Monitoring and characterising human gait and activity with a mobile accelerator device

Daumer M, Goßner T, Kruis E, Scholz M (2), Thaler K for the ActiBelt study team
Sylvia Lawry Centre for Multiple Sclerosis Research, Trium Analysis Online (2), Munich, Germany
daumer@slcmsr.org

Introduction Physical activity is of paramount importance for human health. In a recent meta-analysis it could be shown that even only moderate activity could lower mortality up to 33% [1] in a wide spectrum of diseases. But there is a serious lack of measurability and verifiabilty of activity. In clinical trials and clinical practice there is a enormous demand for measurement instruments, that allow physicians the objective evaluation of the progress of chronic diseases such as Multiple Sclerosis (MS) or the improvement due to a treatment or a rehabilitation measure. For example in the case of Multiple Sclerosis (MS) the walking ability is closely related to the outcome measure as e.g. the Expanded Disability Status Scale (EDSS) [2], which depends in its midrange entirely upon mobility. The recent developments in microsystem technology now opens a new possibility to measure activity with cheap, miniaturized accelerometers. These can be worn by a patient without much inconvenience in his normal environment.

Methods We combined a belt with the accelerometers (one two-axial accelerometer (type ADXL320) and one uni-axial (type MMA1250D) both with a range from −5g to 5g and a resolution of 0.24% and a 12 bit AD converter) integrated in its buckle and a Mobile Digital Assistant (MDA), a small handheld computer to record the data. With this measurement device, called "ActiBelt", accelerations in three mutually orthogonal axes are measured with a sampling frequency of 100 Hz. On the recorded accelerations we removed the outliers by a threshold alarm, smoothed the data with a moving average window with the length 10, segmented the data into one second time sections. With threshold methods (thresholds were determined by exploring measurement values taken from 20 healthy volunteers with different age and gender) we could distinguish between five types of movements: running, walking, standing, sitting and lying (an example is shown in fig. 1). In order to count and characterise the steps in the walking and running sections, we had to link our signal (an example is shown in fig. 2) with the gait phases [3], shown in fig. 3. This was done by simultaneous measurements with the ActiBelt and a three dimensional tracking system with infrared cameras (ARTtrack2, Advanced Realtime Tracking GmbH) at the chair of Computer Aided Medical Procedures (CAMP) (Prof. Navab) at the Technical University of Munich. In a further step we used the infrared tracking system with a target at the belt and one at each foot which we synchronized down to a few ms with the belt to collect 6D data from it and compare it with the according three acceleration data from the belt.We connected those two systems via a motion model which we created and a lot of complicated transformations to better understand the belt data and to get the real trajectory down to the walking distance, different movements and even single steps.

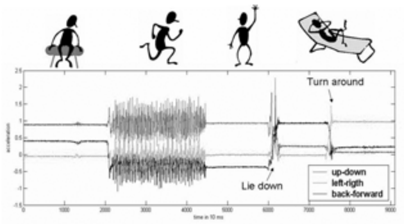

Fig. 1: Data set with different movements: sitting, walking, standing and lying

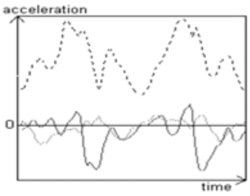

Fig. 2: Measured accelerations for one double step. Dashed line: vertical acceleration; dotted line: left-right acceleration; continuous line: forward-backward accel-eration.

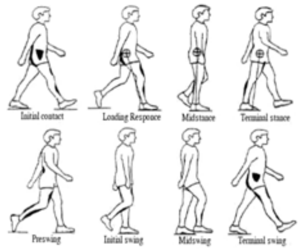

Fig. 3: Gait phases according to [3]

Results Although the tracking measurements are not completed yet, first results led us to the assumption that the first gait phase, called initial contact is associated to a local minimum in our vertical acceleration signal. Therefore we started to count the steps by identifying and counting these local minima. We compared the ability of our system to count steps with two commercially available pedometer (Silva, TCM) in a series of 17 experiments and a total of 4.5 hours and could produce plausible and consistent results (see fig. 4).

Then we started to analyse gait characteristics. One very obvious and easy to measure gait characteristic is asymmetry, that means some gait parameters for the left and right steps differ. The asymmetry between right and left steps of one movement can be calculated via every parameter which can be evaluated separately for right and left steps (e.g. step duration, range, step length etc.) [4].

One of these parameters is the step duration, i.e. the time from one minimum associated to an initial contact to the next associated minimum, an example is shown in fig. 5.

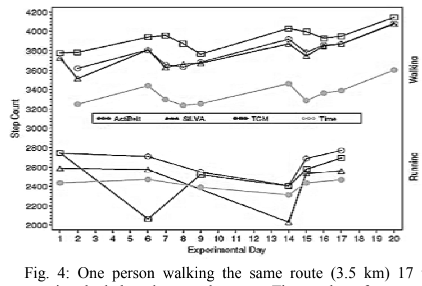

Fig. 4: One person walking the same route (3.5 km) 17 times, wearing the belt and two pedometers. The number of steps counted by the ActiBelt is proportional to the duration of the measurement and is comparable to the number of steps counted by the pedometers.

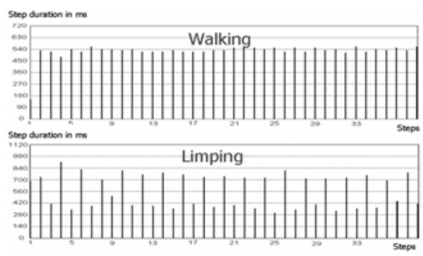

Fig. 5: Normal versus 'pathological' gait: the upper picture shows the step durations of a healthy person's gait (asymmetry: 2.4%), the lower picture shows the step durations of a limping person's gait (asymmetry: 29.2%)

Discussion Based on the recordings that have been done so far, with a total recording time of roughly 125 hours, from healthy volunteers and 30 MS patients, we hope to be able to develop an algorithm that allows to extract the standard step, a baseline step pattern in analogy to the baseline of ECG. A first approach was done by normalizing the step duration and amplitude, translating all single steps of one movement to $[0, \tau]$, where τ is the normalized step duration, and calculating the median and the 20 and 80%-percentiles of the distribution of the accelerations for every point $t \in [0, \tau]$. An example result is shown in fig. 6.

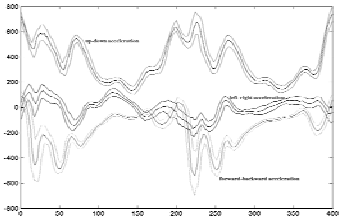

Fig. 6: A normalized step pattern of a healthy volunteer

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