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INTERNSHIP REPORT

Analysis of Anticipatory Postural Adjustments of Parkinson's Patients using Inertial Sensors

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Preface

This report presents my practical work within the Project "Analysis of Anticipatory Postural Adjustments of Parkinson's Patients using Inertial Sensors" at the Research Centre for Information and Communications Technologies of the University of Granada (CITIC-UGR). The Muenster University of Applied Sciences required an internship of at least 10 weeks prior to the final bachelor's thesis.

This is a conjoint project of the University of Granada and the Department of Neurology of the Klinikum Großhadern in Munich, which is part of the Ludwig-Maximilians University. The goal of the project was to carry out an analysis of the so called Anticipatory Postural Adjustments, which are the movements by a human subject between the moment he initiates gait and the first step. The medical community is interested in this procedure, as it can assist the diagnosis of neurodegenerative diseases such as Parkinson's.

Contents

Abbreviations

APAs Anticipatory Postural Adjustments

COM Centre of Mass

COP Centre of Pressure

GRF Ground Reaction Force

HY Hoehn and Yahr scale

IMU Inertial Measurement Unit

MIMU Magnetic Inertial Measurement Unit

PD Parkinson's disease

TUG Timed Up and Go Test

UPDRS Unified Parkinson's Disease Rating Scale

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Chapter 1

Introduction

1.1 General

1.1.1 Parkinson's Disease

According to Patients Medical [3],

> "Parkinson's disease is a progressive, neurodegenerative disease that occurs when the neurons within the brain responsible for producing the chemical dopamine become impaired or die. Dopamine is essential for the smooth control and co-ordination of the movement of voluntary muscle groups. Once approximately 80% of the brain's dopamine producing cells no longer function, the symptoms of Parkinson's disease begin to appear. [...] Parkinson's disease may be termed as a progressive movement disorder that is distinguished by marked slow movements, tremors, and unstable posture."

Especially in advanced stages of the Parkinson's disease (PD) many patients exhibit an episodic, brief inability to step that delays gait initiation or interrupts ongoing gait. This phenomenon is called freezing of gait and is often associated with an alternating shaking of the knees, called knee trembling. However, these clinical signs of balance or gait problems are not evident in early stages of the disease [4][5].

1.1.2 Anticipatory Postural Adjustments

A major challange to the human ballance control system is the fact that we are bipeds having only one foot in contact with the ground while walking, and that two-thirds of our body

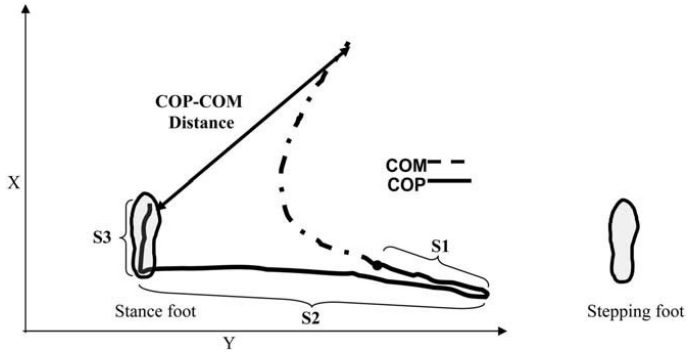

Figure 1.1: Anticipatory Postural Adjustments during forward-oriented gait initiation when stepping with the right foot [1].

mass is located two-thirds of body height above the ground [6]. Thus, to induce stable gait anticipatory postural adjustments (APAs) are necessary. The Encyclopedia of Neuroscience [7, p.133] defines APAs as "A predictive motor response that acts to counter, in a preemptive manner, the postural destabilization associated with a forthcoming movement." As seen in Figure 1.1 the centre of body mass (COM) is accelerated forward and laterally over the stance foot to make sure that the body does not fall laterally toward the stepping foot during the swing phase [7]. The curve of the centre of pressure (COP) is divided in three periods. First, in the S1 period the COP moves posteriorly and toward the intended stepping limb. The deliberate uncoupling of the COP and COM generates forward momentum. Then, in the S2 period, the COP displaces mediolaterally toward the stance foot. Finally, during the S3 period the COP moves anteriorly under the stance foot [1].

1.2 Goals

The goal of the project was to analyse anticipatory postural adjustments prior to step inition and subsequently build a classifier using MATLAB, which is fed with data from both a force plate and a magnetic inertial measurement unit (GaitWatch [8]) to distinguish between Parkinson patients and healthy subjects. To gather the data the subject stood in front of the force plate. Then the GaitWatch and force plate record was started and the subject made a step onto the force plate. After standing a variable time of two to ten seconds the subject left the force plate, made a few steps, turned left und stopped in front of it again. This sequence was repeated ten times.

1.3 Motivation

Advanced PD can increasingly diminish quality of life, since patients are dependent on help from others to accomplish daily tasks. New drugs are currently being developed and are expected to decelerate or stop the course of the disease in early stages [9]. Thus, a quantitative PD classification enabling early diagnosis of the disease could optimise early treatment and could help to validate new treatment methods. Additionally, an objective evaluation of longterm treatment success was ensured.

1.4 State of the art

There are several methods and devices to assess Parkinson's disease and to analyse anticipatory postural adjustments. They differ in terms of practicability, accuracy, validity, portability, and cost. The state of the art at the beginning of the project is described below.

1.4.1 Rating scales

A commonly used rating scale is the Unified Parkinson's Disease Rating Scale (UPDRS), which is a short test performed by a physician [10]. The patient is rated on 31 different items (see Table 1.1) with a score of 0 (normal) to 4 (severely affected). Another method is the rough, but widely utilised and accepted Hoehn and Yahr scale (HY). Parkinsonian motor impairment is categorised in 5 stages: Unilateral (Stage 1) to bilateral disease (Stage 2) without balance difficulties, to the presence of postural instability (Stage 3), loss of physical independence (Stage 4), up to being wheelchair- or bed-bound (Stage 5) [11]. Finally there is the Timed Up and Go Test (TUG). This clinical test consists of rising from a chair, walking 3 metres, turning, walking back, and sitting. The total duration then represents the clinical outcome. It is widely used to rate balance, mobility, and fall risk in PD in its entirety, but does not give information about the single impairements [12].

Without the need of complex technical devices these tests are relatively simple to perform. Klerk et al. [10] mentioned their disadvantages, including subjectivity, short observation periods, and unfamiliarity of the environment that these rating methods bring along.

1.4.2 Instrumentation

In addition to the aforementioned subjective rating scales, there are different devices used to quantify gait and posture and assess them objectively. All of them come with certain pros and cons. The following devices have been used:

Mentation, mood and behavior	Activities of daily living	Motor examination
Intellectual impairment	Speech	Speech
Thought disorder	Salivation	Facial expression
Depression	Swallowing	Tremor at rest
Motivation/initiative	Handwriting	Action or postural tremor of hands
	Use of eating utensils	Rigidity
	Dressing	Finger taps
	Hygiene	Hand movements
	Turning in bed	Rapid alternating movements of hands
	Falling	Food agility
	Freezing when walking	Arising from chair
	Walking	Posture
	Tremor	Gait
	Sensory Complaints	Posture stability
		Body bradikinesia and hypokinesia

Table 1.1: Unified Parkinson's Disease Rating Scale items adapted from [2].

1.4.2.1 Electromyographs

Electromyography is a technique for evaluating the electrical activity of skeletal muscles. Successive action potentials generated by muscle cells are measured, by means of needle electrodes inserted into the muscles, and displayed on a cathode-ray oscilloscope. Thus medical abnormalities can be detected. The instrument used to capture the visual recording, termed electromyogram, is called electromyograph [13]. Electromyography is constrained to clinical application only, but gives indication about the contribution of specific, individual muscles to APAs.

1.4.2.2 Force plates

Force plates quantify the ground reaction force (GRF), which is the force exerted to the human body by the ground. The GRF is a three-dimensional vector with three orthogonal components. One component along the direction of gravity, one parallel to the ground in the sagittal plane, and one parallel to the ground in the frontal plane. Those are vertical planes that divide the body in left and right halves, and ventral and dorsal sections, respectively. A force plate usually gives an electrical voltage proportional to the force in each of the three directions. Force plates can be characterised according to the following criteria: Sensitivity in Volts per Newton, crosstalk (indication of vertical force if a horizontal force is applied and vice versa), repeatability (similar results under the same load), and time- and temperature drift [14]. Froce plates are nonportable and therefore limited to clinical application, too.

They have the advantage that they don't need to be calibrated before each use.

1.4.2.3 Inertial measurement units

Devices that use a combination of inertial sensors like accelerometers and gyroscopes are referred to as inertial measurement units (IMUs). If they also include magnetic field sensors (magnetometers), they are called magnetic inertial measurement units (MIMUs). With these devices the orientation of the body can be obtained with up to nine degrees of freedom, provided that triaxial accelerometers and magnetometers are used, respectively [15].

- Accelerometers measure the acceleration of an object relative to an inertial frame. Since acceleration cannot be measured directly, the force exerted to a reference mass is obtained and the resultant acceleration is computed according to Newton's second law $\mathbf{F} = m \cdot \mathbf{a}$ [16].
- Gyroscopes measure angular velocity and are based on the Coriolis Effect. By means of integration of the angular velocity the rotation angle is obtained [15].
- Magnetometers measure the strength and the direction of the magnetic field in a point in space, using the relationship between magnetic fields, movement and induced currents [15].

MIMUs are portable and relatively inexpensive. They can be easily attached to the body and thus allow non-clinical longterm application. Their drawbacks are complex calibration procedures and drift behaviour over time, depending on intensity and duration of the movement. Hence, in order to maintain a satisfactory degree of precision, periodical recomputation of the calibration parameters is required [15].

1.4.3 Classification

There are several research works in the literature dealing with APA analysis and PD classification, as the evaluation of posture and gait are key components of the clinical evaluation of PD [17].

Klerk et al. [10] developed a measurement system called PD Monitor, implementing an Activity Classifier that quantifies tremor and bradykinesia in the arm, thigh, and trunk, in an ambulant way and over long periods of time. They validated their measurements with video records, which were rated by physicians using the UPDRS and concluded that "the PD monitor can be used for a detailed evaluation of the PD motor symptoms in order to optimize treatment." [10].

Mancini et al. [4] found that the 11 untreated early-to-middle stage Parkinson's patients that took part in their study have a significantly smaller peak COP displacement towards the stepping leg and peak trunk acceleration towards the stance leg compared to the 12 age-matched healthy control subjects. Even though step velocity and step length were not different. The results show that lateral APAs are impaired in early, untreated PD and that they are detectable with inertial sensors. As well as force plate-based, also acceleration-based extracted features can be used to detect impairments equally well. Due to the fact that the acceleration signal can be easily obtained via a sensor on a belt, no matter if in clinical or home environment, APA detection by means of accelerometers is considered as a useful way to characterise patients in early stage of PD without evident clinical symptoms. Additionally in [4] it is proposed to carry out further studies to determine the relationship between small APAs and the probability to develop start hesitation and freezing.

Palmerini et al. [17] states that PD classfication could deliver a tool to follow the progression of the disease during the entire course to examine the efficiency of treatment. They studied classification of PD subjects using triaxial accelerometers on the lower back at L5 level and an ad hoc wrapper feature selection technique designed in [12]. Linear discriminant analysis was used to obtain a classifier that permits clinical interpretation of the results. Twenty early-mild PD subjects and 20 healthy age-matched control subjects had to perform two simple tests (quiet standing, Timed Up and Go test), in two evaluations over a 1-year follow-up, to test accuracy and robustness over time. They achieved satisfactory accuracy of 93.75% and considered feature selection to be essential in this kind of data set. As well as [4] they found that lateral dynamics i.e. range of motion are impaired in early-mild PD and suggested further investigation on validity of measures in later stages.

Hass et al. [1] investigated the magnitude of the separation between the centre of pressure and the centre of body mass during gait initiation and its correlation with the severity of PD. They observed that the peak COP-COM distance during the S3 period (see Figure 1.1), of the 20 participating patients with H&Y score of 2.5 or higher, was 16% smaller than the one of the 23 patients with H&Y score of 2.0 or less. The results showed that this approach can quantify severity-related impairment of balance in PD.

for Parkinson's Research [18]

1.5 Document structure

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