Telecomunication Engeneering

Department:
Signal Theory, Telematics and Communications

University of Granada

Master thesis

Comparison of Posturographic Body-sway Measurements with Inertial Data of Parkinson Patients

Written by:

Verónica Torres Sánchez

Supervised by:

D. Alberto Olivares Vicente

D. Alberto Olivares Vicente, profesor del dpto. de Teoría de la Señal, Telemática y Comunicaciones, como director del Proyecto Fin de Carrera de Dª. Verónica Torres Sánchez,

Informan:

Que el presente trabajo, titulado:

Comparison of Posturographic Body-sway Measurements with Inertial Data of Parkinson Patients.

Ha sido realizado y redactado por el mencionado alumno bajo nuestra dirección, y con esta fecha autorizamos a su presentación.

Granada, a XX de XXX de 2015 Fdo:

D. Alberto Olivares Vicente

Acknowledgements

Abstract

Abbrevations

APA: Anticipatory postural adjustments

SIPBA: Signal processing and Biomedical Applications

FP: force plate

GW: Gait Watch

QS: Qualysis System

PD: Parkinson's disease

IMU: Inertial Measurement Unit

MIMU: Magnetic Inertial Measurement Unit

EMG: Electromyography

MEMS: Microelectromechanical Systems

LTSD: Long Term Spectral Detector

FSD: Framed Spectrum Detector

COP: Center of Pressure

AP: Antero-posterior

ML: Medio Lateral

FIR: Finite Impulse Response.

Contents

List of figures

List of tables

Chapter 1

Introduction

1.1 Context

Parkinson's disease is a chronic and progressive movement disorder due to the malfuction and death of neurons in the brain. Some of these neurons produce dopamina, a chemical that sends messages to the part of the brain that controls movement and coordination. Thus, as Parkinson's disease progresses, the amount of dopamine produced in the brain decreases, leaving the person unable to control movement normally [4].

The disease must be diagnosed by an experienced neurologist. There are no tests that clearly identify the disease, but brain scans and blood test are sometimes used to rule out disorders that could give similar symptoms. One of the main concerns of people with PD is the fear of falling. First motor symptoms in this disease, like rigidity (stiffness of the limbs and trunk), bradykinesia (slowness of movement) and postural changes, contribute to risk of falling. Difficulties in the adaptation of neck and trunk cause postural instability, which, in turn, increase the possibility of suffering a fall.

The center of body mass of a person is situated below the navel and the legs work as a support base. In PD it is common that the center of mass goes out of support base. This fact causes losses of equilibrium in activities such as waking up, bending, spinning around quickly or walking. Also, falls can occur due to a damage in postural reflexes (a series of complex movements that we carry out in an automatic way in order to maintain the equilibrium when we get up and walk), postural changes (tendency to lean forward using short, quick steps and reduced arm movement) and freezing (inability to step that delays gait initiation or interrupts ongoing gait). Research in this field is of vital importance to contribute to the improvement of knowledge about the disease. Scientific research can be the base for field applications that help to improve the people life with PD. [5][4]

With this Project, we aim to contiue the research line initiated by Dr. Alberto Olivares, member of the SIPBA (Signal Processing and Biomedical Applications) research group of the Department of Signal Theory, Telematics and Communications of the University of Granada, Spain, and Prof. Dr. Med. Kai Bötzel, head of the Motion Analysis and Deep Brain Stimulation Laboratory of the Department of Neurology of the Klinikum Grosshadern based in Munich, Germany. In his dissertation ,Dr. Olivares explains in his Ph.D. thesis [6] different signal processing techniques to analyze information from inertial sensors to monitor human body motion. Specifically, our work will be focused on signal processing of data gathered by a force plate and a wearable motion analysis system based on inertial sensors . Nevertheless, this master thesis is part of a broader project which has many different layers (instrumentation, data gathering, firmware, signal processing) in which other people have been working during the last 5 years .

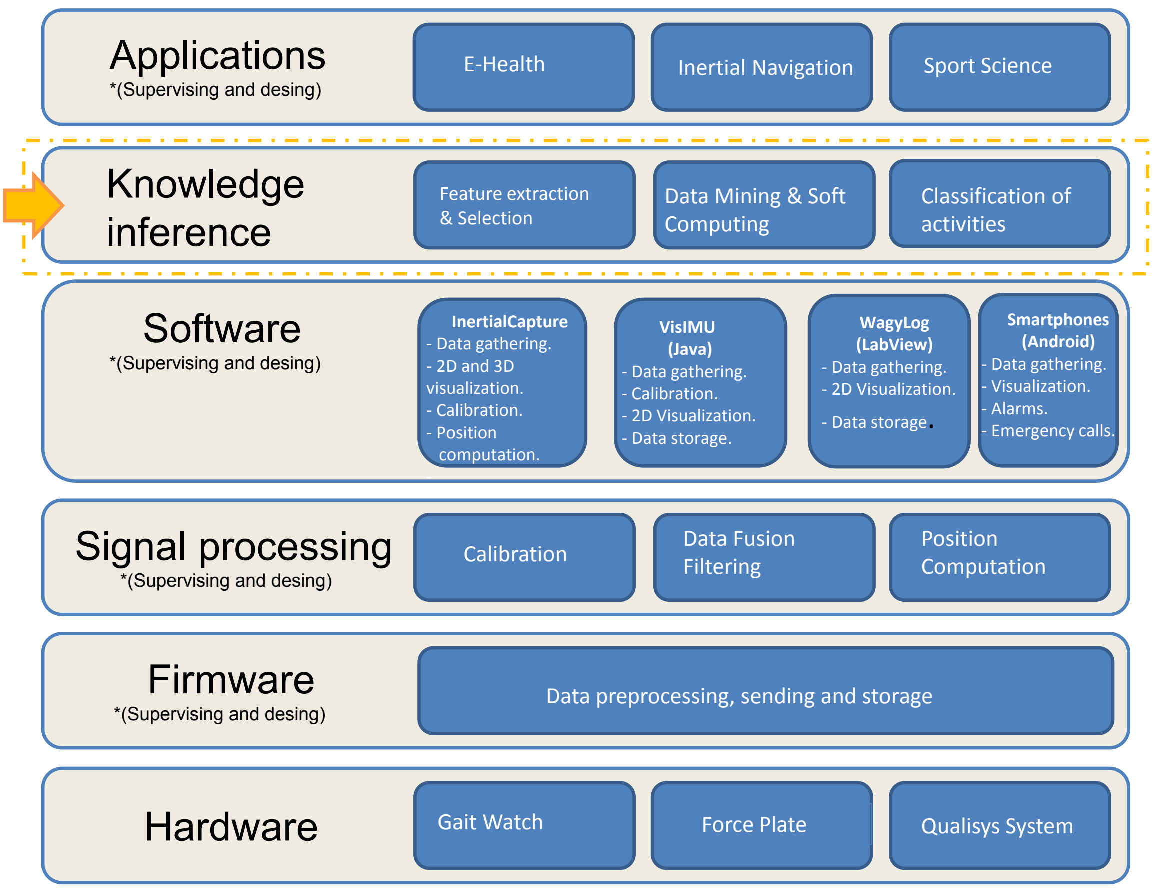

Figure 1.1: Layer structure of this project. Knowledge inference is highlighted as it includes the core of our work.

1.2 Motivation

Parkinson's disease is the second most common neurodegenerative disorder, it is extended globally and affects as much to men as to women. PD is more common among the population over 60 years old. . It is estimated that seven to ten million people worldwide are living with Parkinson's disease. To this date, there is no cure to PD, so all efforts are focused on improving or prolonging the functionality of the patient for as long as possible. Therefore, it's an incentive to work in this field. [5][4]

Furthermore, Intel and Michael J.Fox Fundation have rencently teamed up to create a sensor technology and analytics platforms for Parkinson's treatment and monitoring. Fox Foundation CEO Todd Sherer told Fast Company. "Parkinson's is a motor disorder for the most part, with slowness of movement, tremors, falls, problems sleeping, and many disease symptoms. The way it is measured right now requires episodic periodic visits to a neurologist, who puts patients through fairly subjective and coarse clinical tests, there are many 1-2-3-4 scales. What we need to advance is research that is a much more consistent and objective measure of the disease. People live with Parkinson's 24 hours a day, 7 days a week, not just when they're in the doctor's office."[1]

The goal is tracking the symptoms and progress of Parkinson's disease day by day, and using this information to research on the disease in depth.

Figure 1.2: Illustration of sensors distribution thought up by Intel and Mjf.[1]

Diane Bryant, senior vice president of Intel's Data Center Group, said in a release [1]. "Emerging technologies can not only create a new paradigm for measurement of Parkinson's, but as more data is made available to the medical community, it may also point to currently unidentified features of the disease that could lead to new areas of research" .

1.3 Goals

The main goal of this project is to perform a thorough analysis of Anticipatory Postural Adjustments (referred to as APA in the remainder of this document) of both healthy subjects and PD patients. APAs can be used to characterize step initiation deficits in subjects with PD and also as a differentiating factor which may help early diagnosis of the disease.

To this purpose, we will make use of a database gathered by the medical team in Munich. The database contains both data from a force plate and inertial sensors. The patients wear the motion monitoring system containing the inertial sensors while they step on and down the force plate.

Once the measurements are made, the main objective is to determine whether it is possible to use inertial sensors to extract the information provided by the force plate. That is, we will evaluate the correlation between inertial sensor measurements and the force plate measurements in order to study the feasibility of the wearable device to study APAs in an ambulatory way.

Additionally, we will try observing if APAs are homogeneus in healthy subjects and the differences with PD patients. If that is the case, we would be able to build a classifier which is able to distinguish healthy subjects from PD patients based on the data measured by the wearable device and/or the force plate.

In a nutshell, the ultimate goal is to determine whether doctors can substitute force plates (which strongly limit the range of action of the patients) by the inertial wearable system (which allows ambulatory).

1.4 Project structure

1.5 State of the art

We will start studying some current devices used for body monotoring as well as their benefits.

Later we will search the methods and experimental procedures used in several studies to analyse of Anticipatory Postural Adjustments in diferents cases, as well as their applications.

Finally, we will speak about the commons calibration techniques, signal processing and classification.

1.5.1 Instrumentation

There are several device types used to measure APAs. The most importants are: electromyograph, force platform, inertial sensors and devices based on cameras.

Electromyography (EMG) is a technique that gives us information about the electrical activity produced by skeletal muscles (See figure [1]). The electromyograph can detect the electrical activity due a electrical potencial difference generated by muscle cells. It's very useful to analyse posture, locate injuries like muscle paralysis and the place where they are. [7] [8].

So far, most of realised studies have included like measurement devices, among other things, a platform sensitive to force and pressure. However, the cost and complex of APAs measurement with a traditional movement analysis, using force platform and EMG System limit their applications in the clinical practice. Therefore, small inertial sensors are used recently because they are cheaper and more portables. But even so, we have used this platform, considering the posibility to ignore it in the future. [9] [10].

Devices based in commonly used inertial sensors are IMU (inertial measurement unit), It's a electronic device that measures and reports about speed, orientation and gravity force of equipment, using the combination of accelerometers and gyroscopes. In addition, you can combinate it with magnetometers, but in this case, the device is called MIMO. Some current MIMO are: 3DN-GX4-45 [11], xsens-mvn [12] y mvn-biomech [13], all of them use Microelectromechanical Systems (MEMS).

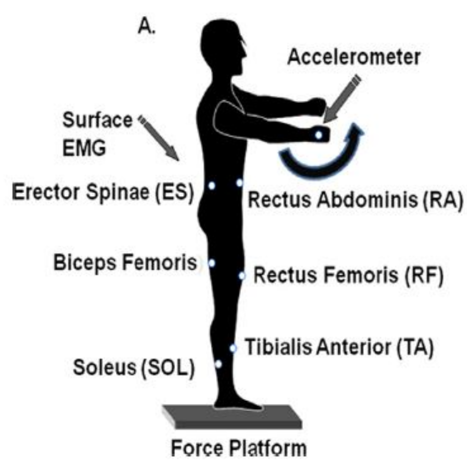

Figure 1.3: EMG, accelerometers y platform [2].

There are infrared-reflective markers that give us a complex posture measurement. They are attached to the body and can provide information about postural strategies, so we can know if the subject uses the ankle strategy or the hip strategy. For example, figure [2] shows the System.

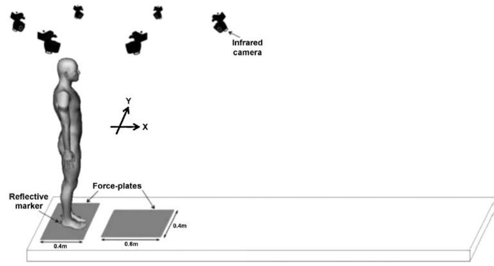

Figure 1.4: Illustration of the experiment with infrared-reflective markers[3].

As mentioned previously, it's possible to use sensors based in cameras that generally are part of a optical System of movement capture such as Kinect. [14].

1.5.2 Methods and procedure

So far, a lot of studies about Anticipatory Postural Adjustments are been done, mainly in the last six years. The finality of the most of this research is be able to deepen knowledge about the posture prior to step initation, and whether there are postural patterns and conditions on which they depend.

If we analyse the state of the art of APAs, we can find that first investigations tried to verify whether APAs are associated to voluntaries movements or no, this hypothesis was confirmed and the conclusion was it's more probable that the adjustments don't appear if step initation isn't planned. It's essential for balance control in gait initation because we can use this knowledge to prevent the falls in some people with movement difficults.[15][16][3][17][18]

After of this, researchers tried to explain the influence of other variables, such as several exercices that estimulate differents muscles and the reaction of others[2]; the age influence for generating postural patterns [19] [20]; the signal type that initiates the movement (visual or auditory) due that it affect initial posture [15][21][22][23]; the fear to fall because it can do that patients adopt differents postures[26]; neurodegenerative disease, like Parkinson and Multiple Sclerosis[9][24][25][26], or cerebral palsy, like hemiplegia and diplegia, [26], generate differences in the APAs too.

All these studies are very important in medical applications. For example, As mentioned previously, there are diseases that affect central nervous System, so it affects the mobility too. Then, it causes falls in many occasions, therefore the people that suffer the fall have fear of fall again. The fact that fear of fall causes variations in the APAs doing people fall again, can help us to prevent them.

1.5.3 Data Analysis

In the last years, it has carried out a lot of Works about calibration of accelerometers and gyroscopes, although the most of them show little variation with others studies done before. One of the most important research [27]explains one form to do the calibration putting the acceleromentes in six differents positions and applying simple algebraic algorithms to the obtained data. The gyroscope is calibrated of different form, using a process based in a known rotation. Also, there are others with the same fundament.

There are other methods that try to be more precise, increasing the number of positions where we record the data [28]. Also, there are others type of calibration techniques like algorithms based in basic algebraic calculation or in FIR filters. [6]

As for estimation of orientation for human-body monitoring, if we study the works done so far, we can see that almost all use a Kalman filter. However, the result with lower signals isn't very accurate.[6]

Finally, we will analysis the state of the art of movement recognition in human and classifiers. Quickly, we can see a lot of information about classification because there are a lot of articles and books about this. However, there are others type of studies, which we focus on it [29], that explains methods for human activity recognition based on a sensor weighting hierarchical classifier. This study shows different classification forms that we can use depending on the activities, such as walking or running.

Chapter 2

Hardware Description

Along this chapter we will introduce a general description of all devices used to data gathering for the development of this project.

It should be noted at this point that there are two clearly differentiated parts. In the first of them, we work with Force Plate and GaitWatch data, taking out their characteristic signals and synchronising them. In the second of them, we work jointly with Gait Watch and Qualisys System data for the purpose of comparing the accuracy in the calculated orientation angles.

2.1 GaitWatch

GaitWatch is an Inertial Measurement Unit (IMU) designed for gait monitoring of patients. It was developed by Prof. Dr. Med. Kai Bötzel at the Department of Neurology of Ludwig-Maximilians University in Munich in conjunction with Dr. Alberto Olivares Vicente from the Department of Signal Theory, Telematics and Communications of the University of Granada. [30]

The system is composed of the central processing unit and a set of measuring units which are wired to it. The measuring units are placed in the patients' thighs, shanks, arms and trunk.

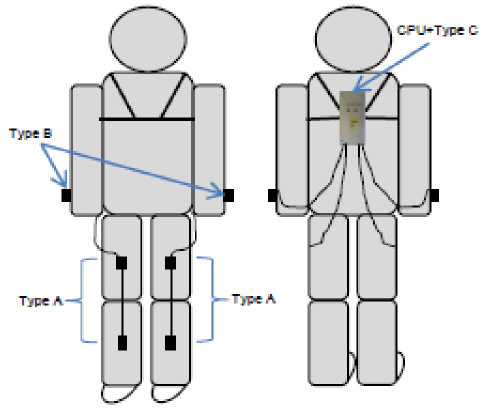

Figure 2.1: General Diagram of the Gait Watch.

The central processing unit has a microcontroller is in charge of gathering the data from the external measurement units and writing it to the memory card. So, this central unit is placed in the trunk inside a box and it contains an AL-XAVRB board with an AVRATxmega processor which contains the necessary embedded firmware to gather the data from all the measurement units and store it in a microSD card. Also, the trunk box contains some embedded magnetic and inertial sensors.

Figure 2.2: Devices used in Gait Watch System.

There are three different kinds of external units with the following components:

- Type A (thighs and shanks):
  - ◇ IMU 5 from Sparkfun. IMU 5 contains an IDG500 biaxial gyroscope (from which only Y axis is actually used) with a measurement range of $\pm 500 deg/s$ and a $\pm 3g$ triaxial accelerometer, ADXL335 .
- Type B (arms):
  - ◇ IDG500 biaxial $\pm 500 deg/s$ gyroscope.
- Type C (trunk box):
  - ◇ ADXL345 triaxial accelerometer with programmable range ($\pm 16g/\pm 8g/\pm 4g/\pm 2g$).
  - ◇ IMU3000 triaxial gyroscope with programmable range ($\pm 250/\pm 500/\pm 1000/\pm 3000(deg/s)$).
  - ◇ Micromag3 triaxial magnetometer ($\pm 11 Gauss$).

2.2 Force Platform

Force Plate (FDM-S Multifunction Force-measuring Plate, Zebris) is a System for force measurement and it can be used as a complete measuring unit for stance and roll-off analysis. [31]

This platform consist of a large number of force sensors and enables the distribution of static and dynamic forces under the feet to be analyzed during stance and gait (65x40 cells of sensors). As a result, foot deformities, foot function and posture can be analysed and are available as an evaluation report. [31]

Therefore, this gathered information can be used afterward to analyse the postural adjustments with the right software.

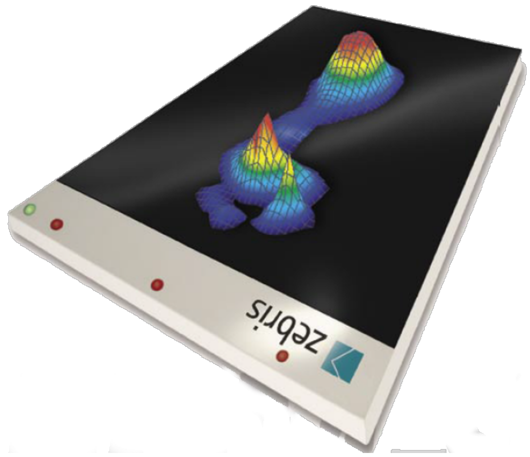

Figure 2.3: Platform used to analyse the force under the feet.

2.3 Qualisys System

The Qualisys optical motion tracker is a system that uses high speed digital cameras to capture the motion of a measurement object with passive or active markers attached. [30]

This technology is used by researchers and clinicians to undertand the basic for human motion or improve treatment during a reabilitation process. Also, it used in industrial applications, for example, the interior design of a car can be improved by using this System to evaluate the confort and safety factors for the car driver. [32]

The technology is precise and delivers high quality data to the observer in real-time. The core component of Qualisys System is one or more infrared optical cameras that emit a beam of infrared light. Also, there are small retro-reflective markers on a object or person. When the cameras emit infrared light onto the markers, these reflect the light back to the camera sensor and this information is used to calculate the position with high spatial resolution [32]. The used system has eight cameras which are distributed around a room.

Figure 2.4: Qualisys optical motion tracker.

The provided software tools allows to perform basic motion calculations, such as speed, acceleration, rotation and angle, as well as other more complex calculations. The precision of this system allows its use as a reference system to evaluate portable motion tracking systems such as the GaitWatch. [30]

Chapter 3

Gait Watch and Force Plate signals processing

3.1 Introduction and chapter's structure

Along this chapter we will introduce the protocol used to obtain the Gait Watch and Force Plate signals as well as the developed software to synchronise and analyse the signals that characterise the anticipatory postural adjustments before gait.

On the one hand, we carry out the synchronisation between the signal from inertial sensors (Gait Watch) and the force signals from the platform. It's very important for comparing both devices, determining the differences and similarities and finally resolving if we can obtain the same information from both systems.

On the other hand, we'll analyse the most interesting signals to characterise the APAs, obtaining the parameters of them which may be of interest.

3.2 Data gathering Protocol

Prior to start of data gathering, it's necessary to set up the protocol for procedure that patients have to carry out while the data are recorded. The establishing this procedure is very important so that the synchronisation works properly because we have to identify a clear movement in both signals to match one signal with the other at the same time. In addition, the realised movements must be representatives to obtain conclusive data which help us to extract characteristics for the purpose of identify differences between patients and control subjects subsequently.

The steps followed by the patients are detailed hereafter:

1. Subject stands in front of the Force Plate.
2. Gait watch record starts for data gathering.
3. Force plate record starts for data gathering.
4. Subject makes a step onto the platform.
5. Subject stands on the platform a variable time between 2 and 10 seconds.
6. Subject makes some step forward and turns left to stand in front of the platform again.

This procedure is repeated ten times by each subject in order to characterise better the movement made. It's important to clarify that the GaitWatch recording contains all these ten episodes (in other cases more) and the platform recording only contains one episode each. So, this is a fact that we have to consider to do the synchronisation.

3.3 Synchronisation

3.3.1 Introduction and chapter's structure

One of the most important aspects whether you have data acquired from multiples devices or channels is the synchronisation. If these data are not appropriately correlated or synchronised, the analysis and conclusions from your use will be erroneous. Also, it's very important doing all automatically when you have a data on a broad scale. Therefore, the following sections explain how the information has been obtained and processed automatically, as well as what features have been calculated to characterise the movements of the patients and to carry out the synchronisation between the Force Plate signals and GaitWatch signals. This content is superficially depicted in 3.1.

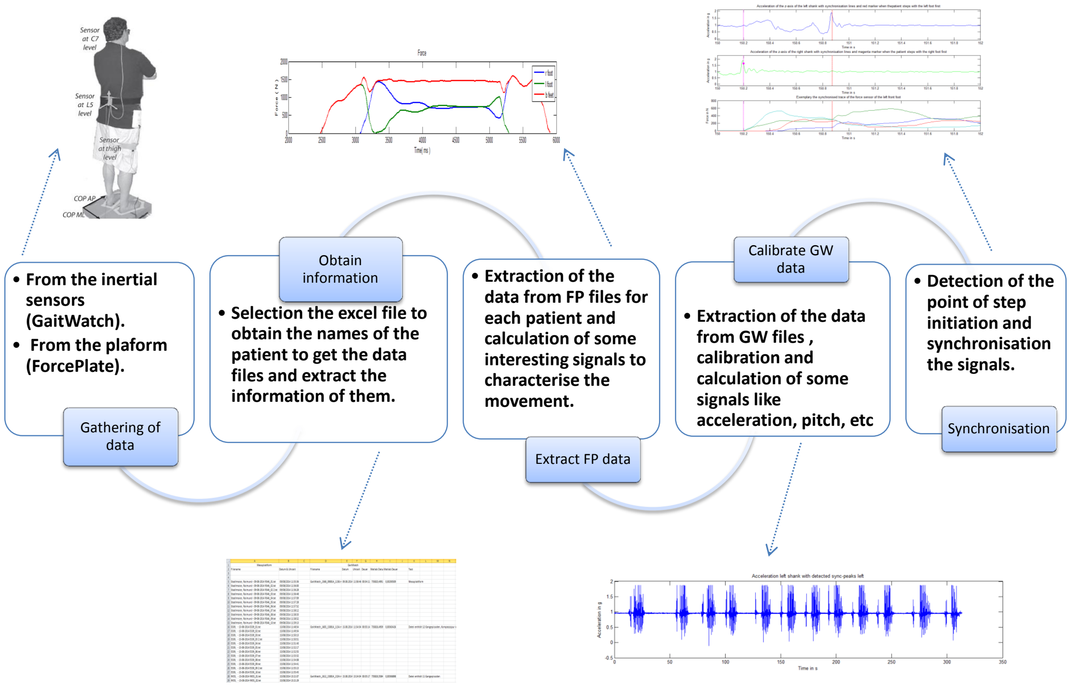

Figure 3.1: Diagram of the Synchronisation's progress.

3.3.2 Design of developed code in Matlab

3.3.2.1 Selection, reading and obtaining of information from the excel file

All patients data , that is, the different files have been generated after the gathering (of the force plate as well as Gait Watch), gathering date, duration of the experiment and other observations are saved in a Excel file.

In order to automate all as much as possible, the code is in charge of extraction of the necessary data (files names) to carry out the appropriate calculations for each patient. This is done once the Excel file has been selected, thus, it have to have a specific structure to be able to read the data correctly.

At the end of this fraction of code, we save all file names of both systems (force plate and Gait Watch) corresponding to each patient, in order to access and extract them posteriorly.

3.3.2.2 Extraction of the forceplate data

As we said before, the force plate data files are recorded independently each others, that is, there is a *.txt file for each repeat. Each file contains the force data of the toes and heels of both feet. It really realises a distribution of the sensors to cover these four segments3.2. Every measure is obtained for each point of time according to the sample frequency. Also, this file contains the force data from each cell that is part of platform in each frame3.3.

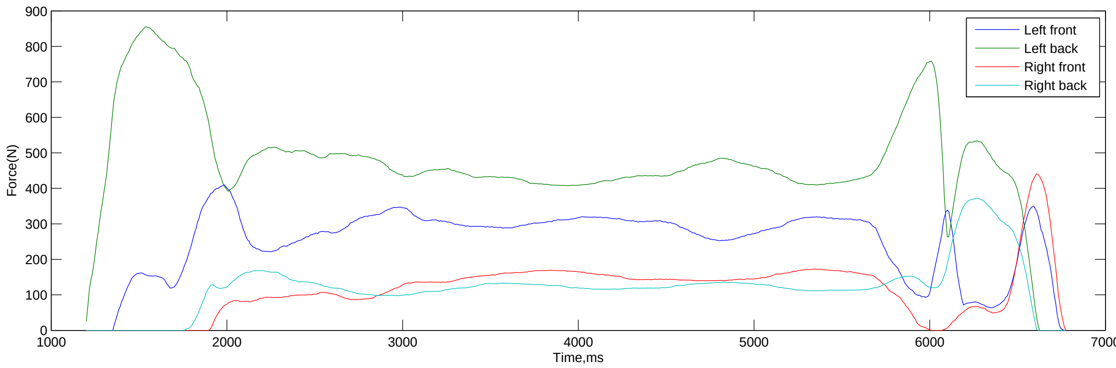

Figure 3.2: Force in each body segment.

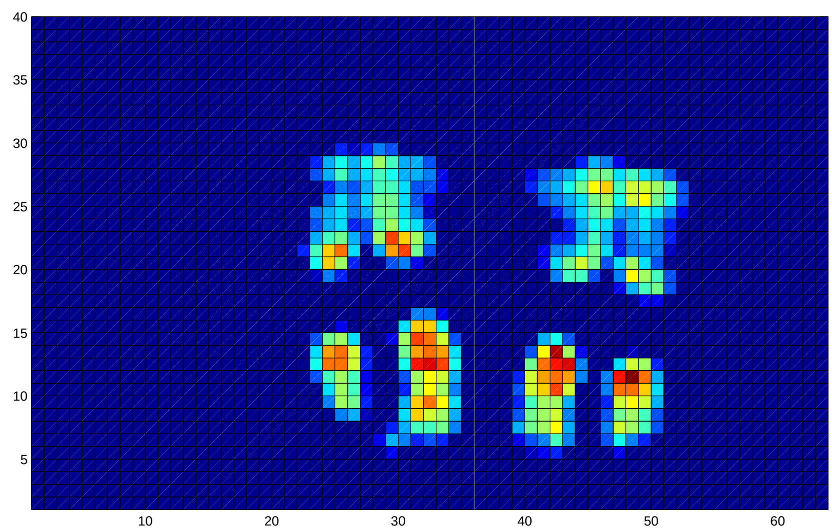

Figure 3.3: Pseudocolor with the force in each cell of the platform

Once we recover this data, some parameters are calculated for the movement characterization carried out over the platform.

- **Midline**: it represents the midline between both feet. This is important to find the gap between feet and it gives us a idea of their position in the platform. Thus, we carry out the sum of cells force in the anterior-posterior direction. So, this line is in the minimum between two maximum corresponding to the position of both feet. We use this parameter to calculate the center of pressure.

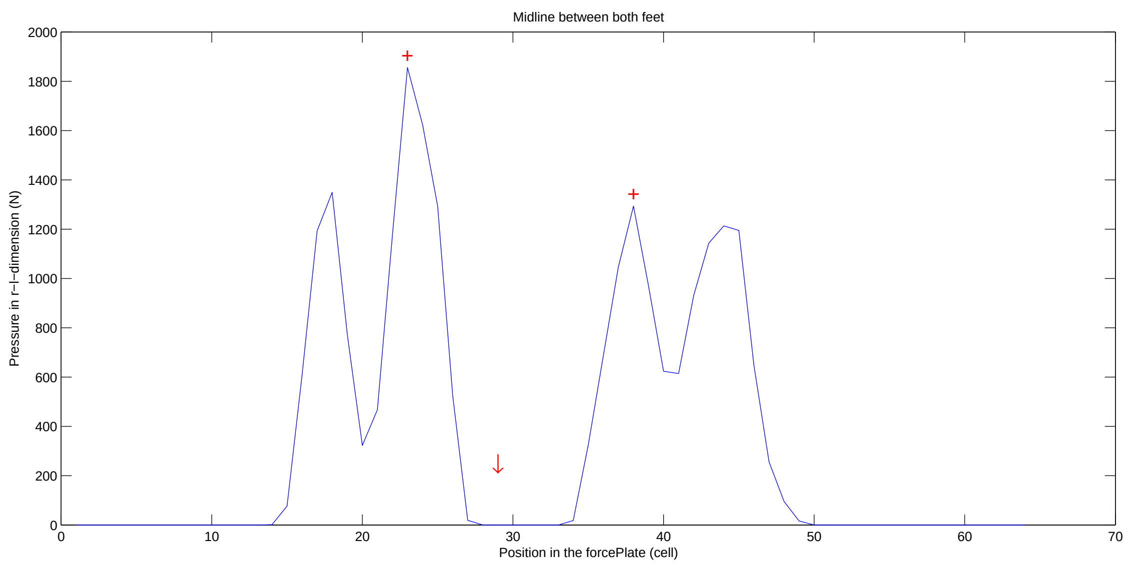

Figure 3.4: Midline between both feet in platform.

- **The total force in the platform for each point of time**: This signal is useful to do the synchronisation due to we can determine clearer when the patient touches the plate.

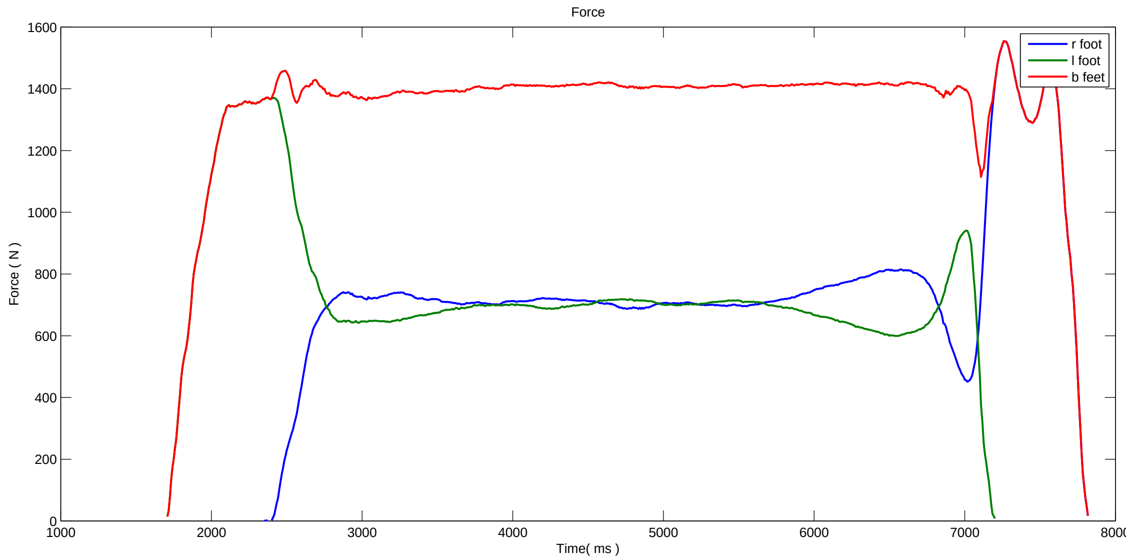

Figure 3.5: Total force in the platform of the right, left and both feet.

- **Antero-posterior COP**: center of pressure in forward-backward direction.

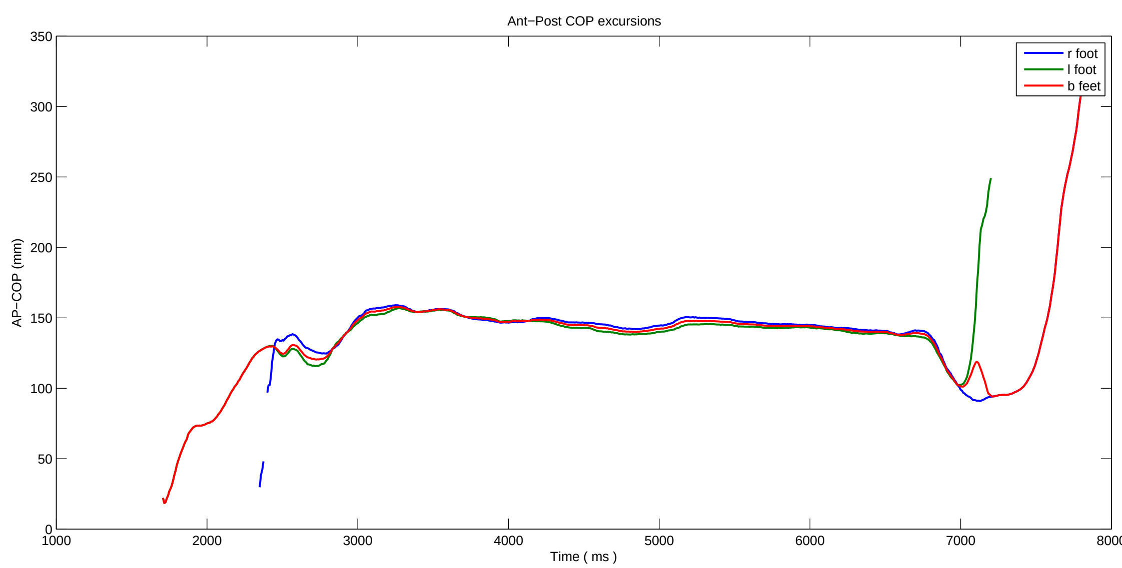

Figure 3.6: Center of Pressure in Antero-Posterior direction.

- **Medio-lateral COP**: center of pressure in right and left direction.

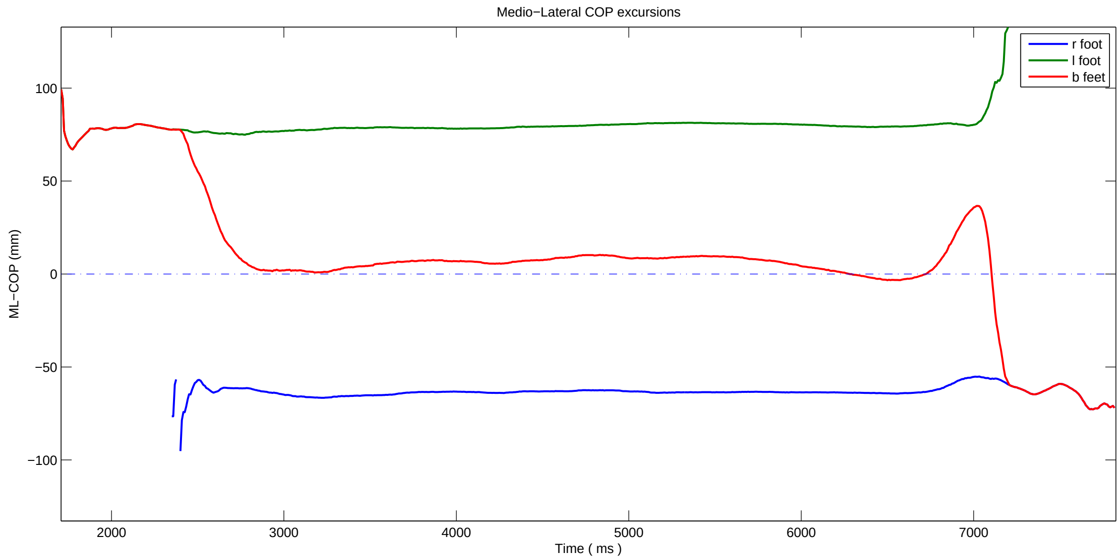

Figure 3.7: Center of Pressure in Medio-Lateral direction.

Center of pressure can be expressed as follows:

$$R = \sum_{i}^{n} m_i r_i \tag{3.1}$$

Where R is the "Center of pressure", M is the total force and mi are the force that are located in space with coordinated ri, in this case, in the plane. This location (ri) is calculate with respect to the midline.

These signals help us to characterise Anticipatory Postural Adjustments before gait. APAs indicate the movement or swinging of body before walk or carry out some movement. Thus, these are the interesting measures to compare between each repeat as well as each patients to characterise the movement, determine if there is a pattern and figure out the differences and similarities between them.

All these signals are saved for each cycle in a single variable corresponding to the patient.

3.3.2.3 Calibration of the GaitWatch data

When we are working with sensors, calibration is one of the most important aspect that needs to be carried out. Prior to the calibration process, the information at the sensors will be a signal composed of integer numbers or real numbers bounded into a range which is determined by the precision of the sensors and converters. These numeric values lack of physical value, so it is absolutely necessary to convert them into a scale that can be measured in physical units.

The sensors present several errors due to some effects like scale factor may not be linear or the triad isn't perfectly orthogonal. To remove these undesired effects, the software include a model to compensate this before the calibration. To do so, we have used the code made by Dr. Alberto Olivares Vicente in his doctoral thesis[6], with minor modifications of his work.

Besides the unwanted effects mentioned above, the output of magnetometers is distorted by wide band measurement noise appearing several large peaks of noise in the signals. To remove this automatically, we used a threshold considering that these peaks are much greater than the mean of the signal 3.8.

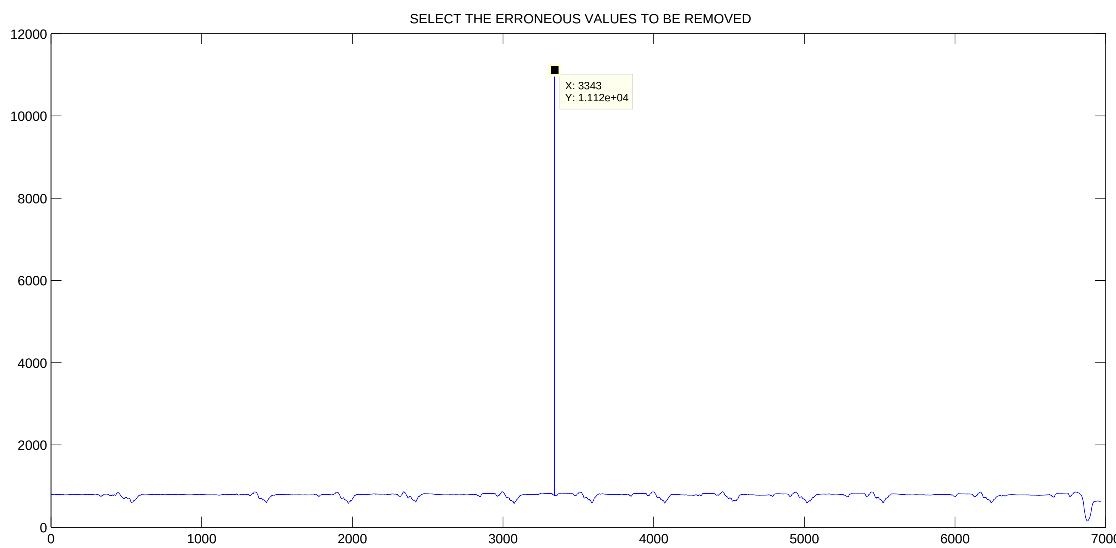

Figure 3.8: Value erroneous in magnetometer signal detected automatically.

The erroneus values in the magnetometer signal are removed sustituting these samples by the subsequent value unless the erroneous value is in the last position of the singal, in which case it is substituted by the preceding value.

3.3.2.4 Synchronisation

In this section we will explain how we carried through the synchronisation of the Force Plate and GaitWatch signals and the considerations adopted to do it properly.

The first step is to detect when the step happens in both systems. In order to do this, we'll use the completed force from force plate system and shank acceleration from the Gait

Watch accelerometer. We chose these signals because it's easy to see in them the point when the patients step.

The time point when the patient do the step in the platform is exactly when the person touches it, that is, the time point that corresponding with the first sample in the force signal with a value other than zero.

In the acceleration signal case, this fact happens in the first positive peak after a negative peak. The reason is that when patient does a step, the first movement is to rise the leg, so the acceleration vector points downwards thus the great negative peak will be when the leg is in the maximum distance from ground. The immediate movement is to lower the leg and touch the platform, so when the patient puts his leg in the force plate there is a positive peak due to the acceleration vector is pointing upward3.9.

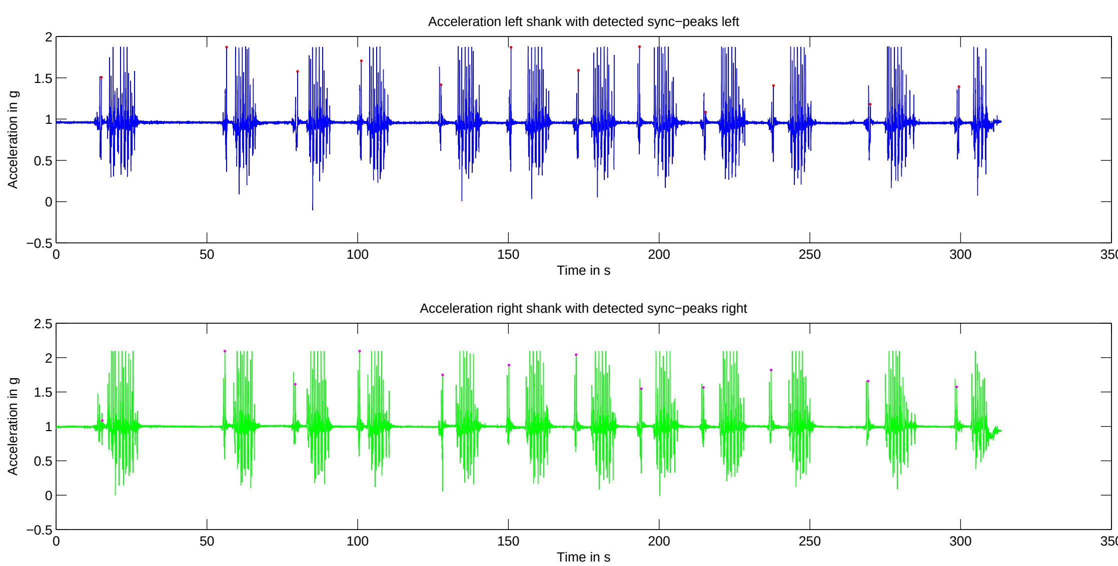

Figure 3.9: Peaks detected to the Synchronisation in the Accelerometer signals.

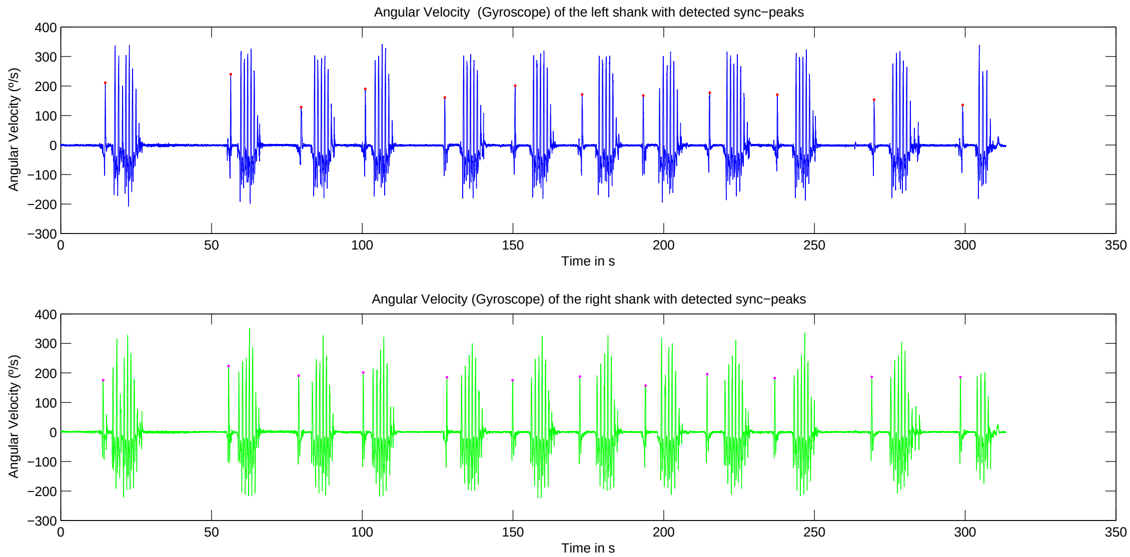

Figure 3.10: Peaks detected to the Synchronisation in the Gyroscope signals.

Once we understand the signal behaviour in connection with the patient movement we have to differentiate each cycles in the signal because we have all repeats together in the same file. To do this, we used activity detection code implemented by Dr. Alberto Olivares Vicente in his Doctoral thesis. Figure 3.11 shows the result.

In addition we did a comparative study testing two different methods based on the computation of the spectrum (Fourier Transform) of the input signal. Also, we tried several input signal to determine which is the best option to do the motion detection in this case.

We will use the Long Term Spectral Detector (LTSD) [33] and a variation of this called Framed Spectrum Detector (FSD). Spectrum-based methods have been used in others kinds of applications like Voice Activity detection [34][35] and activity sequences detection such as running or sitting-standing up[6] .

The technical difference between LTSD and FSD is that the first of them compute the Long term spectral Envelope whereas FSD uses the spectrum of each frame in which the input signal is divided[6]. What we observe when we use them in our signals is that the results are better when we use LTSD instead of FSD method in the most of the cases3.11.

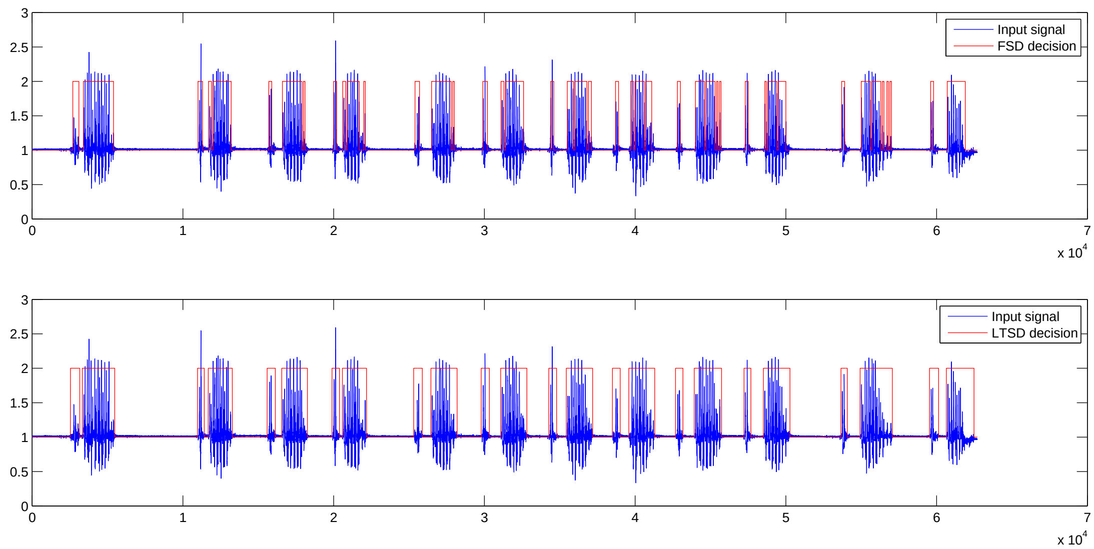

Figure 3.11: Activity Detection with FSD and LTSD Algorithm.

The LTSD method has a better decision rate than FSD method because it is designed to work under condition where the SNR is low, i.e the signal present large noise[6]. In our case, we want detect the differents cycles that corresponding to each repeat so the different peaks of activity inside each period can be a problema to do the detection correctly because really it is interpreted like noise for the detector. Thus, the LTSD method is more interesting for this type of signal.

Once we select the best method for the detection we tested several input signal for the detector: shank acceleration signal, absolute value of the shank acceleration signal and module of the shank acceleration signal. Finally, the best result was obtained when we used module of the shank acceleration signal because when this input signal is used in the resulting output signal is easier to distinguish the different episodes.

Furthermore, the motion activity detection was carried out for the right leg as well as left one. It is not necessary in some cases when the patient does the movements or activities quickly since the detected activity interval include both movements in the same episode. However, when patient waits some time to step again in the same repeat, it is possible that some step is not include in the interval thus the result would be erroneous. Therefore, to realise a general algorithm useful in whatever case we differentiate between both feet.

Now, we have to consider others aspects like the limbs with which the person start to walk. To do all more comfortable for the patients, it was not specified with which leg they had to do the first step, so we have to determinate automatically this fact. To realise this we calculate all interesting peaks in the right shank acceleration as well as left shank acceleration. Then, we identify first peak in time 3.12.

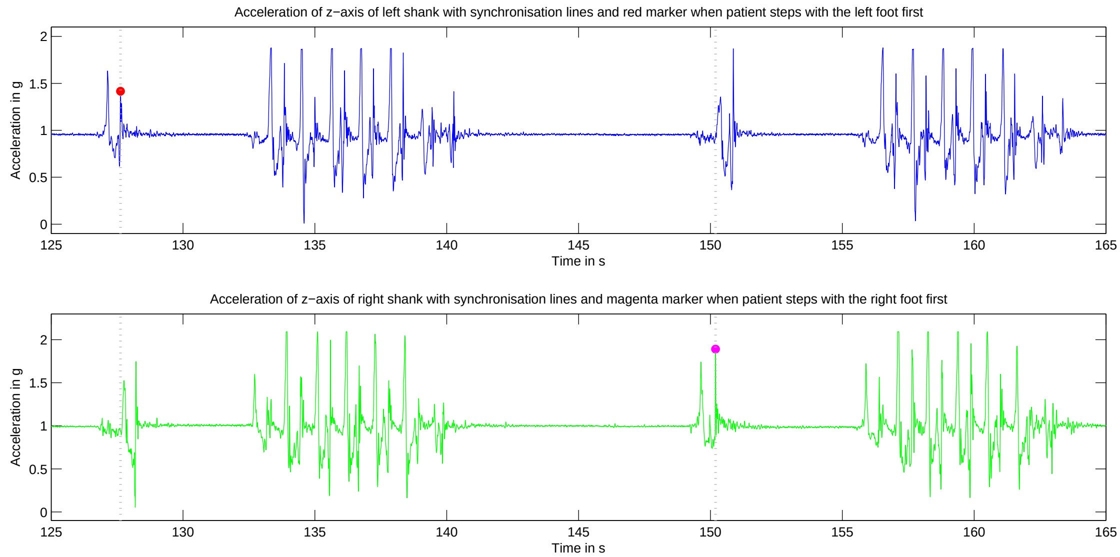

Figure 3.12: Accelerometer signals when the patient starts to step with the left and right foot respectively.

Other important aspect is to consider the sample frequency. The sample frequency is 120 Hz in force plate signals and 200 Hz in GaitWatch signals. Thus, we have to reshape the Force Plate signals to match other signals.

All the key parameters and signals are saved using "time series" for adding descriptive information to the fact.

Finally, we compare the peak detection for the synchronisation between the accelerometers signal and the gyroscopes signal3.10. The behaviour of the gyroscope signal is very similar to prior signal however this is clearer to the naked eye. Nevertheless, the correlation between the peaks detected with both systems are almost the same. This indicates that it was done correctly and these detected points are suitable to do the synchronisation. We can see this in the folllowing figures:

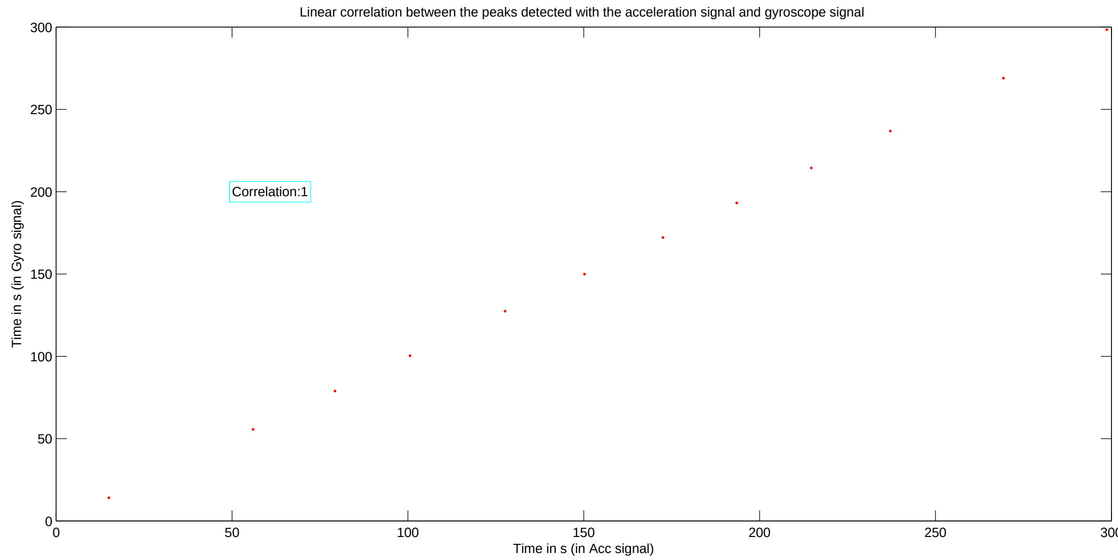

Figure 3.13: Linear Correlation between peak Acc and peak Gyro used for the synchronisation.

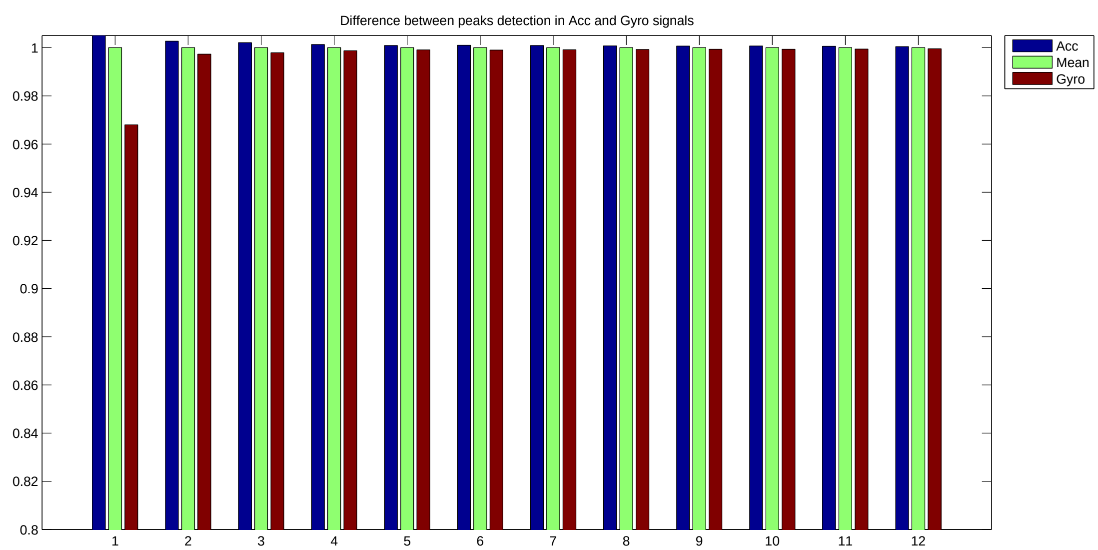

Figure 3.14: Comparation between points synchronisation detected with accelerometers and gyroscopes.

In 3.1 table we can see that the mean of the difference between the peaks detected with the accelerometer and gyroscope signals is less than 0.5 second in all cases, so it is very small. Also, the correlation between them is very high and the probability of no correlation is smaller than 0.05 what want to say that the correlation is significantly different from zero.

Table 3.1: Comparation between the peaks detected with acceletometer and gyroscope

Patient	Average peaks difference	Corr	Prob
ES39	0.3438	1.0	1.096 e-13
RK55	0.3014	1.0	2.720 e-13
RS46o	0.2500	1.0	2.750 e-29
MM57	0.4970	1.0	3.480 e-26
WS42	0.3990	1.0	1.410 e-25
SW47	0.3615	1.0	2.190 e-25
TS40	0.2674	1.0	1.559 e-31

3.4 APA analysis

3.4.1 Introduction and chapter's structure

Anticipatory postural adjustments (APAs) represents balance control that help to stabilise and mobilise the body based on anticipation of forces accompanying voluntary movement such as volitional lifting of the foot during step initiation [36] . Step initiation requires a tight proprioceptive coordination between motor commands for postural adjustments and for stepping, so APAs act to accelerate the center of pressure over the stance foot immediately prior to gait [9] .

APAs, before gait initiation, are bradykinetic in advanced Parkinson's disease and may be one of the factor associated with 'start hesitation' [9] .

Early identification in patients with PD is important because new neuroprotective medications are being tested to slow the progression of this disease and it is necessary to begin early in the disease, prior to significant loss of neurons [37] .

Currently, the most common way to evaluate postural control in the clinic is to use clinical rating scales that are limited by clinician bias, insensitivity to mild impairments and poor reliability. These limitations are serious problems for clinicians and researchers who want to monitor the disease progression, determine intervention efficacy or treat people with mild balance deficits [37] .

Technology avaiable for clinicians and researchers to mesure APAs is generally force plate for the analysis of center of pressure. However, force plate is quite large and expensive and requires a proper installation that may not be practical for clinical use. Thus, Body-worn accelerometers have been proposed as a portable, low-cost alternative to a force plate for measurements of postural sway[37] .

Therefore, along this chapter we will do a comparative study of the measurements obtained of the force plate as well as accelerometers that make up the Gait Watch system. Also, we will compare these measurements with gyroscopes data that form part of this system too, in order to determine what sensors give us the more accurate results.

3.4.2 FP and GW Signals

As we said in the before chapter, leg acceleration in the Gait Watch System as well as force in the Platform System are the most accurate signals to detect when the step happens. This is very important to do the synchronisation of the all signals system. However, the most interesting signals since a medical point of view are the trunk acceleration and the displacement of the center of pressure.

This is because we can observe the Anticipatory Postural Adjustments in these signals, i.e the body movements before stepping. According to prior studies and priori criteria it is thought that could be a good way to characterise the APAs. Therefore, the first process to carry out is the analysis of the trunk acceleration and COP to determine if there is some pattern and whether we will be able to use them to obtain information about the patients.

The first step that needs to be carried out is establish the axes in the platform to define the position over it. The X axis points forward, not existing negatives values because the range is between 0 and 510 mm, that is the platform's dimension in this direction. The Y axis is pointing to the left of the patient, so the positives values indicate a movement toward left with regard to the midline. Comparably, the negatives values are found when the movement is toward the right.

IMAGEN

Now, for the GaitWatch System we have to determine the orientation of the axes of the body frame that we wish to use, as well as the orientation of the rotation around those axes . The most popular configurations is to set the X axis pointing forwards, the Y axis pointing to the right and the Z axis pointing down. This configuration follows the rule of the right hand for the orientation of the axes and the corkscrew rule for the rotation. [**?**]

Since we will be using the GaitWatch device to monitor gait, then we need its X axis to point to the front of the patient, the Y axis pointing to the left of the patient in our case, and the Z axis to the floor. Thus, in our particular , the Y axis points to the left, so it can be like a mirror when we compare with the FP signals.[**?**]

IMAGEN

Once we have identified the axes of the accelerometers, we now proceed to identify the axes of the gyroscopes and their orientation. By convention, as it is depicted in figure 2.1, the sense of the rotation around a given axis is positive when the axis is pointing forwards (from the perspective of the user) and it is turned to the right. However, in this case the rotation is positive toward left. Analogously, the rotation is negative when it is turned to the right [**?**]

IMAGEN

We have to differentiate between the front-back movement and the right-left movement. In the first of the case, we have the acceleration in X axis and the Antero-Posterior COP. In the another case, the movement is traced by the acceleration in Y axis and the Medio-Lateral COP. Whether we focus in the Antero-Posterior movement, before stepping the body is displaced toward the opposite direction. Thus, before the step happens, the pressure is always shifted backward [figure]and the acceleration peak appears in the same direction .[figure]. IMAGEN

Also, we can observe a pattern due to all movement before stepping follows a only trace approximately. So, if we observed the trunk signals when the patient starts with the right and left feet, we see the following signals:

IMAGEN

The pattern of the acceleration in the X-axis (anterior-posterior movement), it's always the same, also regardless of the leg which the patient starts to walk. The signal makes sense because there is a first 'negative' peak, it's exactly when the APA happens, i.e when patient is shifted backwards, and after that, the patient steps ('positive' peak).

Moreover, we discern differences in the Medio-Lateral direction regarding the foot with which the step is done. IMAGES If the patient starts to step with the right foot, the center of pressure is shifted toward left. Seeing the signal, the positive direction is toward left. Therefore when patient starts with the right foot, there'll be a positive peak and after that, other negative when the step is done. [figure]

If the patient starts to step with the left foot, the center of pressure is shifted toward right, so in this case, there will be a first negative peak and after a positive peak when the step is done, in contrast to the above case. [figure]

To sum up, when the patient starts to step with the right foot, the center of pressure is shifted backward and left , so there are a positive peak in the trunk acceleration signal (Y axis), a 'negative' peak in the trunk acceleration signal (X axis), a positive peak in the ML COP and negative peak in AP COP [figure].

When the patient starts to step with the left foot, the center of pressure is shifted backward and right, so there are a negative peak in the trunk acceleration signal (Y axis), a 'negative' peak in the trunk acceleration signal (X axis), a negative peak in the ML COP and negative peak in AP COP[figure].

IMÁGENES

The behaviour of the gyroscope signals is very similar to the accelerometer signals. [figures] There are a negative peak when patient turns to backward before walking in the Antero -Posterior direction. Besides, it will be a negative peak when patient is shifted toward right and positive in the case that the turn was done to left in the Y axis.

3.4.3 Results discurssion

Chapter 4

Potential Applications

After doing a study about the different systems to monitor and analyse the postural adjustments, we proceed to explain possible applications in the real life.

The force plate system is a very accurate system to analyse disorders in the patients, however it is a limited system for its price and portability. So, its applications make restricted to diagnosis some diseases. The same happens with Qualisys System because it is necessary fixed cameras to record data. However it is a interesting way to observe data in real time with precision and robustness .

But, without a doubt, Gait Watch System is one of the most interesting system due to portability and its amount of fields where it can be used such as telerehabilitation, daily activities and performance of some athletics. This is why, the majority of applications will be focused in this system.

All of these implementations will be briefly explained below as well as a business idea as a concrete application of this Project.

4.1 Diseases

There exists a large amount of diseases that distort the motor control of human body or present symptoms that can be identified by the analysis of human body posture and motion. Along this section, we will briefly comment how our study has influence in that.

4.1.1 Telehabilitation

4.1.2 Neurological and Muscular diseases

4.1.3 Sleep disorder

4.2 Dialy activities

4.2.1 Tracking of older people

4.2.2 Athletics

4.3 Business plan

Bibliography

[1] Why intel and the michael j. fox foundation are teaming up to create wearable tech for parkinson's. http://www.fastcompany.com/3034433/why-intel-and-the-michael-j-fox-foundation-are-teaming-up-to-create-wearable-tech-for-parkin.

[2] Gay L. Girolami, Takako Shiratori, and Alexander S. Aruin. Anticipatory postural adjustments in children with hemiplegia and diplegia. *Journal of Electromyography and Kinesiology*, 21:988–997, 2011.

[3] Teddy Caderby, Georges Dalleau, Pierre Leroyer, Bruno Bonazzi, Daniel Chane-Teng, and Manh-Cuong Do. Does an additional load modify the anticipatory postural adjustments in gait initiation? *Gait and Posture*, 37:144–146, 2013.

[4] Parkinson's disease fundation. http://www.pdf.org/.

[5] Parkinson's disease. http://en.wikipedia.org/wiki/Parkinson

[6] A.Olivares. 'signal processing of magnetic and inertial sensor's signals applied to human body motion monitoring'.

[7] Marcio J. Santos, Neeta Kanekar, and Alexander S. Aruin. The role of anticipatory postural adjustments in compensatory control of posture: 1.electromyographic analysis. *Journal of Electromyography and Kinesiology*, 20:388–397, 2010.

[8] Electromiografia. http://www.bioingenieria.edu.ar/academica/catedras/bioingenieria2/archivos/apu

[9] M.Mancini, C. Zampieri, P. Carlson-Kuhta, and L. Chiari ans F.B.Horak. Anticipatory postural adjustments prior to step initation are hypometric in untreated parkinson's disease: an accelerometer-based approach. *European Journal of Neurology*, 16:1028–1034, 2009.

[10] Vennila Krishnan, Alexander S.Aruin, and Mark L.Latash. Two stages and three compoments of the postural preparation to action. *Exp Brain Res*, 212:47–63, 2011.

[11] 3dm-gx3-45. http://www.microstrain.com/inertial/3dm-gx3-45.

[12] Mvn-biomech. http://www.xsens.com/products/mvn-biomech/.

[13] Xsens-mvn. http://www.xsens.com/products/xsens-mvn/.

[14] Kinect. http://www.microsoft.com/en-us/kinectforwindows/.

[15] W.E. Mcllroy and B.E. Maki. Do anticipatory postural adjustments precede compensatory stepping reactions evoked by perturbation? 164:199–202, 1993.

[16] E. Yiou, T. Hussein, and J. LaRue. Influence of temporal pressure on anticipatory postural control of medio-lateral stability during rapid leg flexion. *Gait and Posture*, 35:494–499, 2012.

[17] M-C. Do S. Bouisset. Posture, dynamic stability, and voluntary movement posture, stabilité dynamique et mouvement volontaire. *Neurophysiologie Clinique/Clinical Neurophysiology*, 38:345–362, 2008.

[18] Neeta Kanekar and Alexander S. Aruin. Aging and balance control in response to external perturbations: role of anticipatory and compensatory postural mechanisms. *American Aging Association*, 36:1067–1077, 2014.

[19] Séverine Bleuse, Franc¸ois Cassim, Jean-Louis Blatt, Etienne Labyt, Philippe Derambure, Jean-Daniel Guieu, and Luc Defebvre. Effect of age on anticipatory postural adjustmentsin unilateral arm movement. *Gait and Posture*, 24:203–210, 2006.

[20] Estelle Palluel, Hadrien Ceyte, Isabelle Olivier, and Vincent Nougier. Anticipatory postural adjustments associated with a forward leg raising in children: Effects of age, segmental acceleration and sensory context. *Clinical Neurophysiology*, 119:2546–2554, 2008.

[21] Antonia Ypsilanti, Vassilia Hatzitaki, and George Grouios. Lateralized effects of hand and eye on anticipatory postural adjustments in visually guided aiming movements. *Neuroscience Letters*, 462:121–124, 2009.

[22] Vincent Nougiera, Normand Teasdaleb, Chantal Bardb, and Michelle Fleuryb. Modulation of anticipatory postural adjustments in a reactive and a self-triggered mode in humans. *Neuroscience Letters*, 260:109–112, 1999.

[23] C. TARD, K. DUJARDIN, J.-L. BOURRIEZ, P. DERAMBURE, L. DEFEBVRE, and A. DELVAL. Stimulus-driven attention modulates the release of anticipatory postural adjustments during step initiation. *Neuroscience*, 247:25–34, 2013.

[24] Jebb G.Remelius, Joseph Hamill, Jane Kent-Braun, and Richard E.A.Van Emmerik. Gait initation in multiple sclerosis. *Motor Control*, 12:93–108, 2008.

[25] Chris J.Hass, Dwight E.Waddell, Richard P.Fleming, Jorge L.Juncos, and Robert J.Gregor. Gait initation and dynamic balance control in parkinson‘s disease. *Arch Phys Med Rehabil*, 86, 2005.

[26] L. M. HALL, S. G. BRAUER, F. HORAKb, and P. W. HODGES. The effect of parkinson's disease and levodopa on adaptation of anticipatory postural adjustments. *Neuroscience*, 250:483–492, 2013.

[27] Kian Sek Tee, Member, IAENG, Mohammed Awada, Abbas Dehghani, David Moser, and Saeed Zahedi. Triaxial accelerometer static calibration. *WCE*, 3:6–8, 2011.

[28] Frédéric Camps, Sébastien Harasse, and André Monin. Numerical calibration for 3-axis accelerometers and magnetometers. *IEEE International Conference on Electro/ Information Technology*, 9:217–221, 2009.

[29] Oresti Baños, Miguel Damas, Hector Pomares, Fernando Rojas, Blanca Delgado, and Olga Valenzuela. Human activity recognition based on a sensor weighting hierarchical classifier. *Springer-Verlag*, 2012.

[30] A.Olivares and Kai Bötzel. *GaitWatch: User Manual.*

[31] Zebris force plate. http://www.zebris.de/english/medizin/medizin-kraftverteilungsmessung-fdms.php.

[32] Qualisys system. http://www.qualisys.com/company/motion-capture-technology/.

[33] Carmen Benitez Angel De La Torre Javier Ramirez, Jose C. Segura and Antonio Rubio. Efficient voice activity detection algorithms using long-term speech information. *Speech Communication*, 42:3–4, 2004.

[34] Jose Carlos Segura Carlos G. Puntonet Antonio J. Rubio Senior Member Javier Ramirez, Juan Manuel Gorriz. Speech/non-speech discrimination based on contextual information integrated bispectrum lrt. *IEEE Signal Processing Letters*, 2006.

[35] J. M. Gorriz J. Ramirez, J. C. Segura and L. Garcia. Improved voice activity detection using contextual multiple hypothesis testing for robust speech recognition. *Trans. Audio, Speech and Lang. Proc*, 15(8):2177–2189, 2007.

[36] Martina Mancini and Fay B Horak. The relevance of clinical balance assessment tools to differentiate balance deficits. *Eur J Phys Rehabil Med*, 46(2):239–248, 2010.

[37] Martina Mancini, Arash Salarian, Patricia Carlson-Kuhta, Cris Zampieri, Laurie King, Lorenzo Chiari, and Fay B Horak. Isway: a sensitive, valid and reliable measure of postural control. *Journal of NeuroEngineering and Rehabilitation*, 9:59, 2012.