A proximity sensor for the measurement of the inter-foot distance in static and dynamic tasks

S. Bertuletti [1], A. Cereatti [1, 2], M. Caldara [3], U. Della Croce [1]

[1] *Information Engineering Unit, POLCOMING Department, University of Sassari, Sassari, Italy*
[2] *Politecnico di Torino, Department of Electronics and Telecommunications, Torino, Italy*
[3] *University of Bergamo, Department of Engineering and Applied Sciences, Bergamo, Italy*

INTRODUCTION

Measuring the base of support is of paramount importance in determining human stability during gait or balance tests. While wearable inertial sensors have been successfully employed to quantify numerous gait parameters (velocity, stride length, etc) [1], they could not be used to estimate quantities related to the feet relative position. Thus, alternative technological solutions need to be investigated. Some attempts have been made by combining light intensity infrared or ultrasounds sensors with inertial measurement units [2, 3]. Lately, the Infrared Time-of-Flight technology (IR-ToF) has become popular for measuring distances. IR-ToF sensor measures the time an electromagnetic wave needs to travel a distance. The aim of this work was to investigate the feasibility of the use of an IR-ToF sensor for estimating the inter-foot distance (IFD) in both static and dynamic tasks.

METHODS

An IR-ToF sensor (VL6180X, STM) with a measuring range set to 0-200 mm was applied to the right foot. A cluster of four retro-reflective markers was centered on the IR-ToF sensor (Figure 1) and a similar cluster was attached on the left foot. For validation purposes, markers positions were recorded using a 10-camera stereo-photogrammetric (SP) system (Vicon). Data of five healthy subjects (2 f, 3 m; age [mean ± standard deviation (std)] 28.8 ± 3.3 y.o.; height 1.71 ± 0.10 m) were acquired. The following tasks were performed: (a) subject standing with parallel feet (*Static*); (b) subject standing while oscillating the left leg five times (*Oscillation*); (c) subject walking straight at comfortable speed for six meters (*Gait*). The SP estimate of the IFD (^{SP}IFD) was determined either as the minimum distance (in *Oscillation* and *Gait*) or as the average distance (in *Static*) between the centroids of the right and left foot markers clusters. The error e_i was computed as the difference between SP and the IR-ToF sensor measurements. During *Oscillation* and *Gait* trials the mean error e over the values measured during the different cycles (5 oscillations and about 7 gait cycles) was calculated. The average value of ^{SP}IFD and the grand mean values of mean error (ME), mean absolute error (MAE) and mean absolute percentage error ($MAE_{\%}$) were computed for each condition over the subjects.

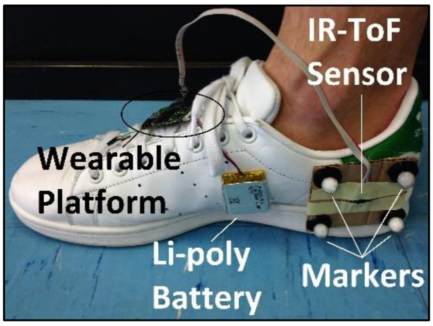

Figure 1. IR-ToF sensor and markers placement. A similar configuration was replicated for the left foot.

RESULTS

Average errors for both static (orthostatic position) and dynamic conditions analysed (single leg oscillations and gait) over five subjects are reported in Table 1.

Table 1. Inter-foot distance errors in mm.

Condition (mean ^{SP}IFD)	*ME* (*std*)	*MAE*	$MAE_{\%}$
Static (135 mm)	-1.1 (4.8)	4.1	3.3
Oscillation (183 mm)	0.1 (8.7)	7.3	4.1
Gait (103 mm)	18.9 (9.4)	19.9	19.8

DISCUSSION

We found very accurate IFD estimates during *Static* ($MAE_{\%}$=3.3%) and *Oscillation* ($MAE_{\%}$=4.1%) conditions and larger errors during *Gait* trials ($MAE_{\%}$=19.8%). However, it is worth noting that whereas in *Static* and *Oscillation* trials the IR emitted signal was constrained to be parallel to the ground and orthogonal to the left foot, during *Gait* trials, IFD was measured during the mid-swing of each leg in which it is expected to be minimum. Due to inter-subject variability, relative feet position and orientation may vary and hence the emitted signal may be not orthogonal to the contralateral foot. This could explain differences found between SP and IR-ToF estimates. The findings of this study confirm that IR-ToF proximity sensors can be effectively used for the IFD estimation. However, the effect of the feet orientation on the IFD estimation requires further investigation.

REFERENCES

[1] D. Trojaniello et al. *Journal of NeuroEngineering and Rehabilitation*; Vol(11): 1-12.
[2] D. Trojaniello et al. *20th IMEKO TC4 International Symposium 2014.*
[3] D. Weenk et al. *IEEE Trans. On Neural Systems and Rehabilitation Engineering*; Vol(23): 817-826.