Fast Trip Detection Using Continuous Wavelet Transform

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I. Introduction

Tripping is a major cause of falls among elderly responsible for up to 53% of all falls. Trip-induced falls and inappropriate pre-impact balance recovery are responsible for up to 11% of all serious injuries [1]. A first step towards mitigating trip-induced falls is to obtain information about trip occurrence. The majority of studies conducted on trip and fall detection used inertial measurement units (IMUs) as prime data source with the fastest reported detection time of 359ms [2]. It is important to acknowledge that the majority of results in the fall detection literature present a pre-impact leading detection time (i.e., time elapsed from fall detection to body-ground impact) and not a trip detection time (i.e., time elapsed from trip onset to trip detection). Therefore, the objective of this study is to provide a fast trip detection algorithm using a single inertial wearable sensor that can detect trip perturbation faster than the human reaction time (~200 ms).

II. Methods

Two young adults participated in this study. A single IMU sampled at 50 Hz frequency was fixed on the participants' lower back. The subjects were instructed to walk along a 10 m walkway at normal speed. An inelastic rope was hooked to a load cell mounted on the participants' heel used to trigger and determine trip onset, defined as when the exerted force exceeded 12 N threshold. Trip was induced using a solenoid-cam cleat rope restriction system to stop the trailing foot during the swing phase of a gait, see Figure 1-a. A total of 30 trip trials were conducted with trip induced at different swing phase portions. The collected data were post-processed. A signal frequency decomposition algorithm called continuous wavelet transform (CWT) was used to identify timing of the gait perturbation using the lower back angular acceleration ($\ddot{\theta}$) in a sagittal plane, which was obtained by numerically integrating the angular velocity measurements. Signal $\ddot{\theta}$ (of length N) was compared to a reference trip signal ψ (of length M) approximated as Gauss wavelet. The similarity between both signals was described by computing the sliding cross-correlation coefficient defined as:

$$Ws\,(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} \ddot{\theta}\, \psi\left(\frac{t-b}{a}\right) dt,$$

where $a = Fc/F$ and b are respectively the scale and time shifts of the reference signal, t is the time, Fc is the center frequency of the wavelet, and F is the frequency corresponding to the scale. The higher the coefficient Ws the higher the similarity. Based on the biomechanics literature, the frequency of human motion during walking is ~2 Hz and therefore in our analysis we considered the frequency equivalent scale $a=15$ [3]. Trip detection was determined as the peak value of the CWT correlation coefficient during the trial. The detection time is the time when the applied force on the load cell exceeded threshold to the timing of the peak value of Ws coefficient.

III. Results & Discussion

Figure 1-b shows the average detection times for trips at different swing phases. The average detection times for the early, mid, and late trips are 63.0 ms, 47.4 ms, and 98.4 ms, respectively. Mid-trips were detected the earliest due to the trunk motion during these perturbations producing the signal most closely matching the center of the mother-wavelet in time domain. Overall, the signal similarity and detection times depend on the amount of presence of noise and characteristic features reflecting the trunk motion. The algorithm effectively detected all trip perturbations shortly after trip onset due to the localized frequency analysis property of CWT that makes it possible to detect and locate sudden changes in the signal.

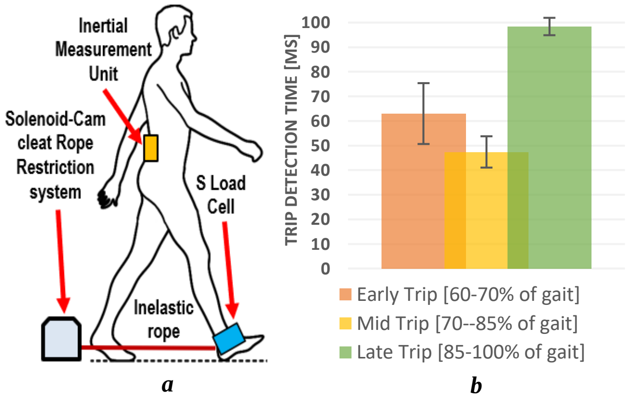

Figure 1: a) General experimental setup, b) Comparison of the average trip detection time across both subjects for each trip onset at different swing phase with one standard deviation error bars included.

IV. Conclusion

In this abstract, a novel method for trip detection is introduced using a continuous wavelet transform approach. The average trip detection time throughout all swing phases was 69.6 ms, which is less than the human voluntary reaction time. The rapid trip detection algorithm can be integrated in the control of assistive devices allowing the time to provide support during the trip recovery to prevent falls and injuries.

References

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