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Survey on an Emerging Era in the Management of Parkinson's Disease

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Abstract: *A more efficient system is required to cope with the growing world population and increased life expectancy, which is associated with a marked prevalence of chronic neurological disorders such as Parkinson's disease (PD). One possible approach to meet this demand is a laterally distributed platform such as the Internet of Things (IoT). Real-time motion metrics in PD could be obtained virtually in any scenario by placing lightweight wearable sensors in the patient's clothes and connecting them to a medical database through mobile devices such as cell phones or tablets. Technologies exist to collect huge amounts of patient data not only during regular medical visits but also at home during activities of daily life. These data could be fed into intelligent algorithms to first discriminate relevant threatening conditions, adjust medications based on online obtained physical deficits, and facilitate strategies to modify disease progression.*

1. Introduction

The worlds population continues to increase longer life expectancies and a predominance of elders and disabled survivors urge us to develop strategies to reduce healthcare costs. Importantly, an older population translates into an increased prevalence of chronic age-related disorders such as Parkinson's disease (PD). In other words, humans are in need of a more efficient healthcare platform, which can serve the demand of larger and older populations at an affordable cost.

Lateralization of different tasks complements the efforts of caregivers in delivering the most appropriate and efficient healthcare. The concept represents accessing the hospitals resources at hand, where patients can retrieve their medical records, monitor their physiological parameters, keep track of medication, and have access to medical assistance anytime and anywhere. This concept is expanded in an interconnected grid of patients sharing similar disease symptoms and experiences, strengthening community bonds.

One can consider PD as a working model of change of the global healthcare system. PD is a neurodegenerative disorder marked by a severe neuronal dysfunction and loss within the substantia nigra. Although the exact molecular mechanisms underlying PD remain unclear, research evidence points to genetic mutations, defected proteins, increased oxidative stress, and mitochondrial dysfunction. The cardinal symptoms of motor impairment in PD are bradykinesia, resting tremor, rigidity, and postural instability. Further symptoms comprise freezing, shuffling gait, dystonia, and other non-motor abnormalities such as cognitive impairments, sleep disorders, and dementia. Presence, appearance during the disease course, and level of impairment vary for each symptom across patients. Thus, the diagnosis of PD remains challenging and requires the expertise of highly specialized neurologists. This review discusses the aforementioned aspects with a focus on PD as a representative disease model of an emerging era in healthcare. We specifically address the following primary concepts: 1) the IoT platform in the context of healthcare; 2) the potential of combining wearable technology with the IoT in the healthcare scenario; 3) the challenge of transforming data into knowledge; and 4) the engagement of patients in symptom assessment, diagnosis, and consecutive treatment options.

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2. PD Monitoring Techniques

Here it is discussed about different techniques that are used for monitoring Parkinson;s Disease.

2.1 Accurate and Reliable Gait Cycle Detection in Parkinson's Disease

There is a growing interest in the use of Inertial Measurement Unit (IMU)-based systems [1] that employ gyroscopes for gait analysis. Here it is described about an improved IMU-based gait

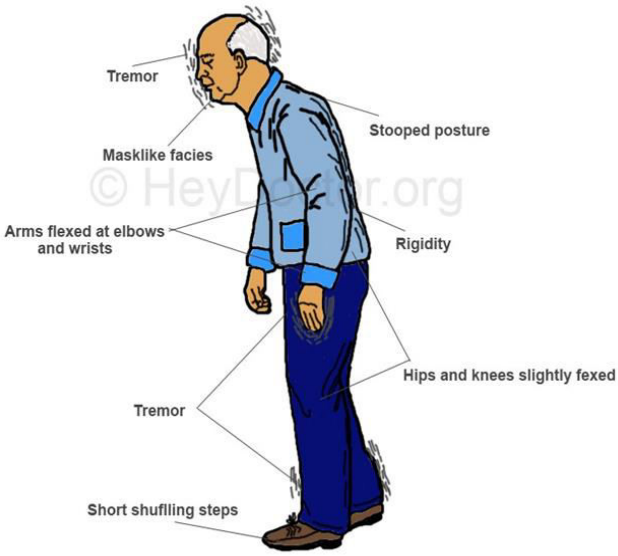

Figure 1: Bradykinesia

analysis processing method that uses gyroscope angular rate reversal to identify the start of each gait cycle during walking. In validation tests with six subjects with Parkinson disease (PD), including those with severe shuffling gait patterns, and seven controls, the probability of True-Positive event detection and False-Positive event detection was 100% and 0%, respectively. Stride time validation tests using high-speed cameras yielded a standard deviation of 6.6 ms for controls and 11.8 ms for those with PD. These data demonstrate that the use of our angular rate reversal algorithm leads to improvements over previous gyroscope-based gait analysis systems. Highly accurate and reliable stride time measurements enabled us to detect subtle changes in stride time variability following a Parkinson's exercise class. It is found about an unacceptable measurement accuracy for stride length when using the Aminian et al. gyro-based biomechanical algorithm, with errors as high as 30% in PD subjects. An alternative method, using synchronized infrared timing gates to measure velocity, combined with accurate mean stride time from our angular rate reversal algorithm, more accurately calculate mean stride length.

2.2 An IoT-based Scheme for Real Time Indor Personal Exposure

Air pollution is an important environmental issue that has a direct effect on human health. In this paper the development of an Internet of Things-based system [2] for real time indoor personal exposure monitoring is described. The system was tested for real time personal exposure assessment to formaldehyde and CO2 air pollutants. It provides accurate and real time personal exposure assessment. The real time and continuous monitoring capability makes it possible to better predict worker health risks and protect them from occupational overexposure to air pollution.

The architecture of an IoT-based system for real time indoor personal exposure monitoring is explained below. Pollutants concentrations and real time personal coordinates data are remotely collected in a data center in which data are processed and made available to users. IoT is implemented as a network of interconnected "things" (Tags and multi-pollutant sensors nodes), each of which can be addressed using unique id and communicates based on standard communication protocols.

1) Multi-pollutant sensor node: sends periodically and wirelessly a message <*Node_Id, T, H, CCO2, CHCHO, Date, Time*> which contains the node identifier, pollutants concentrations and the measured date and time through the gateway to a central storage system in which data are processed.
2) Indoor positioning system: Each employee wears a tag with a unique Id. The tag sends periodically a message contains its Id and the location_Id provides by the zone locator <*Tag_Id, Location_Id*> through the gateway to a central system.
3) Data Center: central system: The central system is a back-end server that stores gathered data and provides those data for several services. Figure 2 shows the flowchart of the algorithm. In the first case, the process detects all workers locations <*Tag_Id, Location_Id*>. Then, the process updates each individual air pollutant concentration Ci(tn) with the new received air pollutant concentration Cj(tn) where j is the microenvironment j where participant is located. In this case the time spent in the microenvironment is Ti = tm – tlast where tm is the new air quality measurement time and tlast is the last event trigger time.

2.3 Detecting Freezing-of-Gait During Unscripted and Unconstrained Activity

A dynamic neural network (DNN) solution for detecting instances of freezing-of-gait (FoG) inParkinson's disease (PD) patients [3] while they perform unconstrained and unscripted activities. The input features to the DNN are derived from the outputs of three tri-axial accelerometer (ACC) sensors and one surface electromyograp-hic (EMG) sensor worn by the PD patient.

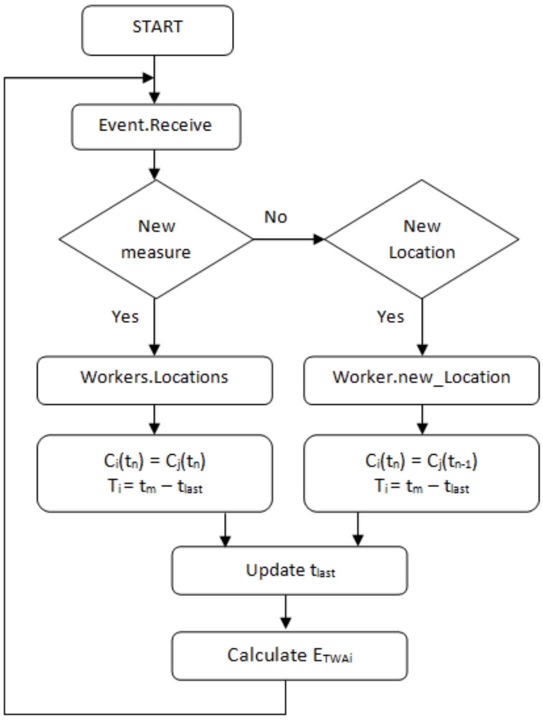

Figure 2: flowchart of real time individual exposure assesment process

The ACC sensors are placed on the shin and thigh of one leg and on one of the forearms while the EMG sensor is placed on the shin. The FoG solution is architecturally distinct from the DNN solutions we have previously designed for detecting dyskinesia or tremor. However, all our DNN solutions utilize the same set of input features from each EMG or ACC sensor worn by the patient. When tested on experimental data from PD patients performing unconstrained and unscripted activities, our FoG detector exhibited 83% sensitivity and 97% specificity on a per second basis.

Figure 3 :EMG

2.4 Biometric and Mobile Gait Analysis for Early Diagnosis and Therapy Monitoring in Parkinson`s Disease

In this study a mobile, lightweight and easily applicable sensor based gait analysis system is applied to measure gait patterns in PD [4] and to distinguish mild and severe impairment of gait.

Examinations of 16 healthy controls, 14 PD patients in an early stage, and 13 PD patients in an intermediate stage were included. Subjects performed standardized gait tests while wearing sport shoes equipped with inertial sensors (gyroscopes and accelerometers). Signals were recorded wirelessly, features were extracted, and distinct subpopulations classified using different classification algorithms. The presented system is able to classify patients and controls (for early diagnosis) with a sensitivity of 88% and a specificity of 86%. In addition it is possible to distinguish mild from severe gait impairment (for therapy monitoring) with 100% sensitivity and 100% specificity. This system may be able to objectively classify PD gait patterns providing important and complementary information for patients, caregivers and therapists.

The Unified Parkinson`s Disease Rating Scale (UPDRS) - Part III is the most commonly used scale to rate motor symptoms in PD . The UPDRS is standardized, but remains subjective and depends on the patient`s momentary status. Nevertheless, the UPDRS is an internationally accepted rating scale to assess efficacy in clinical studies. Additionally it is widely used in outpatient centers for movement disorders. Several studies focus on gait symptoms like "freezing of gait" in PD. It uses accelerometers attached to the leg, detecting gait changes to avoid falls and prevent injuries. The method involves use of a system to monitor motor fluctuations using eight accelerometers attached to the upper and lower limbs including a web-based application to provide information to a clinical center . Gait changes is measured with accelerometers attached to arms, calves, and trunk in a small number of PD patients. Automated movement analysis of the upper extremity has also been introduced to PD patients without assessing gait impairment. General bradykinesia was also detected using accelerometer based systems.

2.5 Inertial Sensor-Based Stride Parameter Calculation From Gait Sequences in Geriatric Patients

A detailed and quantitative gait analysis can provide evidence of various gait impairments in elderly people. To provide an objective decision-making basis for gait analysis, simple applicable tests analyzing a high number of strides are required. A mobile gait analysis system [5], which is mounted on shoes, can fulfill these requirements. Here it presents a method for computing clinically relevant temporal and spatial gait parameters. Therefore, an accelerometer and a gyroscope were positioned laterally below each ankle joint. Temporal gait events were detected by searching for characteristic features in the signals. To calculate stride length, the gravity compensated accelerometer signal was double integrated, and sensor drift was modeled using a piece-wise defined linear function. The presented method was validated using GAITRite-based gait parameters from 101 patients (average age 82.1 years). Subjects performed a normal walking test with and without a wheeled walker. The parameters stride length and stride time showed a correlation of 0.93 and 0.95 between both systems. The absolute error of stride length was 6.26 cm on normal walking test. The developed system as well as the GAITRite showed an increased stride length, when using a four-wheeled walker as walking aid. However, the walking aid interfered with the automated analysis of the GAITRite system, but not with the inertial sensorbased approach. In summary, an algorithm for the calculation of clinically relevant gait parameters derived from inertial sensors is applicable in the diagnostic workup and also during long-term monitoring approaches in the elderly population.

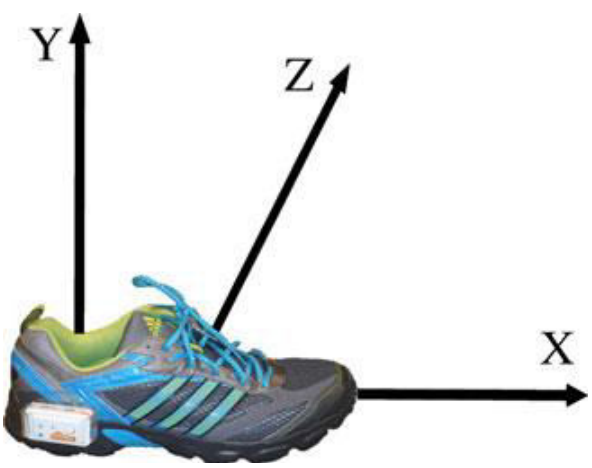

Figure 4. Placement of the sensor and direction of axes.

For data collection, the inertial sensor platform Shimmer 2R was used. It consists of a three-axis gyroscope (range: Fig. 4. Placement of the sensor and direction of axes. ±500 °/*s*) and a three-axis accelerometer (range: ±6 *g*). Subjects wore shoes with a sensor placed laterally right below each ankle joint (see Fig. 4). Every subject wore the same shoe model (adidas Duramo 3) to avoid influences on gait parameters caused by different shoe models. Data were collected with a sampling rate of 102.4 Hz, and a resolution of 12 bits. The *x*-axis was defined in posterior–anterior direction, *y*-axis was in superior–inferior direction, and *z*-axis was in medio-lateral direction. No manual filtering for accelerometer and gyroscope signals, and no automatic filtering for the accelerometer signal was applied. However, the Shimmer2R sensor units use an integrated low-pass filterwith a cutoff frequency of 140 Hz for the gyroscope signals. The established analysis system GAITRite consisting of an electronic walkway containing pressure sensors and a computer with a software that derived the gait parameters from the sensor signals was defined as the gold standard. The device used in this study had a sensitive area of 609.60 cm × 60.96 cm, a spatial accuracy of ±1.27 cm, and a track width of 84 cm. Data were sampled at 120 Hz and processed using GAITRite Platinum software version 4.7.1.

3. Conclusion

We are experiencing a marked change in healthcare delivery to patients. This profound transition is coming along with the technological revolution of wearables, the IoT, and new possibilities using machine learning and artificial intelligence. Treatment of PD and other disorders that progress with similar clinical presentations are guaranteed to benefit from this efficient and affordable approach. During this revolution, patients adopt a protagonistic role in the management of their diseases and in the development of future diagnostic and treatment procedures by sharing data and adopting new technologies as life companions.

Future technological challenges point toward data management and the use of artificial intelligence and smart machine learning. Current challenges include the overload, flow, and handling of information. A consensual criterion for data ownership, data privacy, and data sharing is lacking and is a matter of ongoing vivid legal, social, and ethical debates. After all, the adoption of these technologies depends on its acceptance in society. Because of the diversity of contexts in which this technology is applied the ethical discussion cannot not be addressed with a one-fit-all approach. One possible point of convergence is that data handling should be regularized depending on their type, usage, and users. For that three models of data ownership is proposed: 1) a pay-per-use model, where the users of smart objects can be paid by companies wishing to use data generated from these objects connected to the Internet; 2) a data market model, which would allow users to trade their personal data with companies; and 3) an open data model, based on data collected in public areas such as hospitals and smart cities, supporting the access and control of the general population to their publically captured data.

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