Accurate physical mobility analysis of patients treated by neuromodulation

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Introduction
Spinal cord stimulation (i.e. the electrical stimulation of the dorsal columns of the spinal cord) is increasingly used for the treatment of intractable pain syndromes due to vascular or neurogenic disorders. Despite well-established safety and efficacy in properly selected cases, the use of SCS is still limited and its acceptance by the medical community remains somewhat restricted. This is due to several factors including an unclear mechanism of action and difficulties in determining objective endpoints to assess pain intensity and quality of life improvements in chronic pain patients. We propose a reliable measurement of the spontaneous physical activity, a fundamental determinant of the quality of life. Measurements have been performed in the condition of every day life, before and after the implantation of the spinal cord stimulator.

Method
The proposed measurement setup is based on two kinematic sensors. The first sensor is a bi-axial accelerometer (ADXL202, ±2g) fixed on the chest and measures the trunk acceleration in vertical (avc) and frontal (afc) directions. The second sensor is composed of one miniature gyroscope (Murata, ENC-03J, ±400 deg/sec) that measures thigh angular velocity (gt) in the sagittal plane and one accelerometer measuring the frontal thigh acceleration (aft). The signals are recorded by a portable data logger (Physilog, BioAGM, CH) at 40Hz sampling rate. One-hour recordings were carried out in nine patients with peripheral vascular disease (with or without implanted stimulator). In order to validate the algorithm, an observer with a laptop program has precisely monitored postural transitions. At the end, a file containing information on the type of transitions and the time spent in different postures was created.

A. Sitting and standing detection
A discrete wavelet transform (DWT), well suited for non-stationary signals such as human motion signals, has been used for the detection of sit-stand (Si-St) and stand-sit (St-Si) postural transitions. The DWT allows the analysis of the signal at different frequency bands with different resolutions by decomposing the signal into a coarse approximation (A) and detail (D) information. Wavelet decomposition can be obtained by successive high-pass and low-pass filtering of the time-domain signal with specially designed pair of Finite Impulse Response (FIR) filters called “Quadrature Mirror Filter” pair [1], [2] (Fig. 1).

![Wavelet decomposition tree.](image)

In this study, the DWT of afc acceleration allowed to detect the time of postural transitions (TT) and its duration (TD). The detected transitions have been classified based on the pattern of the aft signal. When
a postural transition was detected, the difference between the signal levels of the aft after low-pass filtering (aft-LPF) was evaluated before and after TT. The transition was classified as follows: St-Si, for a positive difference and Si-St, for a negative difference (Fig.2b). Lying-to-sitting transitions were detected from avc and aft signals (after low-pass filtering).

B. Lying detection
The lying posture was discriminated from sitting and standing by considering the orientation of the trunk vertical acceleration with respect to the direction of gravitational acceleration. In the lying posture, the acceleration signal is almost zero, while in sitting and standing it is around 1g [3].

C. Walking detection
Walking was detected from the gyroscope signal (gt) after discrete wavelet transform and periodicity detection. Physical activity was assessed as walking if more than three successive steps were detected.

Results
Figure 2a shows typical recorded raw signals for 5 minutes monitoring time. The St-Si and Si-St postural transitions have been detected based on aft-LPF and the approximation of trunk frontal acceleration signal (afc-DWT) between scales 5 and 8 (A5-A8) (Fig.2b). The decomposition has been performed with the five-order ‘coiflet’ mother wavelet. The classification of various physical activities during the monitoring time is shown in Fig. 2c.

The algorithm provides data regarding the time spent in different postures (Table 1) and the number of postural transitions as well as the duration of each postural change (Table 2). On the basis of this information it is possible to quantify and qualify the mobility of a patient. In our patients, increased posture transition time can be associated with difficulties related to persistent pain.
Considering the pooled data from all 9 patients, the observer recorded 121 postural changes (St-Si, Si-St), of which 115 was correctly detected and classified by the physical-activity-detection algorithm. This results in sensitivity between 92% and 100% (for 5 patients all postural transitions were correctly detected and classified). Note that the lying posture was detected with sensitivity higher than 95%. The walking activity (at least three successive steps) was detected with sensitivity higher than 90%. Figure 3 shows an example of how the observer and the algorithm have classified the activity recorded in one patient over a period of one hour.

![Figure 3](image)

**Table 1:** Duration of each physical activity in seconds and as a percent of monitoring time.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration (s)</th>
<th>Percent of recording time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting</td>
<td>110</td>
<td>37%</td>
</tr>
<tr>
<td>Standing</td>
<td>69.22</td>
<td>23%</td>
</tr>
<tr>
<td>Walking</td>
<td>58.05</td>
<td>19%</td>
</tr>
<tr>
<td>Lying</td>
<td>62.55</td>
<td>21%</td>
</tr>
</tbody>
</table>

**Table 2:** Total number of Si-St and St-Si postural transitions and duration of each postural transition.

<table>
<thead>
<tr>
<th>Transition</th>
<th>Number of postural transitions</th>
<th>TD (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si-St</td>
<td>3</td>
<td>2.7; 2.3; 3.05</td>
</tr>
<tr>
<td>St-Si</td>
<td>3</td>
<td>2.9; 2.6; 2.9</td>
</tr>
</tbody>
</table>

**Discussion**
We have developed an accurate method of monitoring the spontaneous physical activity that can be used in real life as opposed to laboratory conditions. The rate of measurement error is very low and is related to a few non-detected transitions corresponding to very short (a few seconds) sitting-standing-sitting (or inversely) postural changes. As a result, this algorithm can be used to reliably qualify (posture recognition) and quantify (time spent in each posture and frequency of postural transitions) the spontaneous physical activity over long period of time. In conclusion, our algorithm allows a new insight into the objective measurement of one of the primary determinant of the quality of life and the related improvements provided by neuromodulation treatment modalities.

**References**

**Acknowledgement**
This work was supported by Medtronic Europe S.A. The authors acknowledge the contribution of Mr. J. Gramiger and Mr. P. Morel in the design of the kinematic sensors and portable data logger.