SENSE-PARK

<u>Deliverable D5.2.1:</u>
Report on D5.2 Presentation of algorithms and software for sensor system prototypes

FP7-INFSO-ICT-288557

Name of deliverable: D5.2.1 Report on D5.2 Presentation of algorithms and software for sensor system prototypes

Due date of deliverable:	Month 24 (01/October/2013)
Start date of the project:	1/10/2011
Duration:	36 months
Date of preparation:	15/10/2013
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Responsible of the deliverable:	Partner 5 (HSG-IMIT)
Target Dissemination Level:	PU (Public)
Status of the Document:	DRAFT
Version Document:	0.1
Project web site:	www.sense-park.eu

Executive Summary

This deliverable report D5.2.1 presents the algorithms and software for the sensor system prototypes (Task 5.2, Task 5.3, Task 5.5 and Task 5.6). The development of the algorithms (Task 5.2) has been finished. Testing and optimization (Task 5.3 and Task 5.6) remains to be done based on the results of an upcoming testing series in collaboration with project partner CPT (starting on December 1st in agreement with the project's time schedule).

Regarding the development of a virtual reality-based test and training system with a strong and encouraging gaming character (cf. task 5.4), the consortium followed two approaches that allow to retain the focus on validated measurement: for the assessment of the *cognitive function* domain integration of the training and game environment provided by the RehaCom-Software of project partner HASOMED and for the measurement of the *sway* domain the integration of the Wii balance board that give access to VR gaming environments such as the car driving simulator that has been implemented in the SENSE-PARK system. The validation for the domain *cognitive function* has successfully been done.

History

Version	Date	Due of Creation/Update	Revised/Updated by
0.1	15/10/2013	First Draft	Stefan Meckler (HG-IMIT)

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1 Introduction

We present the work done in work package 5 of the project ‘Supporting and Empowering Parkinson patients in their home environment using a Novel Sensory information system that monitors daily-life-relevant parameters of Parkinson disease and their’ known as SENSE-PARK. The report refers to the following tasks:

Task 5.2: *Algorithms and software development* (HSG-IMIT, EKUT)
- Algorithm development for parameter extraction
- Implementation of algorithms for pre-processing and compression on wrist device
- Implementation of algorithms on home-based PC

Task 5.3: *Tests and optimization* (HSG-IMIT, EKUT)
- Tests with PwP’s in lab environment
- Refinement and optimization of algorithms based on lab test results

Task 5.4. System development (HSG-IMIT, Hasomed)
- Setup of a virtual reality environment
- Incorporation of available gaming interaction hardware

Task 5.5: *Definition & implementation of training procedures* (HSG-IMIT, Hasomed, EKUT)
- Definition of training procedures/games
- Development of scoring methods for training procedures/games

Task 5.6: *Tests and optimization* (HSG-IMIT, EKUT)
- Tests in lab environment with PwP’s
- Optimization based on test results

2 The Software Concept

One of the major goals of the SENSE-PARK project is to develop an information system that can be used in the home environment of PWP's. It provides the patients with tools to continuously monitor and visualize their health conditions. Motion data is acquired and temporarily stored by the wearable sensor hardware system. Additionally, cognitive data are acquired through the application of a set of three games that have already been validated. The temporarily stored sensor information is transferred to the PC, where all acquired data (motion and cognitive) is stored on a database (Deliverable 5.1).

Based on the *sensor data* the PWP's motion characteristics is analyzed in terms of five previously identified domains being important from a medical perspective:

- Tremor
- Sleep
- Sway
- Gait
- Bradykinesia, Akinesia and Dyskinesia:

Every domain is tackled by a specific algorithm that processes the relevant data and provides the results in terms of an output-file which is used for visualization on the user's screen (work package 6). Additionally, the results are stored for a later assessment by the clinical advisor.

Like the sensor data, the *cognitive function data* are also processed in order to draw conclusions based on the users performance. The environment in which the user performs the test includes several games including car drive simulator that was deemed as particularly motivating and providing fun. As for the motion domains, the cognitive function data are additionally stored for a later assessment or sharing.

3 Motion-related algorithms (Tasks 5.2 and 5.3)

For all five domains prototype algorithms were developed using a numerical computing environment (Matlab/Octave). Afterwards, the algorithms were ported to C/C++ and deployed in form of Windows Dynamic Link Libraries (DLLs) being executable on all standard Windows PCs. To keep the interface to the CAT system (WP6) as simple and convenient as possible, every domain relates to only one specific DLL-function with uniquely defined input and output parameters. All parameters are read from/written to specific files with file names and respective paths being defined by the user of the DLL-function when calling it.

3.1 Tremor

Functional Description (Task 5.2)

The algorithm for the tremor domain (cf. previous report) was further improved and transferred into the DLL-format. Afterwards it was integrated into the CAT system (WP6). The algorithmic concept is visualized in **Fig. 2.** An example of the output would be: “Tremor occurred from 10:34:05 to 10:41:55 with mean peak frequency 4.5Hz and mean peak amplitude 16db”.

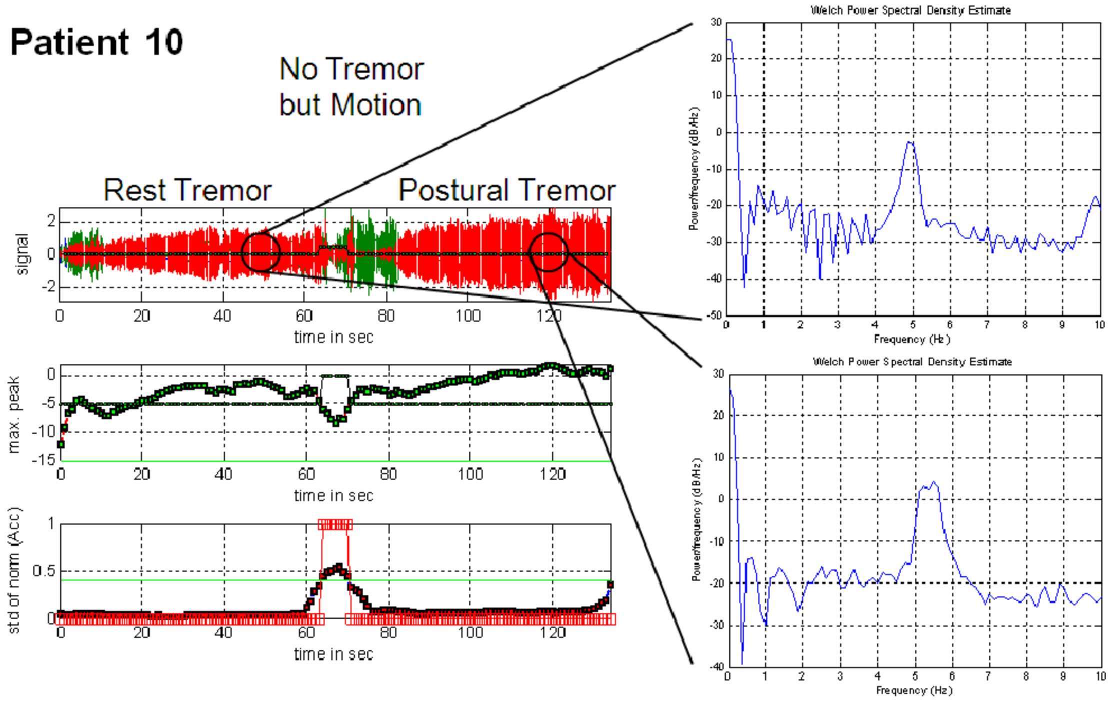

Figure 1: The accelerometer signal in the time domain (upper left) is transformed into a corresponding signal in the frequency domain, as shown for two different time intervals (right). Tremor classification is finally based on the knowledge that a tremor usually has a frequency in the 3.5-10 Hz regime. From the power spectral densities (right) the peak maximum can be deduced as a function of time (center left). Superimposed non-tremor like movements can be extracted by calculating the standard deviation of the signal’s norm (bottom left).

Validation, Testing and Optimization (Task 5.3)

The algorithm was developed and trained using only a subset of the available test data as acquired for various persons with and without Parkinson’s. The remaining, yet unconsidered, test data will be used for validation of the algorithms. In addition the algorithm will be continuously revised with respect to user convenience based on the available user feedba

3.2 Sleep

Functional Description (Task 5.2)

The algorithm for the sleep domain (cf. previous report) was further improved and transferred into the DLL-format. Afterwards it was integrated into the CAT system (WP6). The algorithmic concept is visualized in **Fig. 3.** An example of the output would be: “A trunk transition occurred at 03:15:17 to 03:15:19 with 95° rotation.”

The current version of the algorithm employs error-state Kalman filtering. This approach allows an estimation of the gyroscope offset and thus a more accurate calculation of the rotation angle which is extracted from the angular rate signal by the subsequent application of low pass filtering and signal differentiation. Finally, the algorithm identifies those time intervals when the angular signal changes quickly, i.e. the when the modulus of the angular signal's derivative is above a defined threshold. The angular difference within each interval is finally interpreted as a body rotation during sleeping.

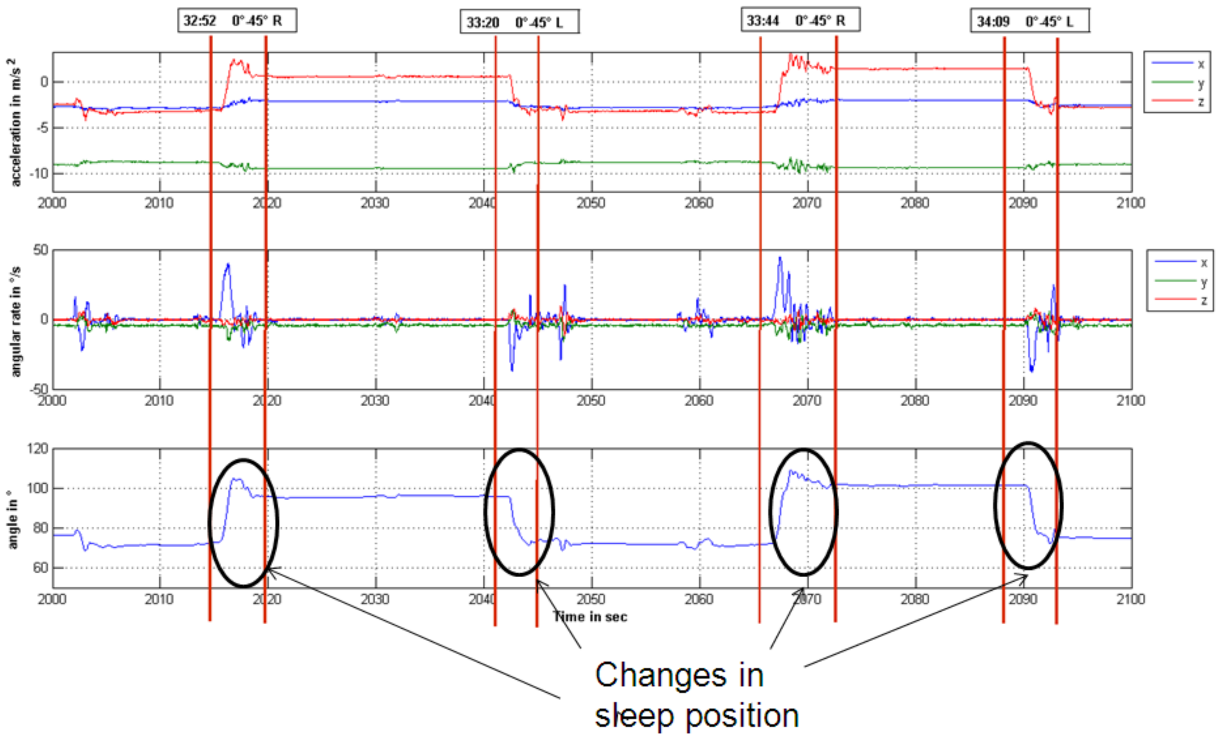

Figure 2: Example for the detection of body rotations during sleep. In the top plot a rotation around an axis parallel to the earth surface is detected by the accelerometer due to gravity. Together with the angular rate given by the gyroscope (center) an accurate and drift free angle measurement for the body rotation during sleep can be calculated (bottom).

<u>Validation, Testing and Optimization (Task 5.3)</u>

The algorithm was developed and trained using only a subset of the available test data as acquired for various persons with and without Parkinson's. The remaining, yet unconsidered, test data will be used for validation of the algorithms. In addition the algorithm will be continuously revised with respect to user convenience based on the available user feedback.

3.3 Sway

<u>Functional Description (Task 5.2, 5.4)</u>

For the measurement of the sway domain the wii balance board was integrated into the systems. This enables the measurement of sway and the respective validation through available validated devices. Based on this the integration and measurement of the VR Rehacom *car driving simulator* is being done and also the connection to the wii gaming environment can be implemented.

The algorithm for the sway domain (cf. previous report) was finished and transferred into the DLL-format. Afterwards it was integrated into the CAT system (WP6). The center-of-mass movement is visualized in **Fig. 4** for three different scenarios. An example of the output would be: “0.05 RMS, mean velocity of 1m/s, 95% of the power is below 1Hz, the frequency dispersion is 0.8 and Jerk is 0.5 m^2/s^5”.

The goal in the sway domain is to gather information on the postural stability of a person. The Wii balance board is used as the measuring device. Therefore the previously described interface to the Wii balance board has been revised and enhanced for a smooth integration into the CAT system (WP6). This includes a logging functionality, additional interface functions for better control as well as the automated detection and connection of the balance board via Bluetooth.

To be able to compute the parameters, the user (or PWP’s) must stand still on the balance board for some time (e.g. 30s). From the recorded balance board (four sensors) the center-of-mass movement (sway path) is calculated. In addition, various statistical measures known from literature on assessing postural stability are calculated (time domain as well as frequency domain parameters). Every parameter is calculated for the antero-posterior as well as the medio-lateral direction.

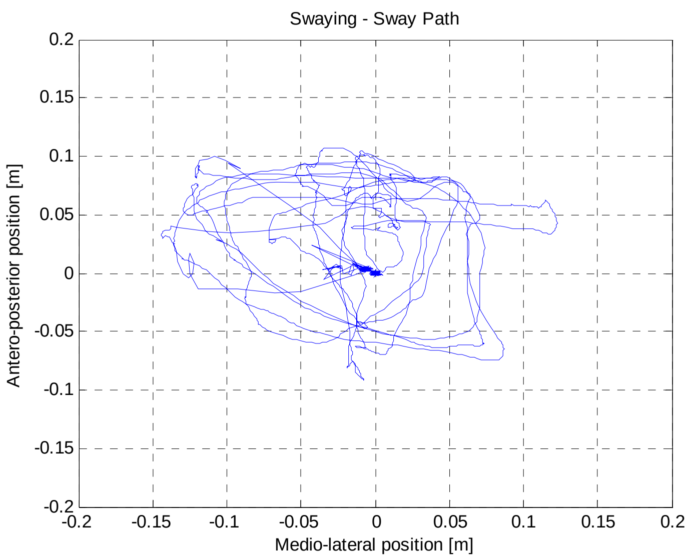

Figure 3: Sway path (about 30s) as calculated from the sensor data (balance board) for a healthy test person. Note, that the swaying ‘radius’ was artificially increased by the test person in order to get a distinctive sway path. Otherwise the observed standard deviation would be much smaller in case of a healthy person.

The first component of the VR gaming environment which has been implemented through the wii balance board is the Rehacom car drive simulator that was deemed as particularly motivating and providing fun. Data stemming from this game can be stored and parameters can be provided, however, for the time being the focus is on having fun. The usefulness of these parameters for the assessment of the disease will not be validated because of the complex nature of this measurement presenting a combination of static sway under (internal) perturbation and cognitive function (e.g. reaction time, dual tasking behaviour, attention).The same applies to all other wii games being played standing on the wii balance board.

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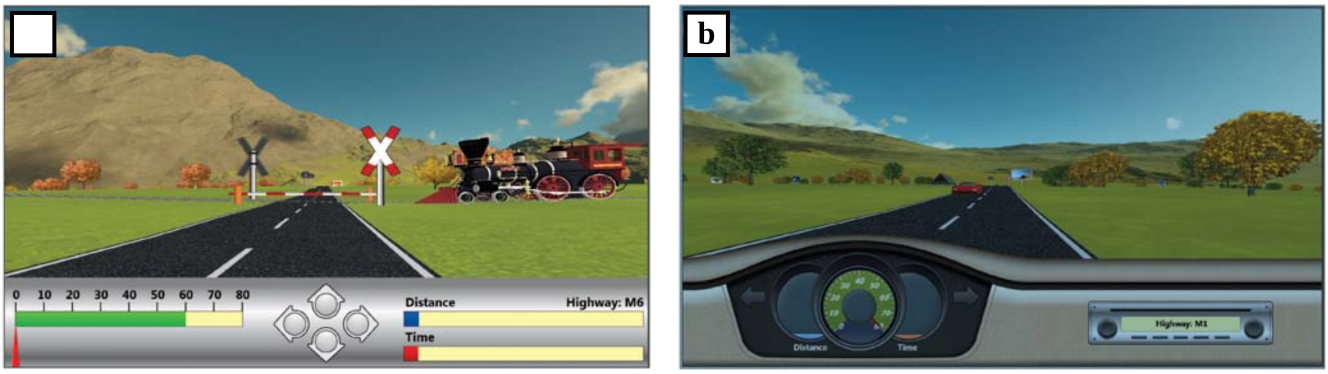

Figure 5: (a) Training surface. (b) Training surface with parameter setting "Cockpit view".

Validation, Testing and Optimization (Task 5.3)

The algorithm was developed and trained using only a subset of the available test data as acquired for various persons with and without Parkinson's. The remaining, yet unconsidered, test data will be used for validation of the algorithms. In addition the algorithm will be continuously revised with respect to user convenience based on the available user feedback.

3.4 Gait

Functional Description (Task 5.2)

The basis for extraction of parameter in the gait domain is a robust step detection algorithm. Different to the description in the last report we use the sensor unit attached to the lower back for the step detection. This has the advantage that arbitrary movements of the legs (e.g. while sitting on a chair) don't lead to a detection of a step. The algorithm for step detection is based on a popular algorithm in literature which proofed to be among the most reliable approaches. Its basic working concept is visualized in **Fig. 5**. The estimation of the step length was discarded as it is not very accurate and should be tuned to every person. On the other hand we now consider a new parameter turning which gives the degree of the turns made during walking. The algorithm is mostly there only the parameter step rhythmicity still needs some revision. An example of the output would be: "walking between 15:00:50 to 15:01:30 with 25 steps a step rhythmicity of 0.2. During this walk there was one turn with 45°".

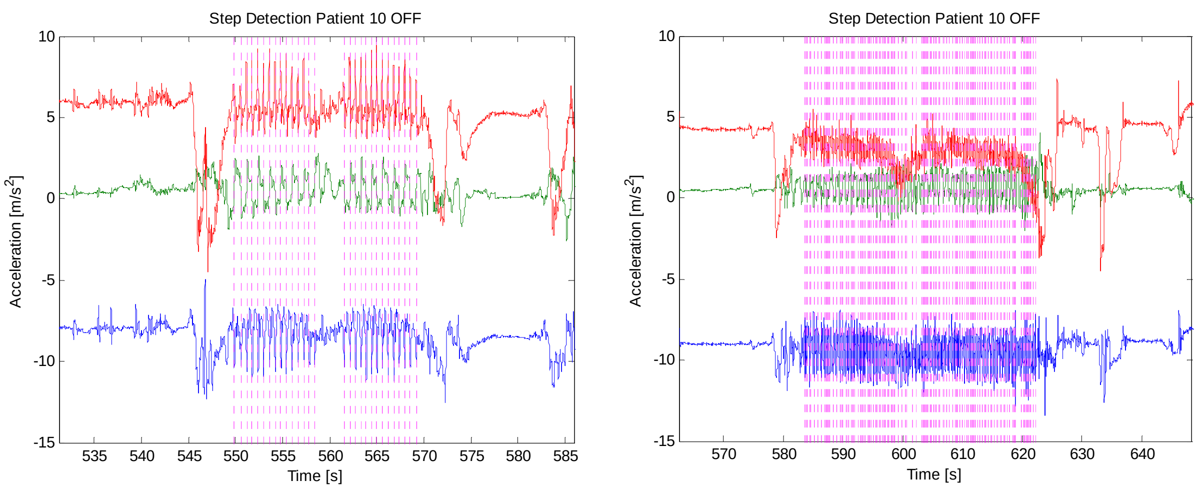

Figure 6: Walking example for a person with a healthy walking pattern (left) and a person with severe gait symptoms (right). The blue, green and red lines show the accelerometer signal recorded by the sensor unit attached to the lower back. The magenta dotted vertical lines indicate the steps detected by the algorithm. Note that the scenario depicted in this signal is standing up from a chair, walking straight about 6m, turn by 180°, walk back to the chair and sit down. While the healthy like person only required about 30 steps to accomplish this, the severely impaired person needed ~160 Steps.

Validation, Testing and Optimization (Task 5.3)

The algorithm was developed and trained using only a subset of the available test data as acquired for various persons with and without Parkinson's. The remaining, yet unconsidered, test data will be used for validation of the algorithms. In addition the algorithm will be continuously revised with respect to user convenience based on the available user feedback.

3.5 Bradykinesia/Akinesia and Dyskinesia

Functional Description (Task 5.2)

For this domain it was decided to follow an approach from the literature which scores the symptoms continuously throughout the day. Whereas Bradykinesia/Akinesia is detected by the algorithm in form of unusually slow motion signals, Dyskinesia is considered to result in shorter periods without movements. First algorithm approaches have been already implemented and some simulations have been carried out, however this domain is still in the early development phase. Unlike in the other domains the parameter extracted here are continuous, i.e. there is a score for each time interval (e.g. 2min).
An example of the output would be: "from 10:34:00 to 10:36:00 the bradykinesia/akinesia score is 20 and the dyskinesia score is 60".

Validation, Testing and Optimization (Task 5.3)

The algorithm was developed and trained using only a subset of the available test data as acquired for various persons with and without Parkinson's. The remaining, yet unconsidered, test data will be used for validation of the algorithms. In addition the algorithm will be continuously revised with respect to user convenience based on the available user feedback.

4 Cognition-related algorithms (Tasks 5.4., 5.5 and 5.6)

Functional Description (Task 5.4, 5.5)

For the assessment of the cognitive function domain the project consortium decided to use and integrate the training and game environment provided by RehaCom-Software of the project partner HASOMED (cf. task 5.4.). Like the sensor data, the *cognitive function data* are also processed in order to draw conclusions based on the users performance.

Validation, Testing and Optimization (Task 5.6)

The neuro-psychological validity of the software has been assessed in the framework of a clinical study at the Instituto de Medicina Molecular at the university of Lisbon (cf. task 5.4).

The validation study showed that for all variables the “games” (i) divided attention, (ii) visual exploration and (iii) working memory were found to perform reliably and also good correlation with neuropsicological tests as well as no learning effect from one visit to the second could be shown. Thus, these three “games” present a validated game environment for measurement of cognitive function.