Development of a novel wearable system for real-time measurement of the inter-foot distance during gait

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INTRODUCTION

The combination of magneto-inertial measurement unit (MIMU) and distance sensor (DS) represents a smart solution for evaluating the distance between feet during various daily-life activities. In particular, when analyzing gait, the latter technology can be used for estimating the instantaneous or average distance between selected points of the feet (IFD) during mid-swing and mid-stance phases [1-3]. The aim of this preliminary work is twofold: a) to develop and validate a novel wearable system (SWING^{2DS}) for the measurement of the IFD during gait; b) to investigate the optimal positioning of the DS on the foot.

METHODS

The SWING^{2DS} system (52L × 38W × 11.5H mm^3), comprises a MIMU (ODR = 100 Hz) and two DSs (ODR = 50 Hz), was attached on a plastic rigid support and positioned on the right foot. DSs were positioned orthogonal to the support and close to the heel (DS_{HEEL}) and the first metatarsophalangeal joint (DS_{MTP}) (Figure 1). For validation purposes, to avoid measurement uncertainties due to the irregular shape of the shoe, a rectangular target (200 × 100 mm^2) was attached on the medial side of the left foot. A cluster of 3 markers was placed on each foot to define a coordinate system. The target and SWING^{2DS} geometries were acquired and expressed in the relevant coordinate systems from the positions of 8 additional markers during a static acquisition. Markers positions were recorded using a 10-camera stereo-photogrammetric system (SP) (Vicon, 100 Hz). Experimental data were acquired on a healthy subject during a six-meter straight walk at slow (*Slow*, 0.6 m/s) and comfortable speed (*Comf*, 0.9 m/s) (3 repetitions). IFD markers-based reference values were calculated as the distance between the DS center and the intersection point between the normal to the DS plane, passing through the DS center, and the target plane placed on the left foot. For each gait cycle, mean values of the distances provided by DS_{HEEL}, DS_{MTP} and SP during swing and stance phases of the right foot were computed and the absolute differences between DSs and SP mean distance values derived. The overall mean absolute error (MAE) was computed averaging differences over gait cycles and trials.

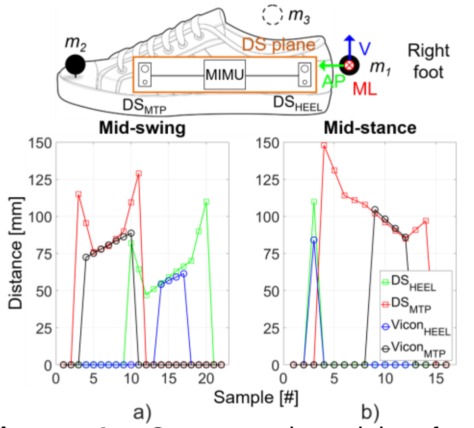

Figure 1. On top the right foot experimental setup; on bottom the distance values measured during *Slow*

RESULTS

The average distance ($\bar{d}$) and MAE values during mid-swing and mid-stance phases of the instrumented right foot are reported in Table 1.

Table 1. Average distances and MAEs during the mid-swing and mid-stance phases of instrumented right foot

Gait	Mid-swing				Mid-stance			
	DS_{HEEL}		DS_{MTP}		DS_{HEEL}		DS_{MTP}	
	$\bar{d}$ [mm]	MAE [mm]	$\bar{d}$ [mm]	MAE [mm]	$\bar{d}$ [mm]	MAE [mm]	$\bar{d}$ [mm]	MAE [mm]
Slow	62.1	8.8	85.2	6.6	79.4	21.7	84.4	9.1
Comf	57.3	4.1	76.2	4.1	71.5	18.8	93.7	6.2

DISCUSSION

Preliminary results showed that the SWING^{2DS} wearable system can be effectively used for accurately measuring the IFD during gait. Interestingly, the accuracy of the IFD estimation is highly affected by the position of the DS on the foot. When the right foot is moving during the mid-swing phase, both DS_{HEEL} and DS_{MTP} provided a similar number of observations (Figure 1a). On the contrary, when right foot is stationary during mid-stance phase, a fewer number of observations are made available using the DS_{HEEL} due to the raised position of the left foot during its mid-swing phase (Figure 1b). The few number of observations affected the accuracy of the DS_{HEEL} (MAE_{HEEL} 18.8-21.7 mm vs MAE_{MTP} 6.2-9.1 mm). Therefore, the recommended DS location is close to the forepart of the foot.

REFERENCES

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