A Simple and Robust Stride Length Estimation Method using Foot-mounted Micro Gyroscopes

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Introduction

One pervasive solution for accurate estimation of walking distance is to make use of motion dynamics contained in the inertial signals such as frequency, maximum/minimum amplitude, to aggregate individual stride. The main challenge for stride length is how to accurately determine the stride length; therefore, a simple and robust stride length estimation method by exploring foot-mounted gyroscope measurements is proposed:

- Key gait events detection to identify the swing phase
- Construction of a simple linear model between the stride length and average angular swing speed
- Estimation of subject-specific linear model parameters

Sensor Placement

BSN sensor platform
- TI MSP430 ultra low power processor
- Chipcon CC2420 RF
- light-weight Li-ion polymer battery
- InvenSense ITG-3200 digital gyroscope
- ADXL330 accelerometer

Key Gait Event Detection

![Figure 1. The illustration of the attachment of our BSN sensor node on the right foot of a subject.](image)

![Figure 2. Illustration of the leg body during movement during a gait cycle. Take the leg in green for example, a gait cycle mainly consists of 6 steps: 1) the heel leaves the ground (heel off); 2) the toe also leaves ground (toe off); 3) the leg swings forward; 4) the heel contacts the ground (heel strike); 5) the toe also contacts the ground (toe strike); 6) the foot stays on the ground to support the other leg swing forward.](image)

![Figure 3. The gyroscope signal in the sagittal plane during a gait cycle.](image)

Linear Model Construction

The positive measurements only exist during the foot swings forward together with the leg. Since the stride length only relates to the swing forward phase during the gait cycle, we will design a simple swing phase detector as:

\[
\text{Swing} = \begin{cases} 
1, & z_i > \lambda \\
0, & \text{else} 
\end{cases}
\]

where \(z_i\) is the gyroscope reading in the sagittal plane at time \(i\), \(\lambda\) is the predefined positive threshold which is set empirically as 0.5 in this paper.

Subject-specific Model Parameters Estimation

In our method, each subject will be asked to walk \(N \geq 2\) calibration trials at different speed. For any trial \(j\), the actual walking distance is \(d_j\) taking \(M_j\) strides. Then we can have:

\[
d_j = K_j \sum_{k=1}^{M_j} z_k + M_j K_j
\]

where \(z_k\) is the average swing speed during the \(k\)th stride.

Define

\[
A_j = \left[ M_j, z_k \right]
\]

then we can expand the above equation as:

\[
d_j = A_j^T D
\]

\[
D = \begin{bmatrix} d_1^T \\ d_2^T \\ \vdots \\ d_N^T \end{bmatrix}
\]

where

\[
A_j = \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_N \end{bmatrix}
\]

and \(D\) is the average swing speed during the \(k\)th stride:

\[
K_j = \left( A^T A \right)^{-1} A^T D
\]

Results

As a preliminary study, a total of 10 healthy subjects participated in the tests (males and females with ages ranging from 25 to 32). During the test procedures, subjects were asked to walk along a 15 meter long corridor following a straight path, back and forth several times. They were asked to maintain a constant velocity for each walk: comfortable, fast and slow. In our method, only the gyroscope measurements in the sagittal plane were used. The results derived from the other four estimators (refer to the references) are also presented for comparison purpose. Three criteria were used to evaluate the performance: 1) walking distance over different subjects; 2) walking distance over different walking speed; 3) the average stride length estimation.

Conclusion

- Presented a simple yet robust stride length estimation method by exploring the foot-mounted gyroscope measurements.
- Key gait events were extracted to detect the swing phase of a gait cycle.
- A simple linear model between the stride length and angular swing speed were then constructed.
- A simple calibration method to determine the linear model parameters was also discussed.

References