DETERMINATION OF GAIT PARAMETERS FROM THE WEARABLE MOTION ANALYSIS SYSTEM eSHOE

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Abstract: Limitation of mobility often leads to considerable loss in quality of life. The mobile motion analysis system eSHOE represents a new method for the detection of gait parameters, in order to enable monitoring of the rehabilitation processes. The system has been tested in a pilot study at a geriatric hospital in Vienna. Autocorrelation and cross-correlation analyses proved to be suitable methods for the extraction of gait parameters from eSHOE data. Based on the results a method for gait symmetry determination will be developed as a next step.

Keywords: gait analysis, geriatric assessment, cross-correlation, pattern recognition, feature extraction

Introduction

Gait disorders and thereby arising limitations in the ability of walking often cause considerable loss in quality of life [1]. Possible consequence of gait disorders is an increased rate of fall incidents, about 30% of persons who are older than 65 and living at home experience a fall once a year [2]. Falls can result in severe injuries, such as femur fracture. The prevalence of gait disorders is 35% among persons over the age of 70 as it has been shown by Sudarsky [3]. Furthermore, Guralnik et al. [4] stated that most gait disorders appear in connection with underlying diseases like stroke, hip fracture or cancer.

The eSHOE research project focuses on developing a new detection-system for gait parameters via a wearable motion analysis sensor-system [5]. One of the research goals is to support the therapy processes in patients with chronic diseases. This will be done by monitoring and quantifying the progress during therapy via the eSHOE system. A currently conducted clinical pilot study evaluates whether eSHOE is capable of detecting the progress of patients’ rehabilitation process after a proximal femur fracture. The superior goal is to generate a significant measurement method for gait symmetry evaluations, in order to quantify the rehabilitation progress. Consequently it is necessary to create a surrogate parameter as indicator for a person’s gait stability and symmetry. In order to achieve this goal, basic gait parameters have to be extracted from the eSHOE data first.

Methods

eSHOE is a wearable, mobile motion analysis system consisting of a pair of orthopaedic shoe insoles, instrumented with sensors and data processing hardware coupled to a base station. It uses a three-axes accelerometer and a three-axes gyroscope for the detection of kinematic gait parameters as well as force sensitive resistors for kinetic parameters beneath the heel, the metatarsal heads I and V as well as the big toe.

For the acquisition of suitable movement data a pilot study has been conducted at a geriatric hospital in Vienna, in close cooperation with experts from the Austrian Society for Geriatrics and Gerontology. It included eleven patients who experienced a fall incident, resulting in a singular proximal femur fracture (PAT) and a group of twelve healthy subjects (CTRL).

Table 1: Test subjects’ demographic and anthropometric characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>PAT</th>
<th>CTRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Gender (m/f)</td>
<td>0/11</td>
<td>6/6</td>
</tr>
<tr>
<td>Age (years)</td>
<td>78,4 ± 7,7</td>
<td>73,2 ± 8,3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>158,5 ± 2,8</td>
<td>168,5 ± 9,2</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>56,9 ± 7,6</td>
<td>76,6 ± 15,1</td>
</tr>
</tbody>
</table>

All subjects had to undergo specially arranged geriatric assessment tests, including a timed “up and go” test, a 10-meter walk test (10MWT), stair climbing and a 6-minute walk test. Each patient performed at least three tests during hospitalization (one per week). The 10MWT test was used to collect standard gait data via the insoles of straight and level walking. The healthy subjects were only tested once, in order to generate the reference data set. All data sets had been cut to 10m length to eliminate start/stop artifacts. For that purpose, the eSHOE data was synchronized with the video data to be able to cut out all data from the first and the last 2.5m. For automated gait cycle recognition it was necessary to determine the pattern of a standard gait cycle in the sensor data. We used autocorrelation analysis on the accelerometer, gyroscope, angle and pressure signals from the CRTLs’ data to define a stable “standard gait cycle” as our reference pattern. The resulting, sensor- and axis-
specific, gait cycle patterns were used to detect gait cycles in the patients’ data via cross-correlation. We further applied feature extraction methods to detect predefined gait events and parameters, e.g. “initial contact”, “toe-off”, “stride time” and “stance phase duration”. Especially the comparison of stance phase and swing phase durations between both feet is an excellent parameter to measure the progression of a therapy in femur fracture patients [6].

Results

Preliminary analyses from the 10MWT have been completed. Autocorrelation has been performed on eight of twelve CTRL data sets resulting in an averaged standard gait cycle pattern for healthy persons.

![Signal patterns](figure1.png)

Figure 1: Signal patterns of a) Acceleration force along the anterior-posterior body axis, b) angular velocity around the medial-lateral body axis, c) pressure beneath the heel, d) inclination (angle) of the foot in the sagittal body plane.

Autocorrelation in combination with additional signal analysis resulted in the “detection” of 96% of all observed gait cycles (n=404) in the angle signal in the sagittal body plane (AN-S), 94% in the acceleration force signal along the anterior-posterior body axis (ACC-AP), 94% in the angular velocity signal around the medial-lateral body axis (AV-ML) and 93% in the pressure beneath the heel (P-H). Fig. 1 depicts the signal patterns of the four above mentioned signals. Each represents the periodically reoccurring signal form during one gait cycle. The signal patterns in Fig. 1 are averaged over all the detected gait cycles. Note that these patterns do not all start at the natural beginning of a gait cycle (the first ground contact of the heel), since the autocorrelation algorithm only searches for reoccurring patterns and starts its search at the beginning of a data track, which is not automatically equal to the beginning of a gait cycle. Autocorrelation results of the rest of the axis-specific sensor signals showed a detection rate of 25% to 91%.

Discussion

The usage of autocorrelation proved to be a powerful method to detect gait cycles in the eSHOE motion data. Autocorrelation is fast to implement and provides a stable way of gait pattern recognition. Nevertheless, the autocorrelation method is not always applicable, especially when the signal to noise ratio is low (e.g. in the ACC-AP and P-H signals). The segmentation via cross-correlation turned out to be applicable and showed good results in detecting gait cycles. The four signals (as shown in Fig.1) proved to provide the most distinctive patterns representing a gait cycle and will therefore be used in a next step to detect gait cycles in the patient data via cross-correlation. However, the results of the cross-correlation will depend on the quality of the motion data and the extracted standard gait cycles. To compute actual gait events from the cross-correlated eSHOE motion data, feature extraction methods will be used.

Results show on the one hand that eSHOE is capable of capturing motion data in an easy and highly unobtrusive way in geriatric setting. On the other hand autocorrelation proved to be an adequate method to detect and segment gait cycles out of the eSHOE data. We assume to be equally successful with the application of cross-correlation. To conclude, the analysis methods are adequate to begin formulating a parameter, which determines the level of quality for gait symmetry in geriatric patients.

Acknowledgement

We would like to thank the patients of the SMZ Sophienspital and the group of citizens of the city of Schwechat who participated voluntarily in the study. Additional thanks go to the staff of the SMZ Sophienspital for their support, patience and understanding.

Bibliography