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Short communication

Estimation of stride length in level walking using an inertial measurement unit attached to the foot: A validation of the zero velocity assumption during stance

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ABSTRACT

In a variety of applications, inertial sensors are used to estimate spatial parameters by double integrating over time their coordinate acceleration components. In human movement applications, the drift inherent to the accelerometer signals is often reduced by exploiting the cyclical nature of gait and under the hypothesis that the velocity of the sensor is zero at some point in stance. In this study, the validity of the latter hypothesis was investigated by determining the minimum velocity of progression of selected points of the foot and shank during the stance phase of the gait cycle while walking at three different speeds on level ground. The errors affecting the accuracy of the stride length estimation resulting from assuming a zero velocity at the beginning of the integration interval were evaluated on twenty healthy subjects. Results showed that the minimum velocity of the selected points on the foot and shank increased as gait speed increased. Whereas the average minimum velocity of the foot locations was lower than 0.011 m/s, the velocity of the shank locations were up to 0.049 m/s corresponding to a percent error of the stride length equal to 3.3%. The preferable foot locations for an inertial sensor resulted to be the calcaneus and the lateral aspect of the rearfoot. In estimating the stride length, the hypothesis that the velocity of the sensor can be set to zero sometimes during stance is acceptable only if the sensor is attached to the foot.

1. Introduction

Measuring and tracking pedestrian displacements and positions, both outdoor and indoor, in non-controlled environment and for prolonged periods of time is essential for a variety of applications, including rescue operations, movement activity monitoring (van Dam et al., 2001) and functional evaluations of gait disorders (Allet et al., 2009). Position tracking of human locomotion, along with the estimation of spatial parameters, such as the stride length, can be conveniently obtained by using wearable inertial measurement units (IMU), which include accelerometers and gyroscopes (Sabatini et al., 2005; Yun et al., 2007). Linear displacements can be obtained by double integrating the IMU linear coordinate acceleration (IMU acceleration components in the global reference frame). IMU coordinate acceleration can be obtained by removing the gravitational contribution from the accelerometer signals. To do so, an estimate of the IMU orientation in the global reference frame is needed (Sabatini et al., 2005; Schepers et al., 2007).

However, the procedure described above is complicated by a number of factors: (a) a drift is commonly present when integrating the accelerometer and gyroscope signals, mostly due to thermal–mechanical and electronic noise, introducing an error in the displacement estimations, which is nonlinearly related to the integration time (Djuric, 2000; Thong et al., 2004); (b) the determination of the IMU orientation with respect to the global reference frame from gyroscopic and accelerometer data is not trivial (Woodman, 2007) and (c) in the integration of the coordinate accelerations an estimate of initial velocity needs to be provided.

The detrimental effects of the drift are typically reduced by exploiting the cyclical nature of gait. This allows reduction of the interval of integration time to a single gait cycle but requires the identification in the cycle of an instant of known velocity to be used as initial velocity in the integration of the acceleration in the global reference frame.

Despite the fact that during stance in level walking the foot rolls from the outer edge to the inner edge (Rodgers, 1988) and the paths of movement of the forefoot and heel differ both in shape and time (Winter, 1984), the velocity of the sensor placed on the different foot and shank locations is often set to zero at the beginning of the integration interval (zero velocity assumption—

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