A system for monitoring health and social care essay

Neurodegenerative diseases are characterized by the progressive loss of neurons in the central nervous system. The most common disorders are Alzheimer's disease and Parkinson's disease (PD). The risk to develop those devastating diseases increases sharply with age: PD affects 1% of the population over 65 years of age, rising to 2% for those over 80 years. With an increasingly ageing population, neurodegenerative diseases will assume greater importance. The cases for PD are expected to double worldwide by the year 2020. Proper medical care of these patients is getting increasingly complex and expensive. Lengthy hospital stays for monitoring and adjustment of the patients' treatment and the problems related with it, contribute to cost increase and morbidity because of the hospitalization itself. In the current medical practice, assessment of PD motor disabilities is based on neurological examination during patient's visits to the clinic and home diaries that the patient or the caregiver keeps. However, the short-time examination may not reveal important information to the neurologist while data from the daily diaries are highly subjective since they rely on the patient's memory and perception of his own symptoms. In addition, most of the patients may not be aware of mild symptoms or not be able to identify early " wearing off", while they may unconsciously exaggerate or attenuate symptoms' severity. To address these problems and to find more objective assessments, several rating scales have been designed and used, with the Unified Parkinson's Disease Rating Scale (UPDRS) being the most widely used [1]. UPDRS is a rating scale that quantifies selected symptoms and signs of PD in a 5-points scoring system. Unfortunately, UPDRS presents intra and inter-observer inconsistencies, while its use is limited to the patient's visits to the hospital. Also, the pattern and severity of PD symptoms may

vary considerably during the day, while clinical rating scales only provide moment-to-moment assessments; and finally, measurements of motor functions made in the clinic may not accurately reflect the actual motor disabilities experienced by the patients in their daily life. In addition to rating scales, akinesia and gait are sometimes evaluated by means of other tests (timed motor performance test, Purdue pegboard test, pronation-supination test, finger dexterity, etc.). Also, objective methods have been suggested to quantify rigidity [2]. While these methods are quantitative, again they only provide information limited to the clinic settings. To overcome these limitations ambulatory monitoring of PD motor symptoms methods have been presented in the literature.

2. Related Work

A limited number of movement analysis systems have been described for the ambulatory measurement of the various aspects of movement disorders in PD. Electromyography (EMG) has been used for a long time to study tremor in PD, detect basic body postures and study gait in PD patients [4]. However, EMG does not directly measure movements while a large number of electrodes may be needed to study complex movements. Recent developments in microelectronics have led to design and production of a new generation of small, cheap and robust sensors that can be used to measure kinematic parameters of the movements of the body segments. These developments have breathed a new life in design of ambulatory systems for long-term monitoring of body movements. Accelerometers and gyroscopes have been used to detect and quantify tremor [4-8], bradykinesia [4, 9] and LID [4, 10-14] in PD patients. Ambulatory gait

analysis systems have been design based on accelerometers [15, 16] and gyroscopes [17] for healthy subjects, elderly and pathological cases. These sensors have been used as activity monitor [18] or for the classification of different body postures [19, 20]. The market offers plenty of solutions concerning the remote health monitoring of people with pathologies involving the motor system such as PD. Some examples of products and projects include: University of Sussex PD tremor and dyskinesia project involves detecting, recording and processing the movement of patients' tremor and dyskinesia to help with looking for symptoms of the disease and to also monitor the changes, once treatment starts and carries on. The prototype system was not portable and data acquisition was made in laboratory settings. Physilog is an ambulatory system for body motion analysis. Movements are measured in one or three dimensions using one or multiple kinematic sensors. Single and three axis sensors are fixed on the body through a belt or directly attached on the skin using medical tape and supports. The project assesses motor function in PD and functional disabilities, during daily activities of the patients. Combination of the signals from different sensors is taken into account to address Tremor, Akinesia and Dyskinesia. The HealthSensor 100 is a fall detection device. It monitors a person's movements with advanced solid-state accelerometers. When specific " fall criteria" are met an alarm is activated. Unlike any other fall detection method, the HealthSensor's " Intelligent Monitoring" technology enables it to distinguish a fall from such routine activities as lying down, sitting down or climbing stairs, virtually eliminating false alarms. Portable Motus System quantifies movement bradykinesia, dyskinesia and tremor, monitors efficacy of drug treatment for movement disorders using a unique

miniature solid state gyroscope which however senses only rotational motion. However most of these commercial products have limited focus on a single motor symptom and not overall assessment and lack important characteristics for Parkinson's disease and monitoring services such as: long-term recording, qualitative and quantitative assessments, high reliability, sensitivity and specificity. Also, a few EU R&D projects have been funded, most of them covering the assessment of motor performance and the design of training and rehabilitation programs for PD patients, by incorporating virtual reality auditory feedback, interactive video conference technologies and conventional kinematic analysis: The Rescue Project an EU funded R&D project investigates a physiotherapy technique to improve mobility for people with Parkinson's disease. It introduces a rehabilitation programme based around the concept of cueing and focuses mainly on the effects of bradykinesia and akinesia on walking and everyday activity. The cueing techniques used can improve the quality of walking and gait-related activities by providing an alternative means to guide movements, helping in overcoming and preventing so-called freezing episodes in which patients with PD report ' being glued to the ground'. PARREHA Assistive technology in Parkinson's rehabilitation is an EU funded R&D project concerned with the assessment of motor performance and design of " therapeutic" Virtual reality exercises supervised by video-conferencing. In May 2003, the PARREHA consortium formed ParkAid, a start-up company whose sole aim is to exploit ParkWalker and build a supporting service around it (ParkService). ParkService extended the PARREHA support to sources of exclusion not specific to PD by providing wireless home connectivity to specialised carers and also off-line services such as reminders to the user of their personal drug

regime. ParkAid also developed ParkWalker from the PARREHA prototypes – concentrating on ease-of-use and comfort. ParkWalker, which recently took the commercial name of INDIGO (INDependent IGO), is based upon a small display which clips on to a normal pair of glasses. Visual stimulation is generated by a small portable device which can also wirelessly connect to a clinician when the user is at home. DAPHNE Detection of Activity Performance for Health with New Equipment is another EU R&D funded project, allowing for quantitative measurement of neurological and psycho-physical health state. It proposes a portable computerized instrument that measures fundamental parameters of Parkinsonian reactive capabilities. The patient can perform several tasks like button pressing and vocal feedback in response to acoustic and visual stimuli. The system collects all reactive parameter changes, caused by different reasons such as stress or fatigue, and transmits them to operational health centres so that a wellness rate can be obtained. NEUROSHIELD is an EU-funded R&D project that addresses the need for new treatments for a range of neuro-degenerative conditions, such as Parkinson's disease, aiming to deliver `an improved range of neuro-active drugs, an enhanced understanding of the mode of action of the drugs and a greater capacity to monitor their application with minimal invasion to the patient's life. Thus, NEUROSHIELD mainly focused on new treatments. In this paper, the PERFORM system is presented Fig. 1. The system is designed and implemented to tackle problems associated with the efficient remote health status monitoring, the qualitative and quantitative assessment and the treatment personalisation for people suffering from PD. The system is based on wearable accelerometers and gyroscopes for monitoring the disease evolution and intelligent techniques for detection and assessment of

common PD motor disabilities. The system has been evaluated under real clinical conditions.

3. Motivation

A difficulty that physicians have to deal with is the inefficient and non-objective recording of the disease symptoms like tremor, levodopa-induced dyskinesia, bradykinesia, gait freezing and falling. The daily symptoms and times of crisis are not adequately described by the patients and, on the other hand, a short office or hospital visit or medical examinations cannot provide a clear picture of the patient's status and the disease progress. PERFORM system becomes the mediator between the physician and the patient by collecting all necessary information on a daily basis allowing thus the physician to be constantly informed about the patient's clinical state and readjust appropriately the treatment plan by changing the medication dosage and food intake (Fig. 2).

4. Perform System

PERFORM system consists of three subsystems: the Wearable Multi-Sensor Monitor Unit, the Local Base Unit and the Centralized Hospital Unit (Fig. 1).

4. 1. System Architecture

4. 1. 1. Wearable Multi-Sensor Monitor Unit

The PERFORM wearable multi-sensor monitor unit (WMSMU) is physically attached to PD patient's body. The key role of this unit is to facilitate the monitoring of patient's daily motor activity and status through the continuous recording of specific signals. As the name implies it is a light-weight wearable device composed of four tri-axial accelerometers (ALA-6g

accelerometers) used to record the accelerations of the movements at each patient extremity, one accelerometer/gyroscope on the waist (AGYRO device) used to record body movement accelerations and angular body velocity during body turning, and one data acquisition unit which is called Parkinson Daily Data Set Logger (PDSL-1 logger), receiving all recorded signals. The AGYRO device must be permanently attached to the PDSL-1 device by means of a long wire, while the ALA-6g accelerometers communicate wirelessly making up a body sensor network (Fig. 3). The sensors position was chosen after careful examination and research on the targeted disease symptoms. The signals recorded through the five sensors are later transferred to the Local Base Unit (see details in section 4. 1. 2) where they are stored and processed.

Functionality

The PERFORM WMSMU and specifically the PDSL-1 logger (which is the main part of the PERFORM WMSMU) support two modes of operation: (i) Personal Computer (PC)-Connected Mode, and (ii) Normal Operating Mode (stand-alone). PC-Connected ModeThe PDSL-1 logger enters automatically to this mode of operation, when a connection with a PC via a standard miniB USB cable is detected during power-on. In PC-Connected Mode the user can perform the following tasks by means of the Simple Detector software tool: Get/Set the device date and time. Configure the device operating parameters. Design the monitoring and testing schedules. Acquire the monitoring and testing sessions sensor data stored into the SD card. Design the patient medicines and appointments schedules. Acquire events occurred. Acquire device malfunctions. Wireless sensor's contact loss/re-

connectionNormal Operating Mode (stand-alone)The PDSL-1 logger enters into this mode of operation, when a USB connection is not detected at power-on (Fig. 4). In Normal Operating Mode, the PDSL-1 logger conducts the following tasks: Executes the predefined monitoring schedules. Executes the predefined testing schedules. Stores sensor data into the SD card. Alerts the patient about the medicines according to the predefined medicines Schedules. Alerts the patient about the appointments with the doctors according to the predefined Appointments Schedules. Sends SMS in the case the patient presses the emergency button or when a patient fall is detected. Receives Acknowledged SMS. Detects sensors contact losses and reestablishments. Monitors memory occupation.

4. 1. 2. Local Base Unit

Local Base Unit (LBU) composed of a touch screen computer which is located in the patient's settings along with the WMSMU and the test devices (Fig. 5). It is mainly responsible for downloading, storage and processing of the raw signals coming from the test devices and the WMSMU, the identification and quantification of motor symptoms, the UPDRS evaluation of the patient and the patient's diary keeping (entries of time of drug and food intake). The signals coming from the PERFORM WMSMU are processed by the Daily Monitoring Processor (DMP) which is composed of the following modules: Tremor (Posture and Resting) Recogniser, Levodopa-Induced Dyskinesia Recogniser, Freezing of Gait Recogniser, Bradykinesia Recogniser and Activity Recognizer. Furthermore, additional data coming from the test devices (glove, camera and microphone) are obtained through the Device Controller and are processed by the Test Processor, which is the component

of LBU, responsible for controlling the functionality of test devices. The Test Processor acts as an intermediate between the Test Devices and the LBU, implementing operations concerning the calibration of the test devices, the management of the connection established between the LBU and the test devices, as well as the data handling of the content recorded by the device. Finally, Test Processor provides the functionality for performing various tests (e. g. Hand Moving, Alternate Hand Moving, Fist/Open Close etc) with the glove device. There are several other modules in the LBU subsystem; each of them is playing a distinctive role. The Scheduler is in charge of monitoring the different patient schedules (monitoring, testing, medication, appointments) and providing reminders to the patient through the LBU user interfaces. It is also responsible for the synchronisation of old and new schedules (updated by the clinician in the Centralized Hospital Unit) and the transfer of these schedules to the wearable multi-sensor monitor unit. The Information Handler controls all the processes and workflows executed and provide a data access layer to the LBU Repository. All modules in the LBU are interfacing with the Information Handler and their outputs are transformed internally in order to be used as inputs for other modules. Finally the Communicator is responsible to retrieve the latest data from the LBU, compose XML messages, encrypt them and transfer them to the Centralized Hospital Unit.

4. 1. 2. 1. Functionality

In this paragraph, we only proceed to an analysis of Patient GUI (P-GUI) functionality and the services that it offers to end users. In section 4. 2, there is a detailed description about the System Intelligent Modules and the

functionality of Intelligent Graphical User Interface (IM-GUI). The patient GUI (P-GUI) of LBU supports different modes of operation (Fig. 6). Emphasis is given in designing an easy to use interface for the PD patient, considering the patient motor disabilities and limited computer familiarity. The designed interface inherits the feel and tough of the phone dialling pad, and all system choices are based on it. The same options are given to the caregiver in case the patient is not capable of using the system due to the severity of his/her symptoms. PD patient uses the interface to declare their subjective estimation of their own status, to gain access to relevant disease information, to receive instructions on life-style interventions, such as medication and good intake and on the execution of tests. Moreover, PD's patients declare medication intake information, which is useful for the patient status assessment. The main functionalities of P-GUI includes: (i) Changing Personal Data, (ii) Checking Appointments Schedule and Monitoring Sessions Set-Ups, (iii) Inserting Medication, Food Intake Information and filling out a Self-Assessment Questionnaire and (iv) Performing Test Sessions. Changing Personal DataThe patient data are shown in the P-GUI. The configuration can be changed in the Configuration Menu> Configure Patient. The personal information can be changed according to the patient's inputs or doctors suggestions (Fig. 7). Checking Appointments Schedule and Monitoring Sessions Set-upsThe appointment and monitoring sessions are shown daily in the P-GUI. Once the doctor schedule a new appointment or monitoring session, the patient can check it in the Schedules Menu > Appointments or in the Schedules Menu > Monitoring Sessions, respectively (Fig. 8). Inserting Medication, Food Intake Information and Filling out a Self-Assessment QuestionnaireThrough the

Questionnaire Menu screen (Fig. 9), the patients could insert the following information: Medication intake (kind, dose and time), Meals (type of food, amount, time), The auto-evaluation questionnaire (PDQ39 for the quality of life). This information is important to be correlated with motor information, fluctuations and dyskinesia. In fact, motor behaviour strongly depends on the assumption of the medication (in the usual patient's dosage) and the metabolism of the drug is influenced by the diet (proteins or fats). Performing Test Sessions. Through Tests Menu screen, the patient is able to initiate any of the available tests such as Speech, Face Expression, Finger Tapping, Fist Open/Close, and Alternative Hand Movement using the virtual reality glove (standalone application) as well as the microphone and video camera of the touch screen (Fig 10). The patient performs the tests as instructed from the visual interface of the P-GUI (Fig. 11).

4. 1. 3. Centralized Hospital Unit

Centralized Hospital Unit (CHU) is actually positioned to the clinician's setting. The CHU is dedicated to processing all patient data and assisting the treating clinician in making appropriate treatment decisions. CHU subsystem is responsible processing further the classified results of LBU in order to extract further knowledge, produce automated proposals for patient treatment, as well as generate alerts to inform the clinician for the patient condition. The three core components of the PERFORM CHU subsystem are: (i) Alert Manager, (ii) Information Manager, and (iii) Interoperability Manager. The Alert Manager can be seen as the administrator of the Clinical Decision Support Systems (CDSS). It is the only module at the CHU subsystem which is aware of the internal data flow and data dependencies of the various

modules in the CDSS, so its role is crucial for system's operation. Depending on the data arriving from the numerous LBUs, the Alert Manager creates the workflow that needs to be executed and then triggers all relevant submodules or CHU models/manager (Gait, ON/OFF, LID, Tremor, Bradykinesia, Often Patient/Fall, Early Wearing Off, Medication Change Proposer and Stability/Worsening). Depending on the alerts generated by these submodules, the Alert Manager handles the prioritization and representation of the newly produced alerts. During this process, the Alert Manager is responsible to keep a log, that contains information about the start and end time of each sub module's process for a specific patient, so as to check if every operation runs on time and the overall system's performance. The Information Manager since is the only module with knowledge on the Repository schema, is responsible of fulfilling the needs for data retrieval and storage of the rest of CHU modules. It triggers the execution of other modules depending on the information received and stores the produced data into the central unit Repository. All of the PERFORM submodules interact directly with the information manager and cannot interact with the PERFORM repository. The information manager is the " middle-man", the link between the PERFORM repository and all sub modules wishing to exchange (either retrieve from or store to) information with it (Fig. 12). Finally the Information Manager is responsible for handling the LBU's User Data Requests, generated by the user interface. The Interoperability manager is the link between the PERFORM system and external hospital and clinical information systems. It coordinates the overall information exchange between these legacy systems and through the information handler it may provide a more holistic view of the patient status, providing past information

stored in external systems. All functions of the information manager are utilised by the PERFORM clinicians, yet they are transparent to these end users.

4. 1. 3. 1. Functionality

Clinician GUI (C-GUI) is web-based application. This application can be accessed either locally or remotely by the treating clinician and the general practitioner, using either a large or small screen access device (e. g. PC, laptop). Clinicians are directed to the home system screen, which presents the produced patient alerts to the patient specific screen, which provides the information needed to evaluate visually the patient condition. On request, the actual recorded signal and tests are downloaded from the patient-side to the healthcare centre for review. The focus is on the provision of an adequate visual description of the patient status within one screen, minimising the time spend by a clinician. Clinicians access the system periodically to check patient status, but the option to be alerted when patient status changes are also available. The key functionalities of P-GUI includes: Searching for a Specific Patient, Patient Summary, Patients Tests, Extracting Information of Symptoms Appearance, Extracting Information about ON/OFF Periods, Changing medication intake Changing an appointment, Searching for a specific patientOn the right corner of the Main Menu of the Web Site, the user can search for particular patient names. As shown in the following figure (Fig. 13), all names matching the text typed in this text field are shown in a drop-down list, in order to make it easier for the clinician to find the patient name. Patient summaryAn overview of all patient events is presented on this page (Fig. 14). Tremor, LID, Bradykinesia,

Freezing Events, Falls, Test results, Meals and medication intakes are presented (depending on the time each one happened) on a scheduler timeline. In addition, a clinician is able to propose a new medication to the patient or ask the patient to run several tests. These test results will also be shown on the scheduler, as soon as is defined by the treating clinician. Patient TestsEach patient performs tests by using a monitoring set. All the results of these tests are available to the clinician on Tests Page (Fig. 15). Extracting information of symptoms appearanceTremor, LID, events and falls are the four symptoms which are represented on graphs (Fig. 16). For each of the above symptoms, one daily, one weekly and one monthly graph is created for the duration (Tremor, LID and Bradykinesia), the severity (Tremor, LID, Bradykinesia), the asymmetry (Tremor, Bradykinesia), the onset (Tremor, LID, Bradykinesia) and for the number of falls the patient had that where or where not connected to freezing. The clinician is able to choose the symptom he/she wants to view on graphs from the first drop-down list. Then he/she can choose to view all or one of the graphs separately, by making a selection from the second drop-down list. Finally, all these results which are presented on these graphs, can be exported to an excel file, by choosing the start and end dates and pressing " Save" button. Extracting information about ON/OFF periodsDoctor can extract information about ON/OFF period accessing to a specific interface page (Fig. 17). On this page all the UPDRS Scores for the selected patient are available for the user on UPDRS Scores Page. On the left of the page there are all the scores for the selected date. The selection is made using the date-time picker on the upper right corner of the page. On the right side of the page there is a weekly demonstration of the scores on charts. There is also the ability to

have all these scores for selected dates in an excel file, by pressing the "

Print" button on top of the page. Changing medication intakeThe clinician

can prescribe a new medication to the patient and ask to perform some tests

or day monitoring sessions (Fig. 18). This can be done by right clicking on

the scheduler and choosing " New Scheduled Event" on the menu that shows

up. The form which is used for this purpose is depicted in figure 18. Changing

an appointmentClinicians can define and review their appointments with

their patients on Appointments Page (Fig. 19). On this page, there is a

scheduler (which is kind of an agenda), on which all appointments are

depicted as boxes on the time line which corresponds to the time of the

appointment. If the clinician has made his/her customizations concerning

working hours, this scheduler (calendar) starts from the working hours of

each clinician. On the scheduler, there are all the appointments for the

selected date. The clinician can change dates with two different ways: by

clicking the arrows on the left upper corner of the scheduler, or by right

clicking on the scheduler and selecting " Go to Date" from the menu which

shows up. This menu also contains " New Appointment". If a clinician clicks

on it, a new form shows up and the user can edit a new appointment for any

patient. All the appointments on the scheduler can be changed any time, by

right clicking on the appointment the user wants to edit and choosing "

Open". A form containing previous information about this appointment shows

up. The fields of this form are editable, and the clinician can choose between

saving changes and cancelling the action. A clinician can also change the

time of the appointment by dragging and dropping it on another time line.

Any appointment can be deleted permanently, either by right clicking on it

and selecting " Delete", or by right clicking on it, selecting " Open" and then pressing " Delete" button on the form which shows up.

System Intelligent Modules

The core of the PERFORM system is a set of intelligent modules capable of automatically assessing PD common motor disabilities based on processing of the accelerometer and gyroscope signals and machine learning techniques. In order to provide a complete tool to the neurologist, the PERFORM system includes intelligent modules for tremor, bradykinesia, LID and FoG, which comprise the most common PD motor disabilities, along with several additional tools.

4. 2. 1. Functionality

Upon connection of the data logger to the LBU, all files included in the data logger are identified and can be downloaded locally, i. e. from the data logger to the LBU (Fig. 20). Then the selected signal is downloaded and processed using the set of intelligent modules. After processing is finished, the results menu is displayed (Fig. 21). By selection the appropriate button, the results of the analysis of the signal is displayed (Fig. 22). In the same context, results can be presented for all functionalities presented in Fig. 23. Indicative results for LID, activity, bradykinesia, FOG and akinesia are presented in the next image.

4. 2. 2. Intelligent Modules creation and Validation

All intelligent modules have been created using a database of short-term (~15 min) recordings, created using the recording device described above, in hospital environment. The recording started with the subject lying on the

bed. The protocol consisted of three major tasks: (i) lying on the bed, (ii) rising from the bed and sitting on a chair located by the bed, and (iii) standing up from the chair and performing a series of tasks (walking, opening and closing a door, drinking, random movements). During the recording, the subjects were instructed to act freely, speak and make voluntary movements if they need to. The procedure (performing the tasks) was videotaped. Clinical annotation was provided by expert neurologists during the recording and afterwards via visual inspection of the video footage. For the clinical annotation, the UPDRS was used. The short-term dataset included 34 recordings from 25 patients in different states (ON/OFF) and included all motor symptoms. The PERFORM system was also used from long-term recordings. These included two recordings (~4 hours each, one in the morning and the second in the afternoon) for five consecutive days, at patient's home. The patient (or the caregiver) was asked to record his/her motor condition in the home diary every half an hour during the day, using a different level of classification for each PD symptom (e. g. ON-OFF state, bradykinesia, tremor or LID). Then, the diary entries were compared to the output of the intelligent modules. Twelve patients were enrolled in the long-term recordings phase.

4. 2. 2. 1. Tremor Assessment Module

Tremor assessment module is based on the analysis of signals obtained from accelerometers attached to specific body segments. Several features are extracted from the recorded signals, related to time and frequency domain characteristics, including features indicative of low frequency movements, which can discriminate tremor from the other PD motor symptoms. Using a

feature selection method, a subset of features is selected and incorporated into a Hidden Markov Model (HMM) for tremor severity recognition. For the discrimination of tremor type (resting/postural), spatial features were extracted based on the gravity force applied on each accelerometer axis and the angles between different body segments. Again, a subset of features is selected using a feature selection method, and these features are fed into a second HMM for body action-posture recognition. The information from the two HMMs is merged resulting into a thorough tremor assessment addressing both its severity and type. The evaluation results indicate 87% classification accuracy using the short-term dataset and 0. 088 mean normalized absolute error using the long-term dataset (first two days).

4. 2. 2. 2. LID Assessment Module

The LID assessment module is based on the analysis of the signals recorded from the sensors. The signals are analysed using a sliding window of 1 sec length and 0. 5 sec overlap, and several features are extracted (from each window), including mean value, standard deviation, entropy, energy in specific frequency sub-bands and entropy of the frequency spectrum. Based on these features a decision tree is used for LID detection and the classification of its severity. The results obtained using the short-term dataset indicate high classification ability, being 85. 4% (using the leave-one-patient-out cross validation technique) and having 0. 31 mean normalized absolute error using the long-term dataset (first two days).

4. 2. 2. 3. Bradykinesia Assessment Module

The classification methodology used for the bradykinesia assessment module includes three steps. Initially the signals from the sensors are filtered using a

band-pass filter with cut off frequency of 1-3 Hz. Then, several features are extracted from the filtered signals, including Approximate Entropy and Sample Entropy. These features are used as input into an SVM classifier. The module was evaluated and the obtained results indicated 74. 5% classification accuracy using the short-term dataset and 0. 25 mean normalized absolute error using the long-term dataset (first two days).

4. 2. 2. 4. FoG Detection Module

The FoG detection module methodology consists of three stages. In the first stage preprocessing of the signals is performed and then the signals are analysed using a sliding window of 1 sec length and 0. 5 sec overlap. The entropy of the signal for each axis of each sensor is extracted; these values formulate a feature vector which is used for the classification of each second of the recorded signals as FoG or not, based on a Random Forest classifier. The evaluation results indicate 79% classification accuracy using the short-term dataset and 0. 79 mean normalized absolute error using the long-term dataset (first two days).

Discussion

The PERFORM project aimed to tackle problems associated with the efficient remote health status monitoring, the qualitative and quantitative assessment and the treatment personalisation for people suffering from neurodegenerative diseases and movement disorders, such as Parkinson's disease. The PERFORM project researched and developed an innovative, intelligent system for monitoring neurodegenerative disease evolution through the employment of wearable sensors, advanced knowledge processing and fusion algorithms. Advanced sensors, are able to " sense" the

user's behaviour and motor status and store the recorded data in a local portable/handheld device. These data are then processed and seamlessly transmitted to the centralised system for further fusion, monitoring and evaluation. Some of the current measurements currently use motor signals acquisition through accelerometers and gyroscopes. The system is modular and extensible, to enable different combinations of measurements. All monitoring devices are wirelessly connected and seamlessly integrated to produce a user-friendly and patient-customised monitoring tool. The recorded signals are pre-processed and stored at the patient site. At the point of care (hospital centre), the supervisor health professionals are able to remotely monitor their patients, personalise their treatment and medication schedules and generate statistical data, so as to study and evaluate the efficacy of medication, based on the patients' specific personal and medical characteristics. PERFORM system aimed to improve the prevalent philosophy in the follow up of Parkinson's disease patients and to change the paradigm in Parkinson's disease treatment. The new paradigm will support the continuous follow up of patients with easy to wear sensors and computer intelligence to be used by doctors in order to optimize treatment, delay the appearance of symptoms and improve quality of patients' lives. In order to comprehend the strategic impact of the work performed, we need to have a clear view of the Parkinson's disease background. Parkinson's disease is a chronic, progressive neurological disorder. It is the second most common neurodegenerative disease, affecting more than 2 per 1000 people in Europe. It affects men and women equally. Although Parkinson's disease is most common in the over 60's, many people are diagnosed in their 40's and younger. The number of patients is continually growing due to the ageing of

the populationThe aetiology of the disease is not known in most cases, although various studies show that a combination of genetic and environmental factors play a significant role. Currently no cure is known for the disease and complex medication treatment is necessary in order to control the devastating symptoms of this progressive disease. Patients present intense movement disorders such as tremor, bradykinesia and postural instability. Apart from the classical motor symptoms, patients with Parkinson's disease also present secondary non-motor symptoms such as depression, sleep disorders, speech disturbances, and autonomic system and cognitive impairments, which can become more disabling that the primary symptoms and prohibit patients from performing even simple daily activities. Additionally, the complex medication (i. e. up to 10 different drugs in more than 30 doses daily) usually causes adverse effects such as sudden and unpredicted motor fluctuations, abnormal involuntary movements, nausea, cardiac arrhythmia, epigastric discomfort and various psychiatric disturbances. Current medication used to control the variant and changing symptoms of the disease requires individualization to the patient's specific medical characteristics and continuous Parkinson's disease, which is often practically unfeasible. Contemporary drug treatment has proved to increase the mean life expectancy for treated Parkinson's disease almost back to normal. In any case it not just a matter of survival but an issue of quality of life. Considering all these severe implications of the disease for the Parkinson's patients which are also common in other neurodegenerative diseases, PERFORM: provides in an innovative and state of the art way, through continuous monitoring and assessment of the disease evolution, automated diagnosis & decision support technologies, microelectronics,

wireless communication and security mechanisms in order to provide neurodegenerative diseases patients and their health professionals with an assistive tool for assessing the course of the disease and evaluating the medication efficiency. Introduces a smart portable system, based on wearable multi-parametric sensor data processing, for monitoring neurodegenerative diseases patients, quantifying the disease symptoms and assessing the treatment in long-stay setting. Creates new classes of capabilities for e-Health, ranging from crisis-avoidance to novel and natural means for proving perception-of-proximity for family members and communities, promoting e-Inclusion and ensuring in this way equal access and participation for all in Europe. Does not only provide advanced, seamless monitoring but also decision support (i. e. fusion of activity measurements and vital signs) in quantifying disease symptoms-which is currently done in a subjective qualitative approach by health professionals-assessment of the disease course and evaluation/adaptation of the medical treatment based on the changing symptoms and efficiency of drug intake (type of drug, dose, timing). Better control of the disease symptoms will have a synergistic positive effect on the psychosocial and physical functioning of the patients. Therefore patients are empowered to play a full role in society by living independently, working, participating in social activities and enjoying life. Although the final system will be tested on Parkinson's disease patients, it will be designed baring in mind the needs of other neurodegenerative diseases and Parkinsonian syndromes with similar motor and mental disabilities. Thus it offers a great potential for easy future exploitation for most neurodegenerative syndromes (e. g. Huntington's disease, Tourette's disease, idiopathic dystonia). Also PERFORM will achieve cost and effort

savings related to frequent visits to hospitals for assessment and treatment modification, having in mind that most patients are elderly, have movement disabilities and may live in rural areas. More specifically, medication treatment is fairly expensive, since it involves the use of a combination of drugs that are taken for a lifetime. Apart from the prominent impact in the patients' life, PERFORM will also: provide work efficiency to healthcare professionals (e. g. through the utilisation of multi-parametric information fusion and consistent decision support tools, remote monitoring, reduction of patient visits health assessment and treatment adjustment). Advance medical research through the provision of innovative decision support tools and the exploitation of the vast pool of monitored parameters and the generated statistical data for the production of new diagnostic models and protocolsImprove development and enhance competitiveness is the pharmaceutical industry, through the development and exploitation of an innovative tool, able to " quantify" the drug-induced complications and side effects and thus evaluate the efficiency of specific drugs in various patient groups. Additionally, PERFORM exploits European strengths, such as mobile communications, consumer electronics and embedded software in medical data fusion to provide a future generation application, in which intelligence and computing is integrated into everyday environment and rendered through easy-to-use human interfaces contributing to the development of the European " ambient intelligence" vision. It introduces the development of a new generation of autonomous wireless intelligent sensor agents for health monitoring and treatment assessment. The aim is to join emerging research activities in multi-sensor data fusion and automated diagnosis combined in a flexible, modular wearable platform that supports intuitive, non-obstructing

interaction with elderly and people with disabilities (e. g. Parkinsonian patients), in order to better manage their health status. It will develop miniaturized smart sensors are integrated correlating vital signs measurements with kinetic signals, to produce an accurate estimation of the health progress and treatment assessment providing improved diagnostic and prognostic performance for the health professionals. PERFORM's emerging technology supports the pervasive deployment of small intelligent sensors such and biosensors, to permit flexible use of input modes and increased capabilities to understand the users' condition. Combination of data coming from multiple sensors increases the meaningfulness of the derived context and improves error detection and correction facilitating the difficult task of " quantifying" the drug-induced complications and side effects. PERFORM places emphasis on research in the promising field of Neuro-Informatics combining neurological assessment algorithms, multimodal human-computer interfaces, machine learning and knowledge discovery. Distinctively PERFORM proposes sensors' architectures for seamless integration that will eventually allow for easier sensor fusion and knowledge acquisition. Various knowledge-based techniques and algorithms are researched, utilised and appropriately combined to provide valuable diagnostic information to the health professional. A model-based multi-sensor fusion system able to integrate a variety of sensors has been implemented. Furthermore new algorithms are implemented that assesses a person's health status based on various medical and motion measurements. Implemented technological building blocks, such as smart sensors, advanced processing and classification algorithms, wireless networks and user interfaces, enable new types of gathering, processing and evaluating vital

and kinetic signals. PERFORM's results are essential to the European research community fostering the creation of new applications, as they could be easily adapted and embedded into other systems and services making Europe industrially competitive.

Conclusions

In contrast with other diseases there is no treatment and therapeutic schema for PD. The dosage and the way of medication administration are totally personalized for every patient. When the PD disease appears the treatment seems very simple but in the course of time the treatment becomes complicated and requires more and more the patient's participation. During the short visit of PD patient the clinician must be informed for the patient's day motor status. This is required to configure the treatment strategy, drug time intake, drug doses, intervals between doses, combination of drugs depending on the food intake and other details. The clinician tries to retrieve information for patient's motor status for the previous days or weeks. This is almost impossible since it is difficult for PD patients to describe their symptoms and they cannot assess exactly their reaction to the drug. Consequently, the clinician cannot receive proper information to define realistically the drug administration treatment. The PERFORM system offers daily help to the clinician neurologist who tries through conflicting information from the patients and their relatives to determine the optimal therapeutically schema. PERFORM system is used by the PD patients at home and in a simple, safe, painless and non-invasive way to record patient motor status for long-time intervals. In this way, the clinician can have a precise, long-term and objective view of patient's motor status in relation to

drug and food intake; all the aforementioned factors are directly involved in the drug absorption and action. With the PERFORM system the clinician can remotely receive precise information for the PD patient's motor status on previous days and define the optimal therapeutical treatment.