Ambulatory gait analysis in stroke patients using ultrasound and inertial sensors

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Abstract- Objective ambulatory assessment of movements of patients is important for an optimal recovery. In this study an ambulatory system is used for assessing gait parameters in stroke patients. Ultrasound range estimates are fused with inertial sensors using an extended Kalman filter to estimate 3D positions, velocities and orientations. For eight stroke patients step lengths and swing and stance times are calculated from a ten meter walk trial and compared to the Berg balance scale. First results show a correlation between step lengths and Berg balance scale score. However, more patients are to be measured and different activities will be investigated in the coming months.

Keywords-component; inertial sensors; ultrasound; stroke patients; gait analysis

1. INTRODUCTION

Stroke often results in impaired movement, which decreases the performance of daily-life activities. For an optimal rehabilitation, medical professionals need objective information about the movements of the patients [1]. Traditionally, optical systems are used for movement analysis, however measurements are restricted to a lab, making it unsuitable for measuring daily-life activities. Over the last years inertial sensors have become more and more popular. Disadvantage is that only position changes can be estimated. Because the begin positions are often unknown this does not result in relative positions of the feet. Another disadvantage is the drift due to double integration of accelerations. Therefore we fused the inertial sensors with ultrasound range estimates for a 3D estimation of relative foot positions. In addition stance and swing times are investigated and compared with Berg balance scale scores.

2. MATERIAL AND METHODS

Measurements and sensors

Measurements recorded for the INTERACTION project are used in this study. For the INTERACTION project 20 stroke patients will be measured performing several daily-life tasks in a simulated ambulatory setting [1]. Subjects are measured with Xsens ForceShoes™ (Fig. 1) and ultrasound sensors, approved by the local medical ethics committee. So far, 8 patients (seven male, one female, age 64.7±9.7 years) were measured. In this study only the 10 meter walk tests (two trials for each patient) are used. In addition to the measurements, the Berg balance scale (BBS) test was performed [1]. With this clinical body balance assessment, patients are scored on several tasks. A larger score indicates less impaired balance. Scores of less than 45 out of a maximum of 56 are accepted as indicative of balance impairment [2]. In our case 3 patients scored lower than 45.

Figure 1. Xsens ForceShoes™ containing two inertial and two force/moment sensors. Near the inertial sensor in the forefeet an ultrasound transducer is mounted in each shoe.

Each Xsens ForceShoe™ contains two inertial and magnetic sensors and two force/moment sensors. Only the inertial sensors in the forefoot segments, that is, 3D accelerations and 3D angular velocities, were used in this study. The sample frequency was 50 Hz, which was the upper limit due to the attached force sensors. Near the inertial sensors in the forefoot segments of the shoes two ultrasound transducers were mounted (Fig. 1). A 40 KHz pulse was sent from one shoe to another from which time of flight was estimated using a threshold applied to the envelope of the received signal. With this system the distance between the feet can be estimated approximately 13 times per second. More details and a validation of this range estimation using an optical reference is described in [3]. The mean absolute distance difference between the ultrasound sensor and an optical reference system was 7.0 mm over six walking trials.

Sensor fusion

To fuse the inertial sensors with the ultrasound range estimates an extended Kalman filter was implemented. This filter operates on a state vector with 3D position and velocity of each foot. To be able to accurately subtract gravitational accelerations from measured acceleration, the orientation of each inertial sensor needs to be estimated. Therefore orientation error and gyroscope bias error are also included in the state vector. A more detailed description of the filter and a validation using an optical system is described in [4]. Mean absolute difference for step lengths calculated with the filter versus the optical system was approximately 1.8 cm. After a prediction step, zero velocity-, height- and ultrasound range updates are performed based on a zero velocity detection algorithm as described by Skog *et al.* in [5].

Gait analysis

In addition to the filter outputs, 3D positions, velocities and orientations, step lengths and stride widths are calculated using methods in Huxham *et al.* [6]. From step lengths and stride widths of each trial the mean was calculated after neglecting the first and last step of each foot. To be able to compare different patients, the step lengths were normalized to body height.

Based on the zero velocity detection used for the filter, stance and swing times can be calculated easily. From each trial the mean of these parameters were calculated as well.

3. Results

In Fig.2 a top down view of the positions of the feet is shown for one walking trial of a patient with Berg balance scale score of 42. The stance positions are indicated by the triangles from which step lengths were calculated.

In Fig. 3 the mean step lengths for the affected side versus the unaffected side are shown for all trials. Overall the walking trials are relatively symmetric, except for the two trials of patient nr. 3 (±0.2 vs ±0.3 normalized step length) with Berg balance scale (BBS) of 43. The step lengths are smaller for patients with a smaller BBS score.

A larger asymmetry can be observed when looking at stance and swing times of the affected versus the unaffected side (Fig. 4 and 5). Especially the stance times of the more impaired patients are larger for the unaffected side than for the affected side (Fig. 5).

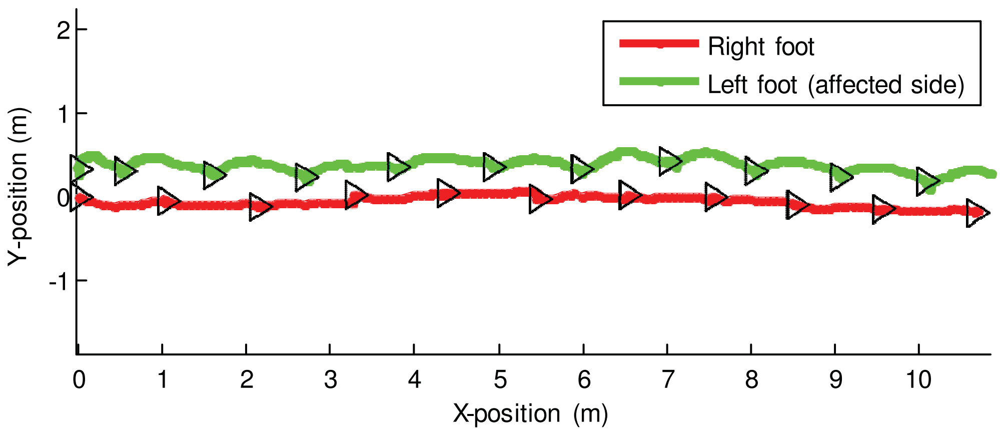

Figure 2. Example of the top down view of foot positions from one walking trial of a subject with left side affected and Berg balance scale score 42. Step lengths are calculated from the stance positions, indicated by the triangles. Mean step length for affected side is 0.548 m and for unaffected side 0.525 m. Mean swing time for affected side is 0.77 s versus 0.55 s for the unaffected side. The stance times are 0.72 s and 0.95 s respectively.

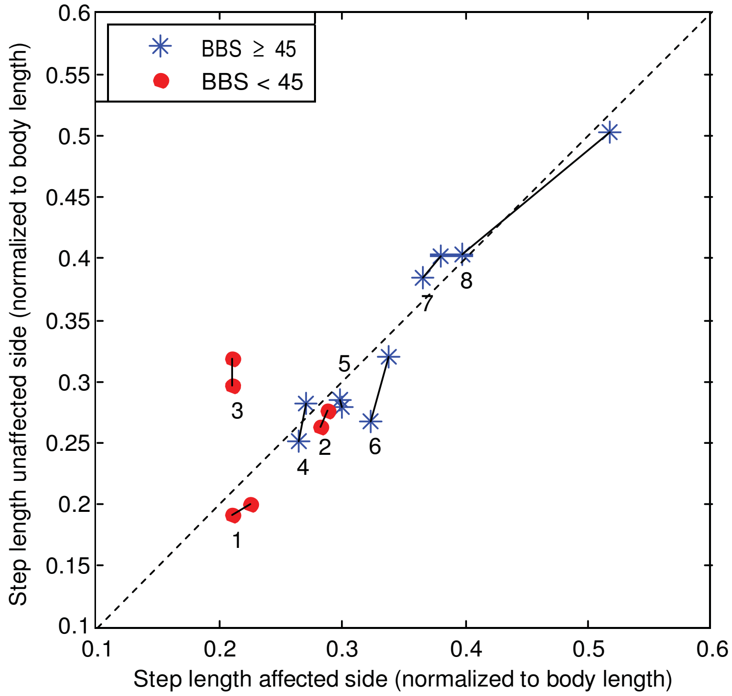

Figure 3. Mean step length for affected versus unaffected side, normalized to body length for 16 walking trials of eight stroke patients. Both trials of a patient are connected with a line. The numbers indicate the first trial of each patient, who were sorted from small to large BBS score. The line $x = y$ is plotted to indicate a symmetric walking pattern. Overall the walking trials are relatively symmetric, except for the two trials of patient nr. 3 (±0.2 vs ±0.3 normalized step length) with BBS score of 43. Notice that the step length is smaller for patients with a smaller BBS score.

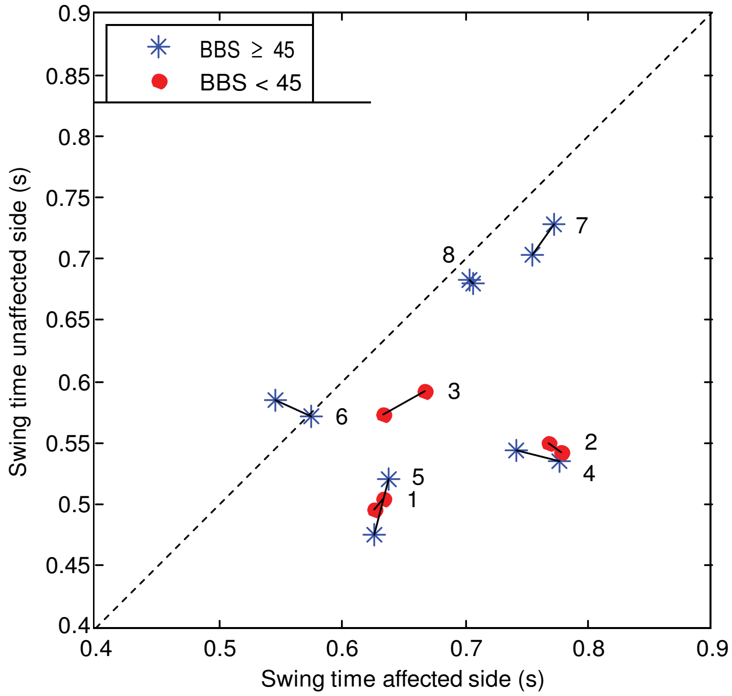

Figure 4. Mean swing time for affected versus unaffected side for 16 walking trials of eight stroke patients. Both trials of a patient are connected with a line. The numbers indicate the first trial of each patient, who were sorted from small to large BBS score. The line $x = y$ is plotted to indicate a symmetric walking pattern. Most patients had larger swing time for affected side than for the unaffected side.

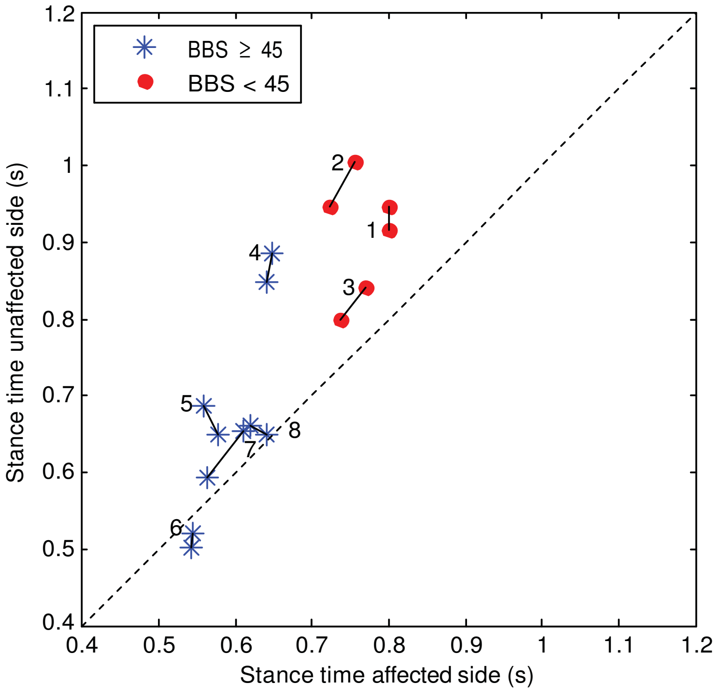

Figure 5. Mean stance time for affected versus unaffected side for 16 walking trials of eight stroke patients. Both trials of a patient are connected with a line. The numbers indicate the first trial of each patient, who were sorted from small to large BBS score. The line $x = y$ is plotted to indicate a symmetric walking pattern. Most patients had larger stance time for unaffected side than for the affected side. Especially the four patients with the smallest BBS score.

4. Discussion

These first results show that it is possible to perform gait analysis in stroke patients, including estimating step lengths, stride widths and stance and swing times using only one inertial sensor and one ultrasound transducer on each foot. This makes it a quick and easy to use system for gait analysis in clinical practice but also in an in-home situation.

In the coming months 11 more patients will be measured and analysed. Also other activities of daily living will be investigated.

5. Acknowledgment

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6. References

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