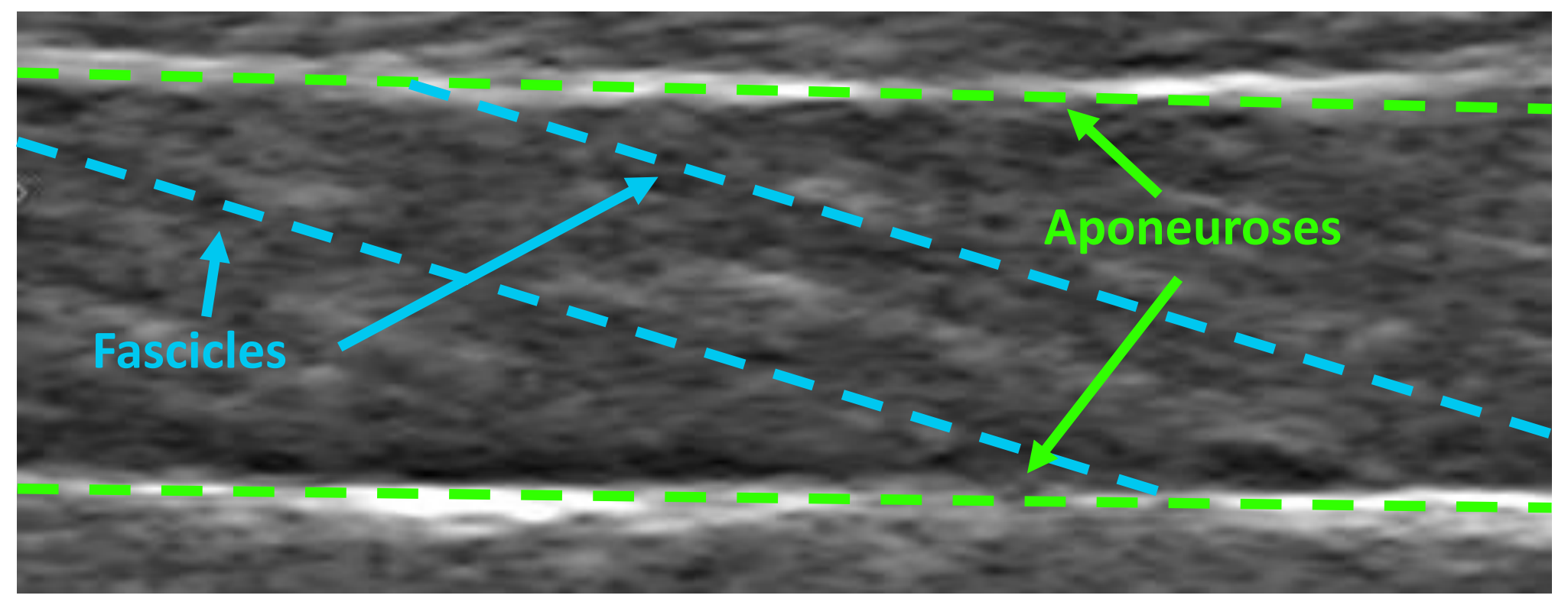


Fig. 2: Ultrasound image of the soleus, adapted from [4].

Methods

Challenges:

- Affine flow approaches are prone to drifting.
- Heuristic approaches can jitter, introducing large amounts of noise.

Algorithm approach: Balance strengths and weaknesses of approaches.

1. Track endpoint positions using affine flow (reduce jitter).
2. Detect aponeuroses with a heuristic, approximate them as lines.
3. Constrain affine flow output to aponeurosis lines (reduce drift).
4. Filter length output with a 4Hz low-pass Butterworth filter.

Endpoint constraints:

- **Line constraint:** move the endpoint to the nearest aponeurosis.
- **Line region constraint:** move the endpoint to the nearest aponeurosis if it has drifted more than 10 pixels away.

Data: We used two ultrasound videos recorded at 60FPS of people walking for ~24 seconds, obtained from [4].

Metrics: The following metrics were used for analysis:

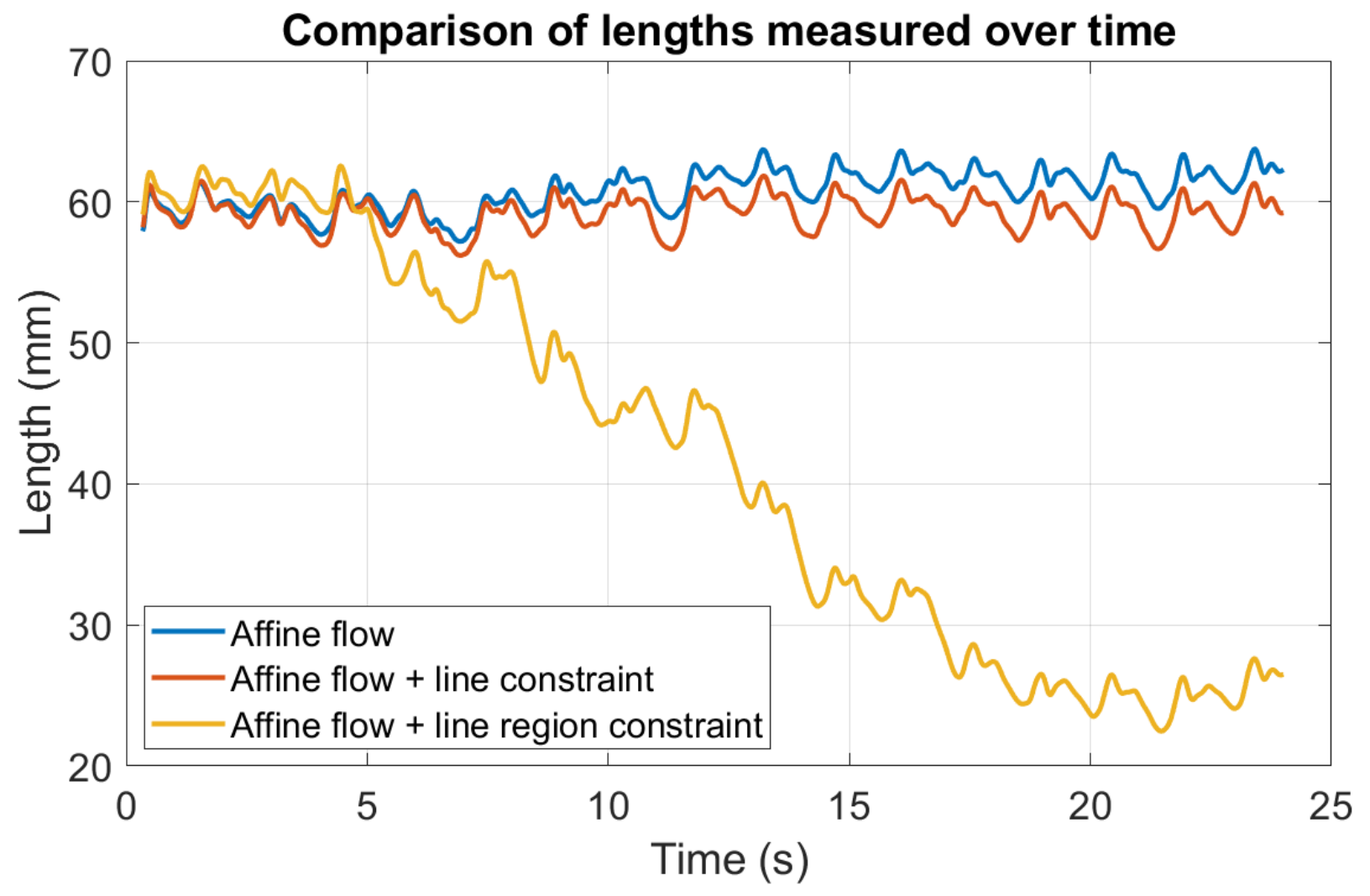
- **Frames per second (FPS, Hz):** Processing speed, used to evaluate real-time feasibility.
- **Drift (mm):** The difference in fascicle length between the first and last steps when the toe pushes off the ground.

Results

- Affine flow operates faster without the constraint step in both videos.
- Affine flow with no constraints operates with similar processing speed in both videos, but the processing speed for algorithms with constraints is ~28FPS lower in Video 2 than in Video 1.
- The line region constraint reduces drift the most in Video 2 but performed the worst in Video 1.
- No algorithm completely eliminated drift in Video 2.

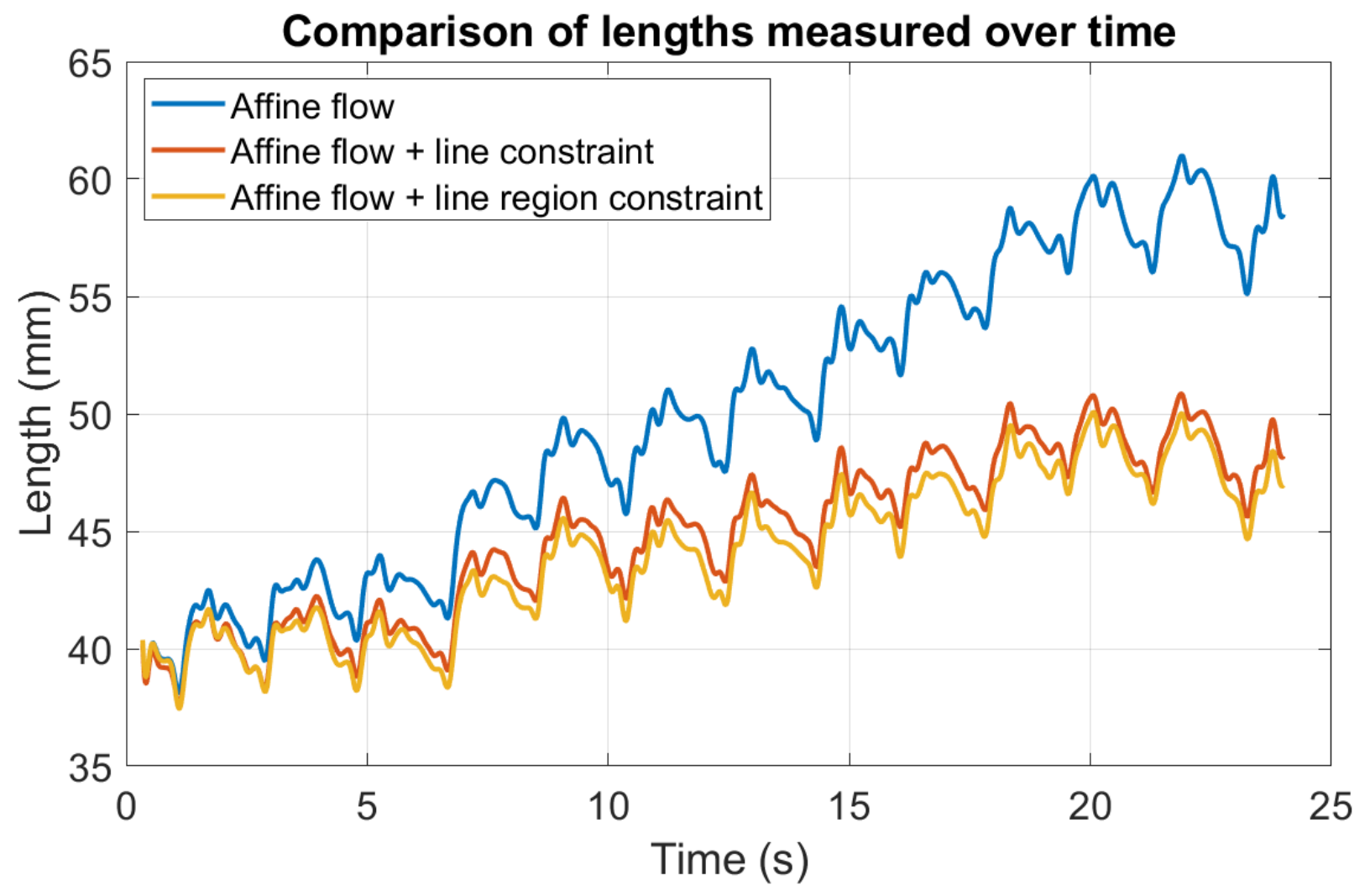
Video 1 Results

Algorithm	FPS	Drift
Affine flow	**216**	2.2
Affine flow + line constraint	104	**-0.5**
Affine flow + line region constraint	101	-35.3



Video 2 Results

Algorithm	FPS	Drift
Affine flow	**217**	17.0
Affine flow + line constraint	77	8.0
Affine flow + line region constraint	73	**7.2**



Discussion

- As shown by the line region constraint's drift in Video 1, these constraints may not work in all situations.
- These constraints only keep the fascicle endpoints near the aponeuroses. They do not prevent drift along aponeuroses, which caused the divergence in the line region constraint in Video 1.
- The line constraint reduced drift in both videos, producing similar or better results than the line region constraint.
- Because no algorithm mitigated drift in Video 2, these constraints are likely not sufficient for general use.
- The processing speed difference in constrained algorithms indicates that performance depends on the video.
- All algorithms operated at a higher framerate than the speed at which the videos were recorded (60Hz), which is promising for real-time exoskeleton use.

Limitations

Data analysis

- We did not assess the accuracy of the output against a ground truth. Hand-labeling is ongoing for comparison to a ground truth.
- While UltraTrack, a software for semi-automated fascicle measurements [6], is currently the most supported method for labeling data without professional examination [7], we did not use it for comparison because its underlying algorithm is also affine flow. This would have been comparing an algorithm against itself.

Exoskeleton use

- Video 1 and Video 2 were selected because the algorithms could run on both without alterations between them. The aponeurosis detection expects to find aponeuroses within a specific region, and if a person has calf muscles of significantly different shape or size from these videos, it cannot detect them.
- This algorithm depends on an initial fascicle, which was entered manually. For the exoskeleton control algorithm, it would be ideal for the initialization to be automatic.
- These algorithms ran on a laptop with an Intel 8th Gen. i5 CPU and an NVIDIA GTX 1050 GPU. Exoskeletons typically require lightweight hardware, which may not yield the same performance statistics.

Conclusions & Future Work

- The line constraint reduced drift found in affine flow, demonstrating potential for future drift mitigating strategies.
- More work must be done to reduce the computational complexity of the algorithm, allowing use on small exoskeleton hardware.
- A large set of accurately-labeled comparison metrics would ensure that the output is correct and usable.
- Once a functional fascicle measurement algorithm has been created, we can integrate it into the untested exoskeleton control algorithm proposed in [1] to see its effects on wearers.

References

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