Comparing Algorithms for Real-Time Toe-Off and Initial Contact Detection in Prosthetic Technology

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Semi-active prosthetics aim to mimic the passive mechanical properties of the biological ankle and offer benefits such as low cost, low weight, and greater adaptability compared to active devices and versatility compared to passive prosthetics. The goal of this research is to develop an adaptive algorithm to perform real-time gait phase determination using readings from an inertial measurement unit (IMU) on the shank, and evaluate its phase detection latency in comparison to two established algorithms [1,2]. The algorithm is designed to use sensors that can be built into the prosthesis for convenience. This abstract describes a work in progress that will be updated for the conference poster.

Selection of Algorithms: Our proposed algorithm will be compared to the delays of detecting gait events reported in two well-established algorithms from the literature [1, 2]. Since their code is not publicly available, we will aim to replicate their experimental setup and compare our latency of gait event detection with theirs. The objective is to determine the effectiveness of our techniques in detecting TO (toe-off) and IC (initial contact).

Data Acquisition: Ten participants will walk on a flat surface for about 50 meters in four self-selected speed conditions: slow, normal, fast, and varying speed. The participant's right shank will have an IMU attached, while force-sensitive resistors (FSR's), will be affixed to the heel and toe of the shoe to definitively measure IC and TO timing.

Evaluation Metrics: We will evaluate the algorithms based on the latency in detection of IC and TO events from the shank IMU, using IC and TO detected by the FSR's as a reference. A positive signal on the heel FSR indicates IC, while a drop in signal from the toe FSR indicates TO. The time between the actual occurrence of these events and their detection by the IMU algorithm will be used to determine the latency.

Algorithm: Our real-time gait phase determination algorithm tracks swing and stance cycles based on the sagittal-axis angular velocity measured by the IMU. Our algorithm tracks four features: maximum peak, initial contact trough, stance peak, and toes off trough, with tracking restarting once the maximum peak threshold is triggered in each swing phase. We wait for the negative threshold to be reached for initial contact before recognizing it as IC, then wait for the stance peak threshold. To recognize the TO event, we wait for the signal to drop below and rise above the toe-off threshold. We calculate the stance time average to avoid error due to noise, and we continuously adapt the thresholds as a function of the average of recorded peaks in the last three steps. We plan to experiment with other ways of determining thresholds, so the algorithm is not yet finalized. The algorithm requires a calibration step and dynamically adjusts thresholds as the person walks, accommodating variability in walking speed and pattern.

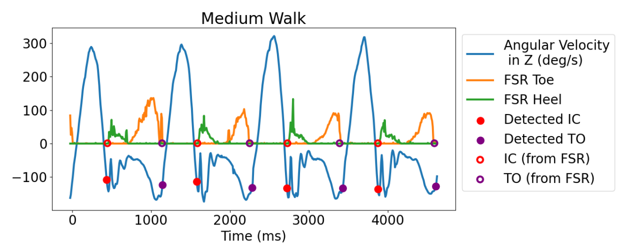

Figure 1: Line graph of angular velocity, FSR signals, and detected IC and TO for a medium speed walk.

We have obtained some initial data for medium speed walking and are continuing to collect data for fast, slow, and variable-speed trials. Our data in (Figure 1) reveals a commonly reported angular velocity pattern that is consistent with previous studies [2]. Furthermore, the FSR data reveal a consistent pattern between the swing and stance phases. The peaks of the angular velocity data correspond to swing phases, indicated by no FSR signals. Conversely, during other times, the FSR detects some level of signal as the foot enters the stance phase.

The preliminary results (Figure 1, excerpted from a short 10 m trial) show IC and TO detection for medium walking speed. In a 50 m medium speed trial, the algorithm achieved 9.75 ms for IC latency and 25.475 ms for TO latency. This is in range compared to the reported values in literature of 2.9-10.2 ms optimal IC latency with accelerometers [1], 10.7 ms IC latency with angular velocity [2], and -7.6 ms TO latency with angular velocity [2]. In the future, we plan to investigate the implementation of filters, auto-regressive detection, and adding other IMU signals to improve our delay; conduct testing on individuals with different walking gaits and speeds; and optimize the detection algorithm for the special control needs of semi-active prostheses (avoiding late IC or early TO).

[1] Hanlon et al 2009, Gait & posture, 30(4), 523–527.
[2] Maqbool et al 2017, TNSRE, 25(9), 1500–1509.