Ambulatory estimation of ankle and foot dynamics and center of mass movement

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Introduction

Traditionally, human body movement analysis is done in so-called ‘gait laboratories’, equipped with several measurement systems such as optical position measurement systems, EMG or force plates. The measured signals are used to estimate important gait variables. An important variable is the center of mass, an imaginary point at which the total body mass can be assumed to be concentrated. Several methods exist for center of mass estimation, of which the segmental kinematics method and the double integration of ground reaction force method are the most important ones. Other important variables are joint moment and powers. These can be estimated from estimations of body movement and ground reaction forces by applying inverse dynamics methods. A major drawback of the existing systems is the restriction to the laboratory environment. Therefore research is required for the development of measurement systems to perform these measurements in an ambulatory environment.

The objective of this study is to give an overview of the possibilities of the forceshoe. The forceshoe is an ambulatory measurement system able to measure the ground reaction force and movement of foot and ankle.

Methods

The forceshoe consists of an orthopaedic sandal equipped with two six-degrees-of-freedom force/moment sensors (ATI-Mini45-SI-580-20, Schunk GmbH & Co. KG) beneath the heel and the forefoot. Moreover, an inertial sensor is rigidly attached to each force/moment sensor (Figure 1).

The estimation of ankle and foot dynamics requires the ground reaction force and movement of foot and ankle to be determined. The ground reaction force is measured by the force/moment sensors beneath the sole of the forceshoe. The movement of foot and ankle is estimated from signals measured by the inertial sensors (Xsens, MTx, Enschede, The Netherlands) connected to the force/moment sensors. A detailed description of the measurement system and methods can be found in [1].

The estimation of center of mass movement is based on fusion of center of pressure data with double integrated ground reaction force data, both estimated from signals measured by the forceshoe. The fusion is based on a frequency domain method, which is described in [2].

Several measurements were performed with the forceshoe. During the measurements, a subject was asked to walk through the gait laboratory while wearing the forceshoe. The accuracy of the ambulatory system was validated by comparing it to a reference system consisting of an optical measurement system and two force plates.

Figure 1. *Picture of the forceshoe with two force/moment sensors beneath the heel and the forefoot and two inertial sensors rigidly attached to the force/moment sensors.*

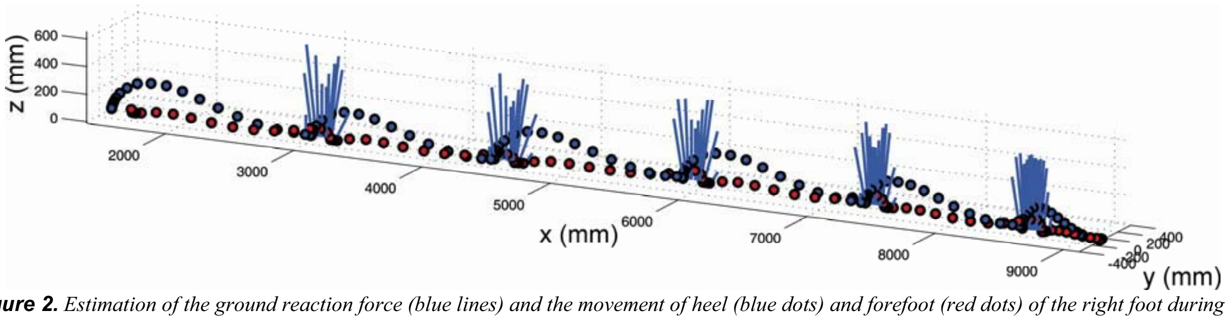

Figure 2. *Estimation of the ground reaction force (blue lines) and the movement of heel (blue dots) and forefoot (red dots) of the right foot during several steps.*

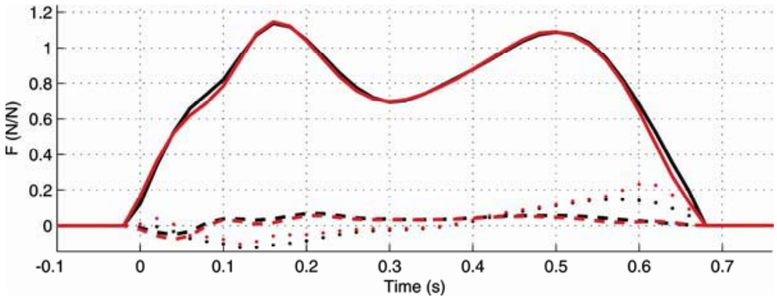

Figure 3. *Three components of the ground reaction force as a function of time estimated by the ambulatory (red) and reference (black) systems (forward: dotted, lateral: dashed, vertical solid).*

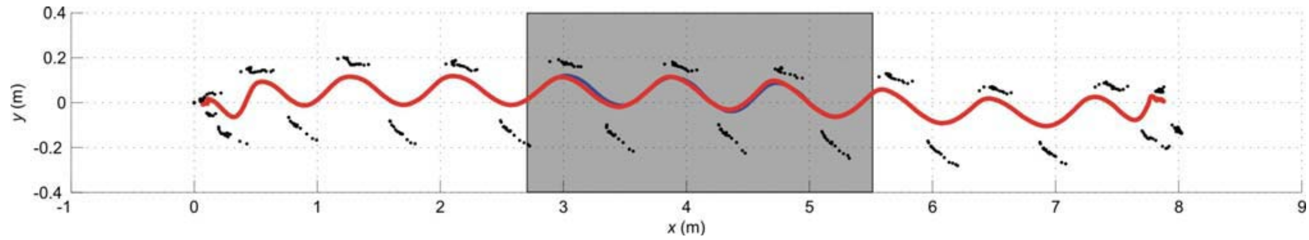

Figure 4. *Estimated center of mass by the ambulatory (red) and reference (blue) systems. The center of pressure is indicated by the black dots on either side of the center of mass, where each dot represents a time sample. Moreover, the measurement volume of the reference system is indicated by the gray area.*

Results

An estimation of the ground reaction force is shown in Figure 3. The signals measured with the forceshoe show good correspondence with the signals measured with the force plate, which is confirmed by the rms difference between the magnitudes of the ground reaction force, being 0.02 N/N or 1.8 % of the maximal magnitude.

Figure 2 shows an integration of the measured ground reaction force with the estimated position of the heel and forefoot sensor. The figure indicates the possibility of the ambulatory measurement system to measure several steps during a single measurement, which is not possible with the reference system. This is also shown in Figure 4, which shows the estimated center of mass movement estimated by the ambulatory (red) and reference (blue) systems. On either side of the center of mass, the center of pressure is indicated by the black dots where each dot represents a time sample. The rms difference between the magnitudes of the center of mass displacement estimated by the ambulatory and the reference measurement systems was 0.025 ± 0.007 m.

Discussion

This study has shown the ability of the forceshoe for ambulatory measurements. Ankle and foot dynamics as well as the movement of the center of mass were estimated and the accuracy was validated using a reference measurement system. A more detailed evaluation with respect to the performance of the forceshoe can be found in [1,2]. Overall, the accuracy of the results obtained with the ambulatory measurement system was comparable to other studies described in literature [3,4].

Acknowledgment

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References

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