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Master thesis

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

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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:

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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.

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Chapter 1

Introduction

1.1 Context

Parkinson's disease is a chronic and progressive movement disorder caused by the malfunction and death of neurons in the brain. Some of these neurons produce dopamine, 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 [5].

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 and works as a support base. In PD it is common that the center of mass goes out of the support base. This fact causes losses of equilibrium in activities such as getting 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 advancement of knowledge about the disease. Scientific research can be the base for field applications that help to improve the people life with PD. [6][5]

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 [7] 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 .

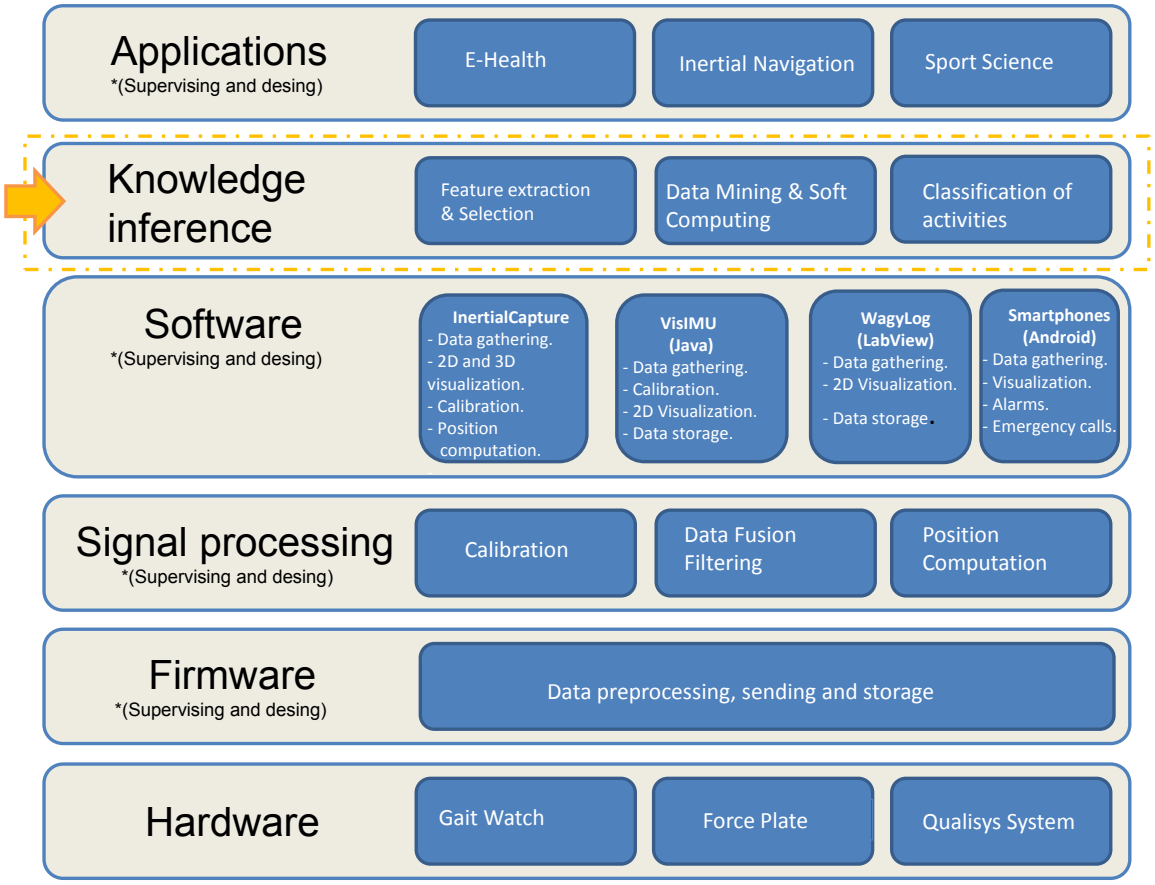

Figure 1.1: Layer structure of this project. Knowledge inference is highlighted as it includes the core of our work.

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. [6][5]

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.

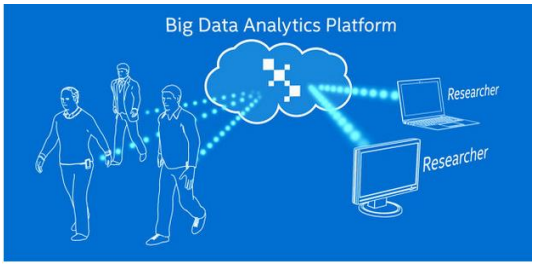

Figure 1.2: Illustration of sensors distribution thought up by Intel and Mjf.[1]

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 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 making a comparative study between the pitch angles calculated in both inertial sensors and Qualisys optical motion tracking system. The precision of this system allows its use as a reference system to evaluate portable motion tracking systems such as the GaitWatch. To carry out this comparation, healthy people were walking over a treadmill at differents velocities.

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

We can see a visual summary of the project structure in the first appendix.

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. [8] [9].

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. [10] [11].

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 [12], xsens-mvn [13] y mvn-biomech [14], all of them use Microelectromechanical Systems (MEMS).

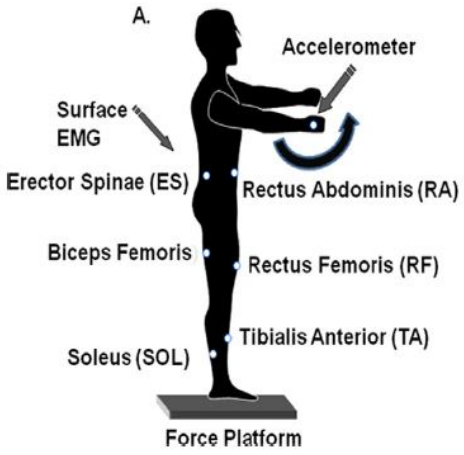

Figure 1.3: EMG, accelerometers y platform [2].

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.

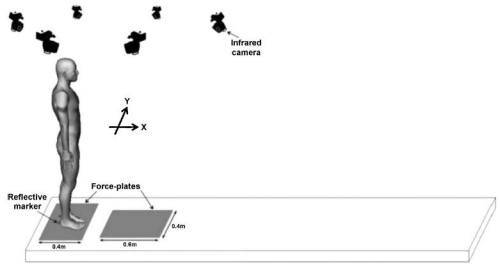

Figure 1.4: Illustration of the experiment with infrared-reflective markers[3].

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. [15].

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.[16][17][3][18][19]

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 [20] [21]; the signal type that initiates the movement (visual or auditory) due that it affect initial posture [16][22][23][24]; the fear to fall because it can do that patients adopt differents postures[26]; neurodegenerative disease, like Parkinson and Multiple Sclerosis[10][25][26][27], or cerebral palsy, like hemiplegia and diplegia, [27], 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 [28]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 [29]. Also, there are others type of calibration techniques like algorithms based in basic algebraic calculation or in FIR filters. [7]

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.[7]

Finally, we will analysis the state of the art of movement recognition in human, feature extraction 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 them [30] [31][32], that explain methods for obtaining gait features, pattern definition and human activity recognition based on a sensor weighting hierarchical classifier.

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 B¨otzel 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. [4]

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.

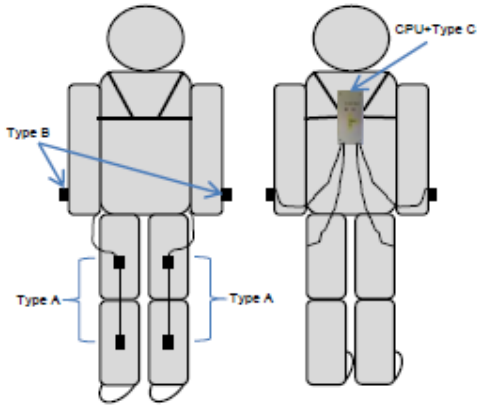

Figure 2.1: General Diagram of the Gait Watch.

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. [33]

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. [33]

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

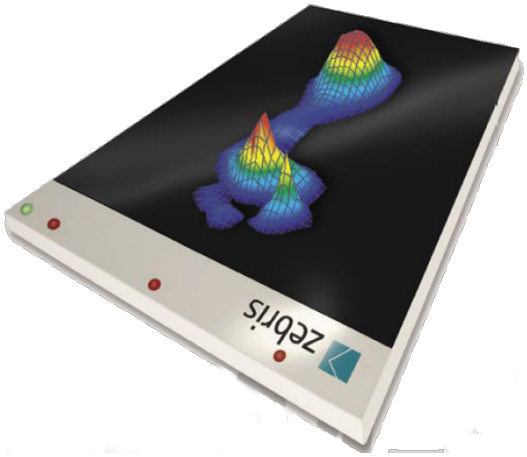

Figure 2.3: Platform used to analyse the force under the feet.

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. [4]

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. [34]

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 [34]. 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. [4]

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.

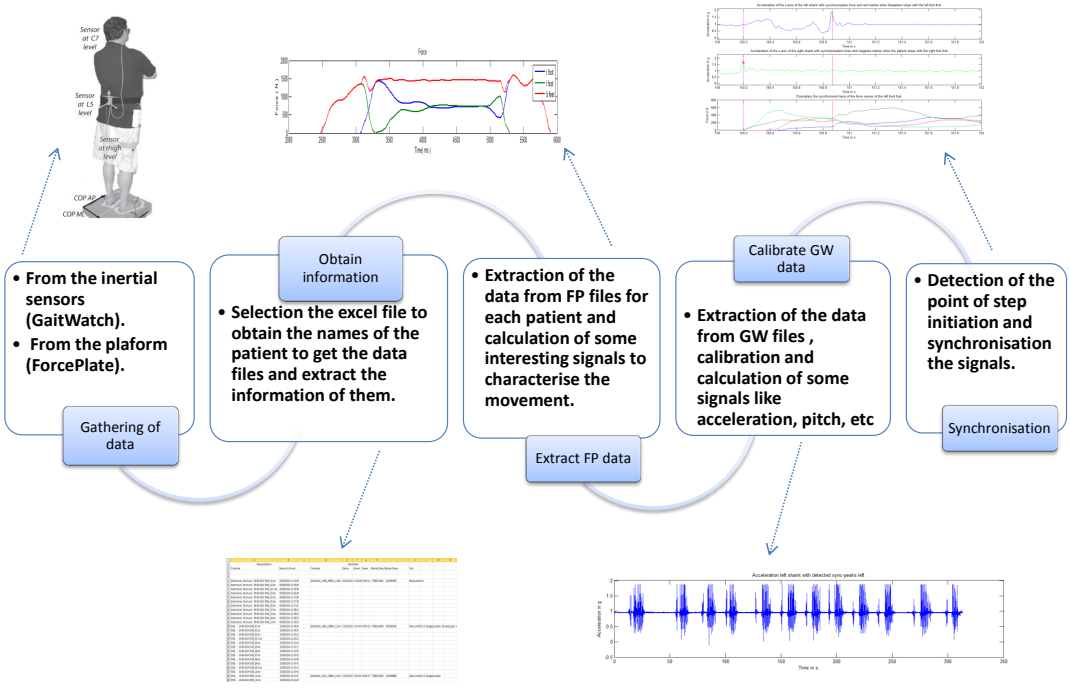

Figure 3.1: Diagram of the Synchronisation's progress.

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.

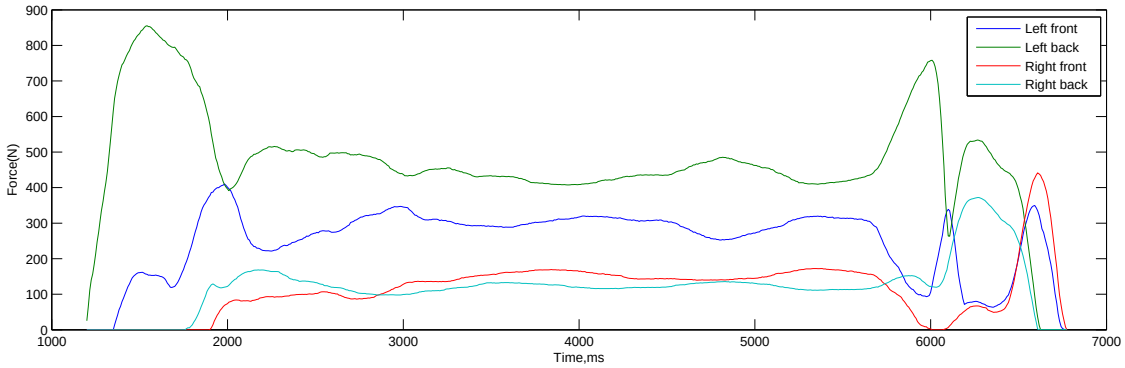

Figure 3.2: Force in each body segment.

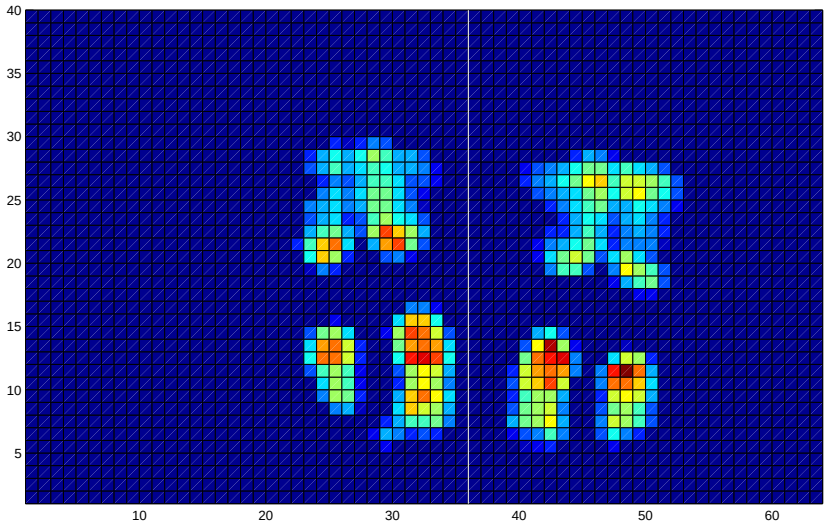

Figure 3.3: Pseudocolor with the force in each cell of the platform

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.

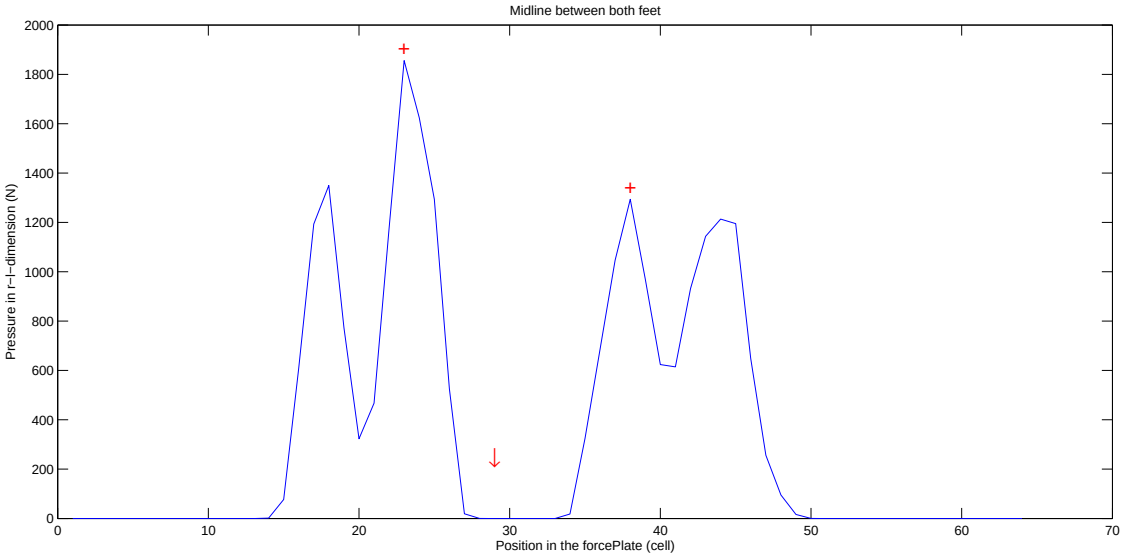

Figure 3.4: Midline between both feet in platform.

- **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.

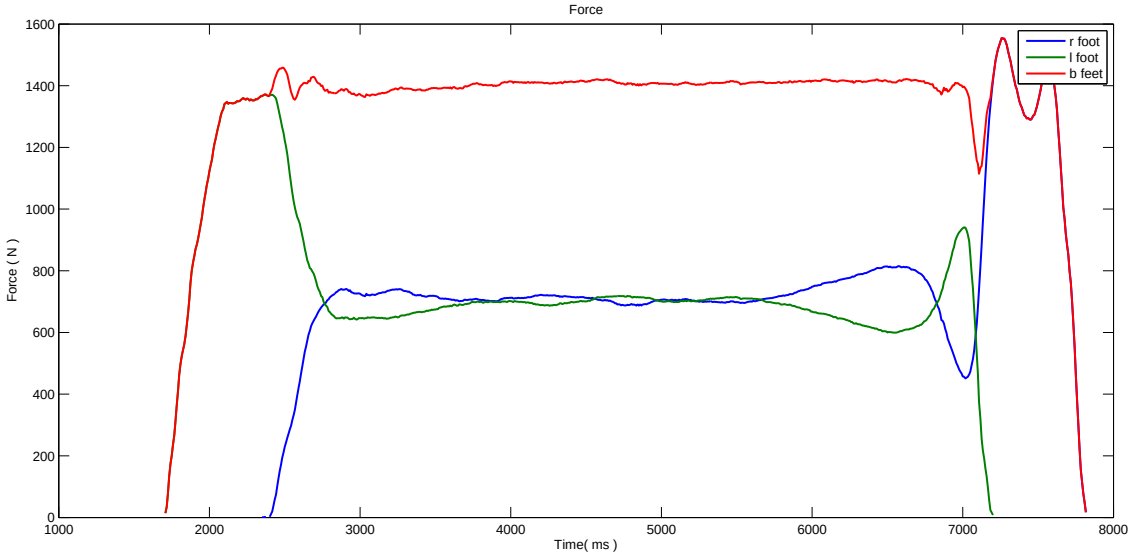

Figure 3.5: Total force in the platform of the right, left and both feet.

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

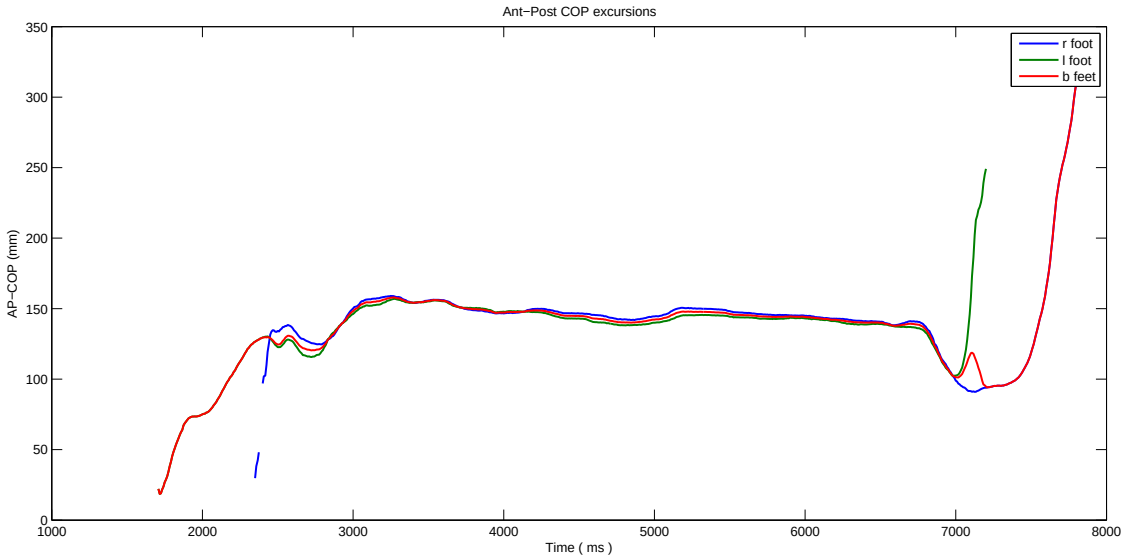

Figure 3.6: Center of Pressure in Antero-Posterior direction.

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

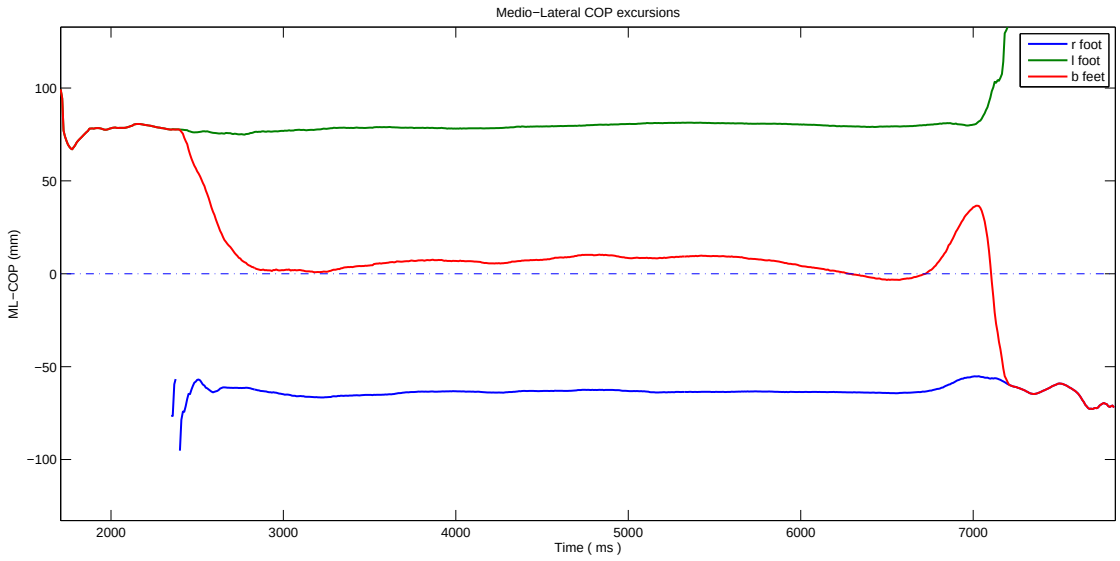

Figure 3.7: Center of Pressure in Medio-Lateral direction.

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[7], 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.

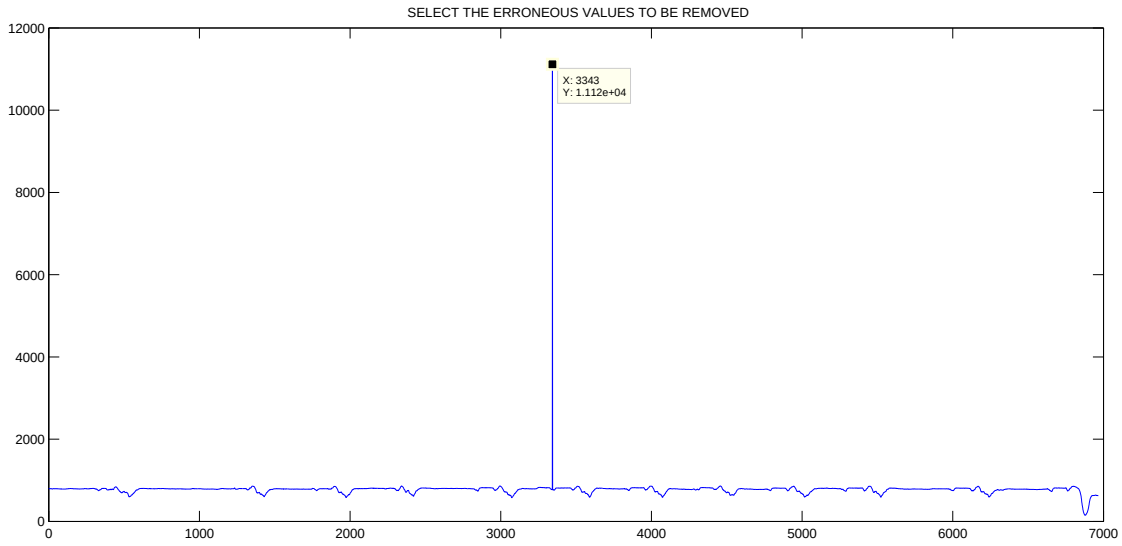

Figure 3.8: Value erroneous in magnetometer signal detected automatically.

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.

Once we have selected the right signals to do the synchronisation we have to differentiate each cycles in the acceleration 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 3.9 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) [35] 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 [36][37] and activity sequences detection such as running or sitting-standing up[7] .

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[7]. 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 cases3.9.

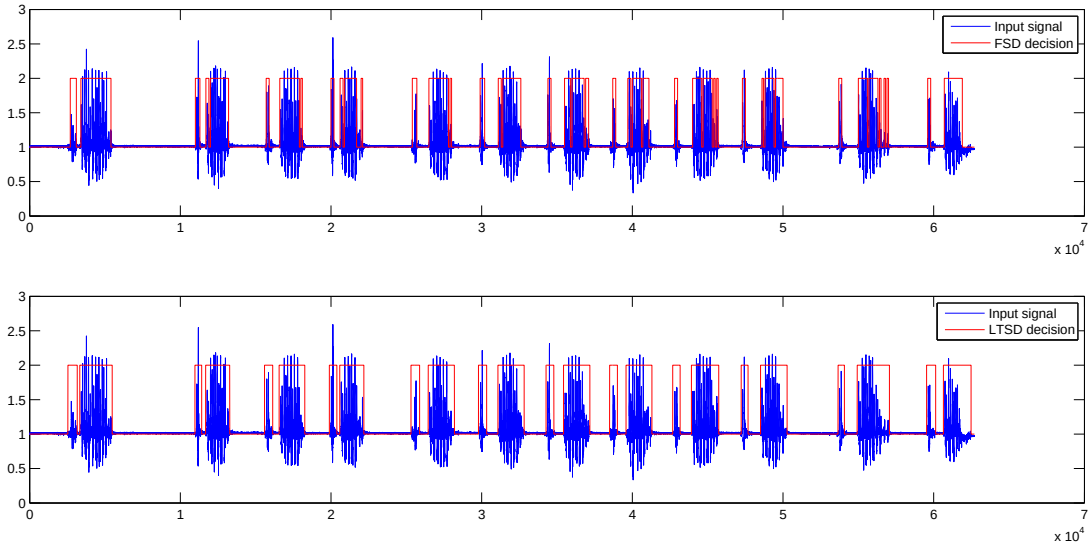

Figure 3.9: Activity Detection with FSD and LTSD Algorithm.

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[7]. 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.

Once the cycles have been separated, we are going to detect the key points in the signals to do the synchronisation.

On the one hand, the time point when the patient does 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.

On the other hand, in the acceleration signal case, this fact happens in the second positive peak3.11. The reason is that when patient does a step, the first movement is to rise the leg, so the acceleration vector points upwards thus the great positive peak will be when the leg is in the máximum distance from ground.Then, there is a change of direction and it appears a negative peak in this trace. 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 upward again.3.15.

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 3.10.

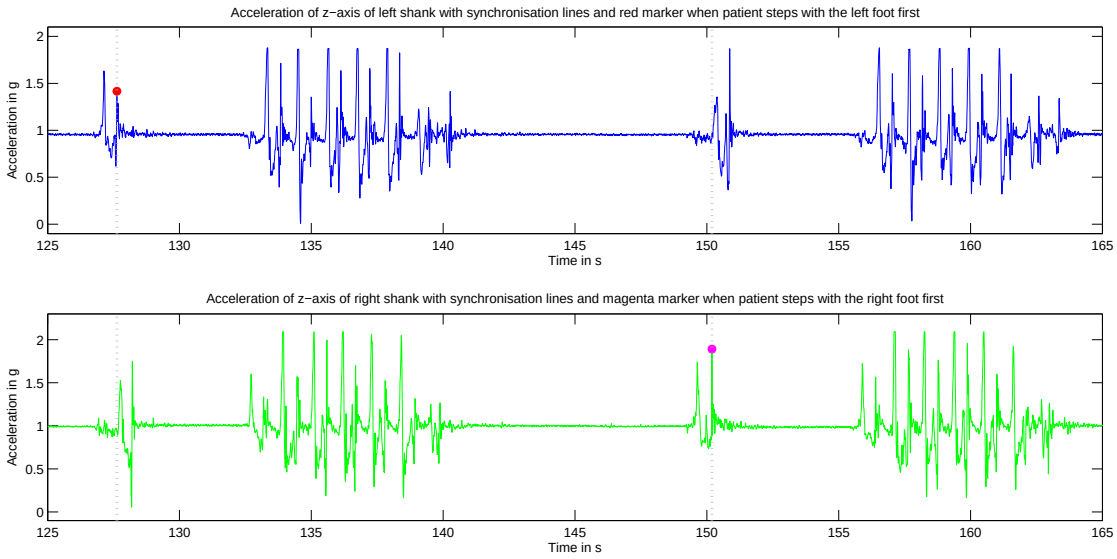

Figure 3.10: Accelerometer signals when the patient starts to step with the left and right foot respectively.

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 signal. The behaviour of the gyroscope signal is clearer to the naked eye. We can sense there are a negative peak when the patient raises his leg to step. This is negative because the movement is upwards and the Z axes is pointing to the floor so the Angular Velocity is negative. The next positive peak of happends when the person touches the platform so this is the key point to use in the synchronisation3.12.

If we compare the behaviour of both signal, it makes sense because a peak of acceleration have to appear when there is a strong growth (or decrement) of the velocity, and this happends when the person go up or down the limbs3.113.12.

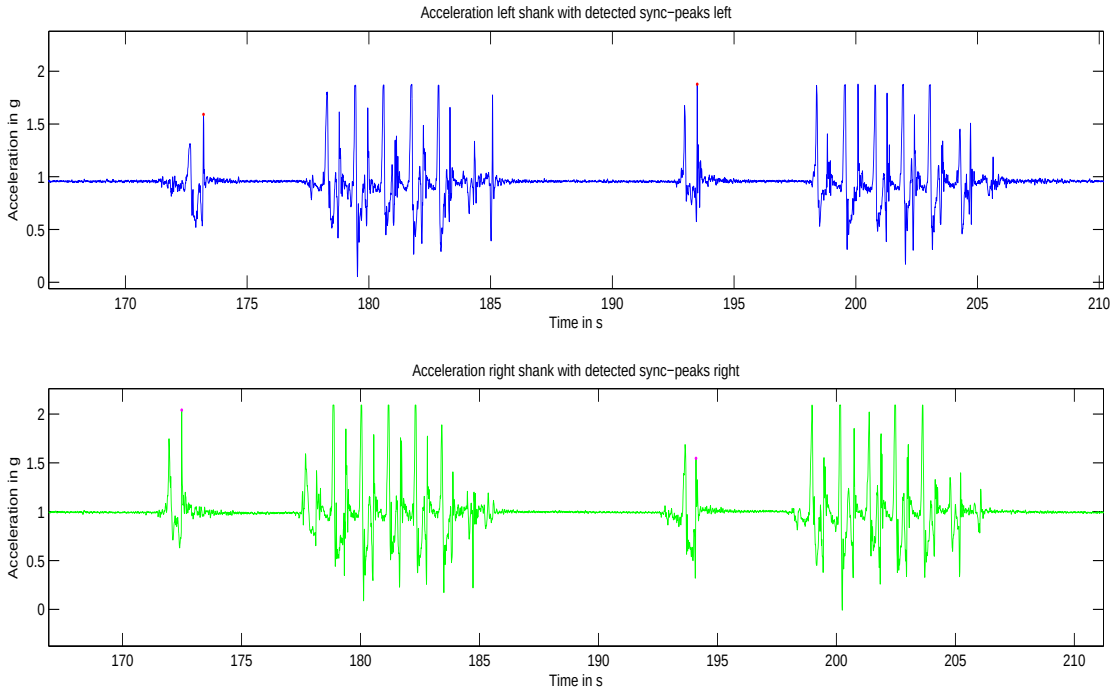

Figure 3.11: Peaks detected for the Synchronisation in the Accelerometer signals.

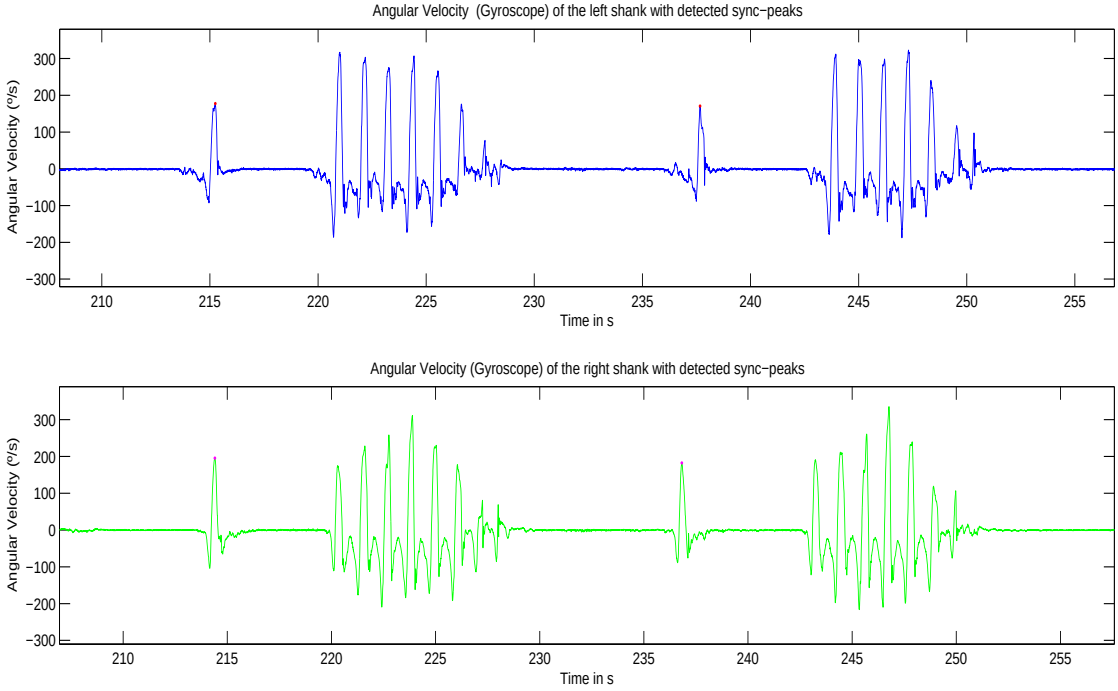

Figure 3.12: Peaks detected for the Synchronisation in the Gyroscope signals.

The correlation between the peaks detected with both systems is very high and the difference between the locations of the peaks are very small as well. 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:

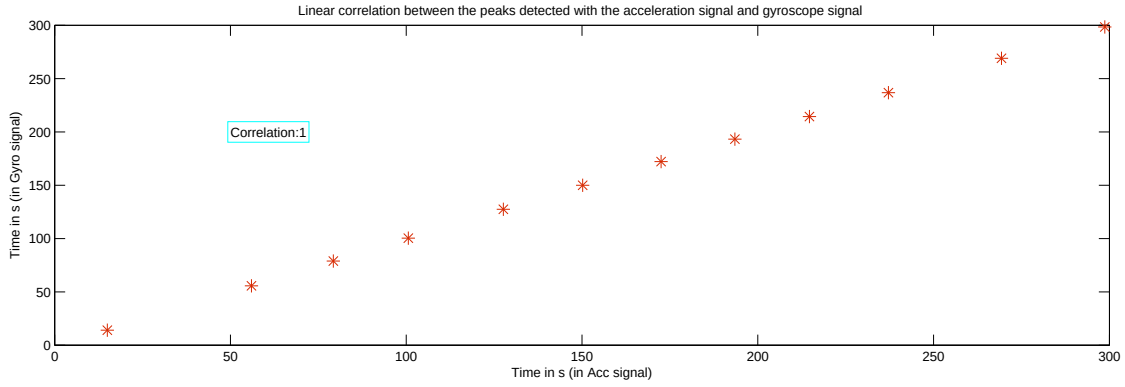

Figure 3.13: Linear Correlation between peak Acc and peak Gyro used for the synchronisation.

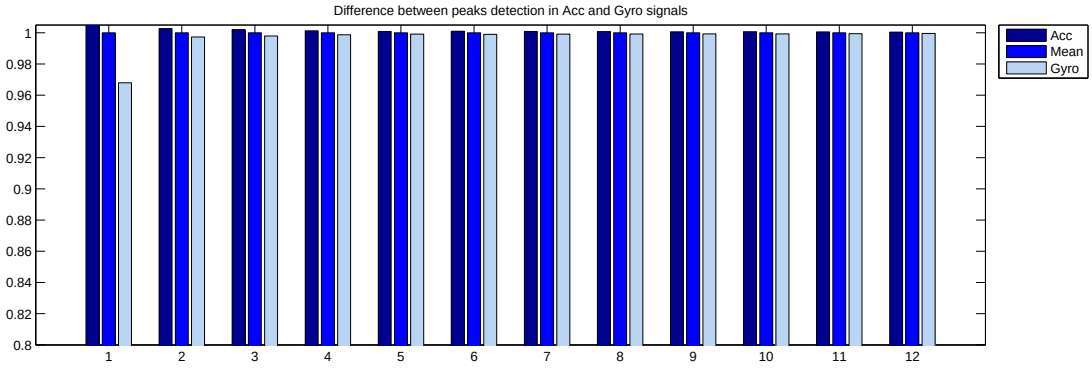

Figure 3.14: Comparation between points synchronisation detected with accelerometers and gyroscopes.

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

Finally, the result of the synchronisation can be seen in following figure:

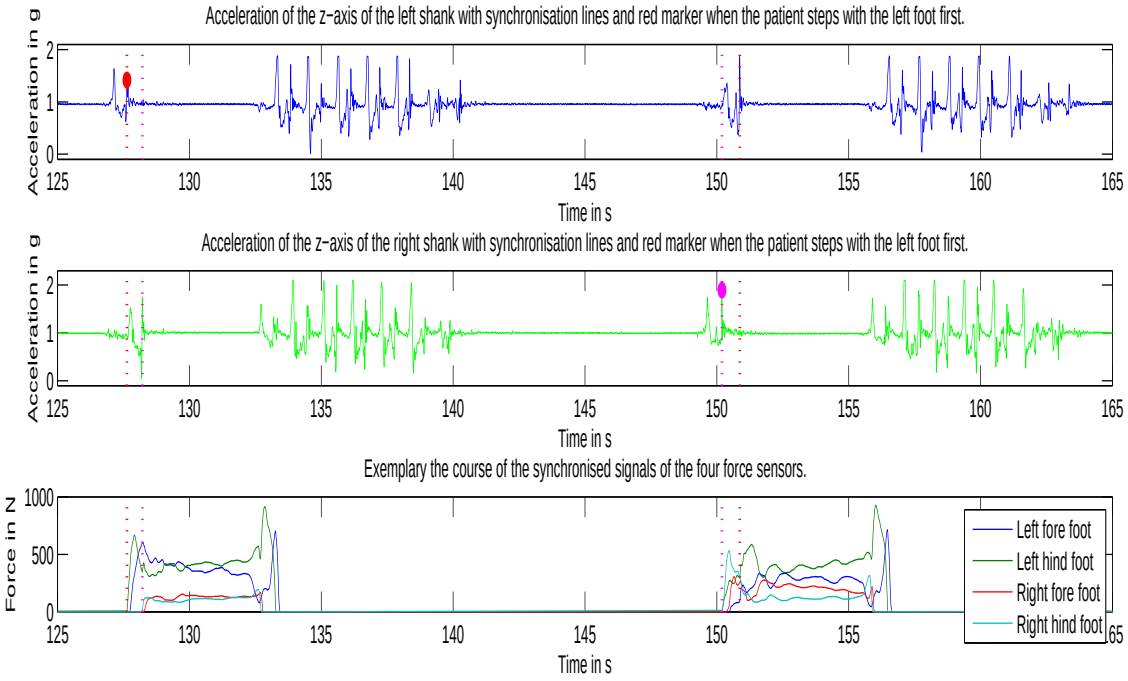

Figure 3.15: Synchronisation of the Force from the FP and Acceleration from the GW System .

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 [38] . 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 [10] .

APAs, before gait initiation, are bradykinetic in advanced Parkinson's disease and may be one of the factor associated with 'start hesitation' [10] .

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 [39] .

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 [39] .

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[39] .

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's 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 of the 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 right of the patient, so the positives values indicate a movement toward right with regard to the midline. Comparably, the negatives values are found when the movement is toward the left3.16.

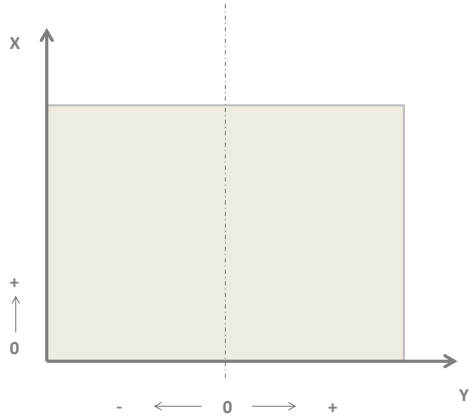

Figure 3.16: Definition of the axes in the Platform.

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 [4].

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 right of the patient, and the Z axis to the floor3.17[4].

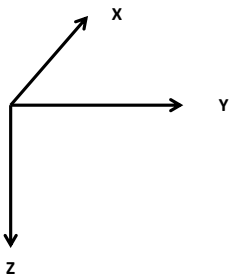

Figure 3.17: Definition of the axes in the accelerometers ans gyroscopes.

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. So, in this case the rotation is positive toward right3.18. Analogously, the rotation is negative when it is turned to the left [4]

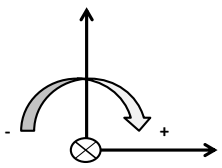

Figure 3.18: Orientation of the axis rotation in gyroscopes.

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, the body is displaced forward while the step is being completed. Thus, the center of mass is shifted backward in this period of the movement. In the case of center of pressure, we can find first movement backward to gain momentum and after that COP moves forwards under the stance of the foot3.19.

Since kinematic point of view, the trunk is moved anteriorly while the patient steps. Therefore, there will be a peak of acceleration in the X axis pointing forward, so we will find a 'negative' peak at this moment because the acceleration vector points in the opposite direction to the movement. After that, there is a positive peak that corresponding with the direction change just when the step finishes.

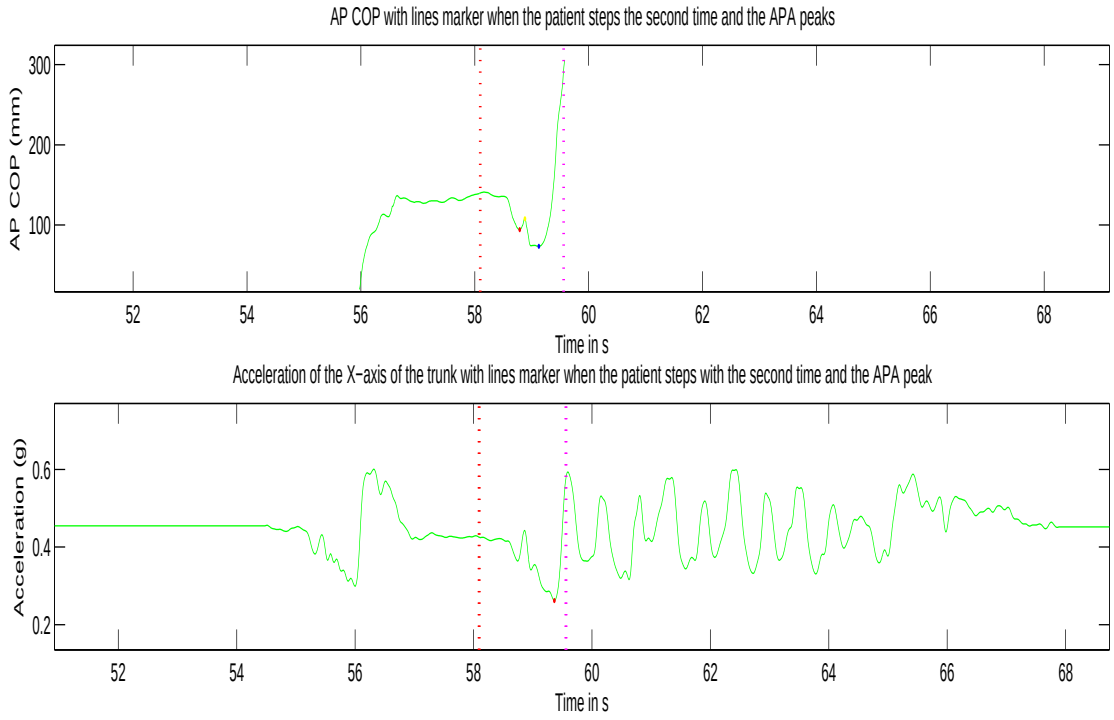

Figure 3.19: COP and acceleration in Antero-Posterior direction.

Also, we can observe a pattern due to all movements before stepping follows a only trace approximately. The pattern of the acceleration in the X-axis (anterior-posterior movement) is always the same, regardless of the leg which the patient starts to walk.

Moreover, we discern differences in the Medio-Lateral direction regarding the foot with

which the step is done.

If the patient starts to step with the right foot, the center of mass is accelerated toward left because the major body heigh is located in the foot over the ground. However, the center of pressure is shifted toward right and then the COP displaces mediolaterally to left, toward the foot is contact with the ground. For the acceleration in the Y axis, there is a negative peak because the movement is towards right and the acceleration vector points in the opposite direction, with negatives values. After this, we find a negative peak due to the change of direction3.20.

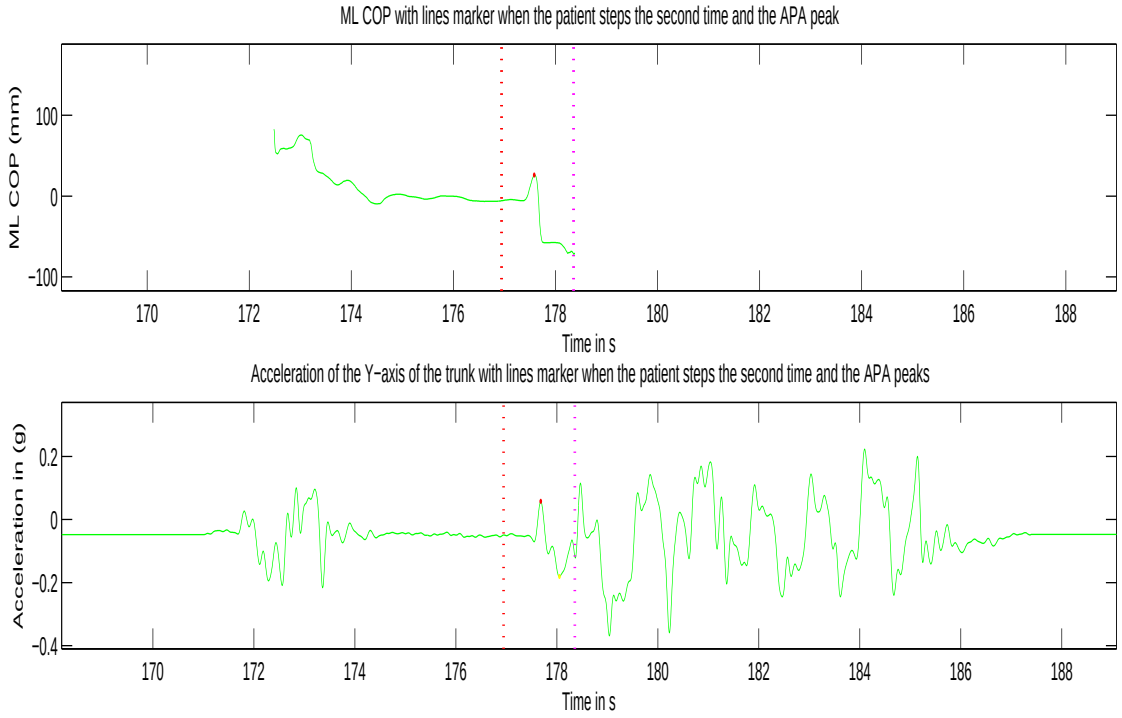

Figure 3.20: COP and acceleration in Medio-Lateral direction when patient steps with the right foot.

If the patient starts to step with the left foot, the movements are the same than in the prior case unless the movement directions are just the opposite. We can perceive this in 3.21

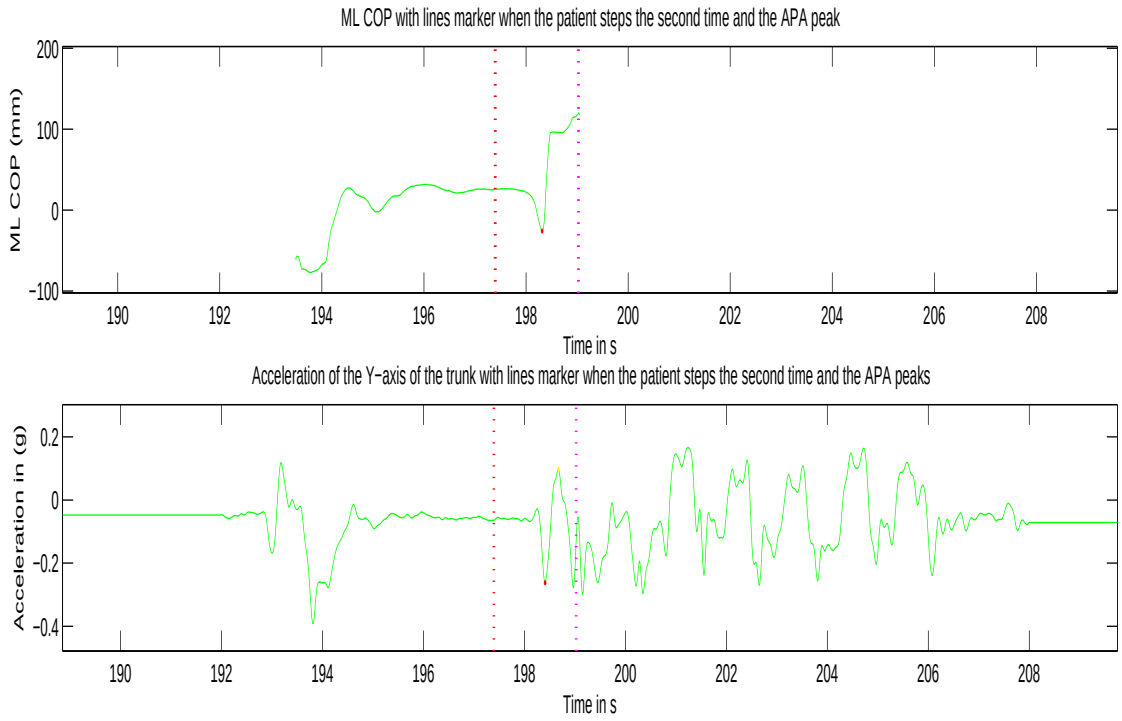

Figure 3.21: COP and acceleration in Medio-Lateral direction when patient steps with the left foot.

To sum up, we have to differentiate between the foot which the step is done (stepping foot) and the foot over the ground (stance foot) to understand the behaviour of the APAs. The center of mass (COM) is shifted toward the stance foot to maintain the equilibrium during the balance phase. The center of pressure (COP) is divided in differents phases. Firstly, the COP moves toward the stepping foot and backward to generate the momentum to step (S1 period). Hereafter, the COP is displaced toward the stance foot. This happens at time when the other foot is in the air (S2 period). Finally, the COP moves forward and under the stance foot(S3 period).

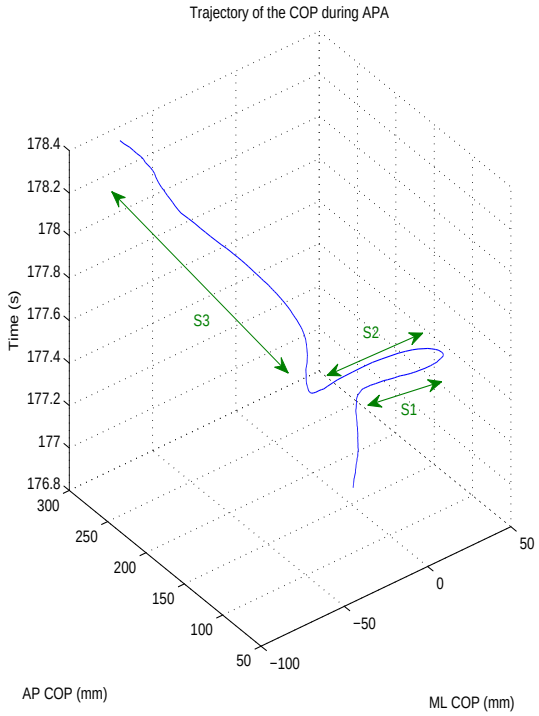

Figure 3.22: Trajectory of COP when patient steps with the right foot.

Bearing in mind the same phases for the acceleration than in the above case, in the first period (S1 period) the body is accelerated forward while the momentum is generated to step. After, the trunk is slightly accelerated toward left (S2 period) and finally, in the last period the body is moved fordward anf toward rigth to complete the step (S3 period).

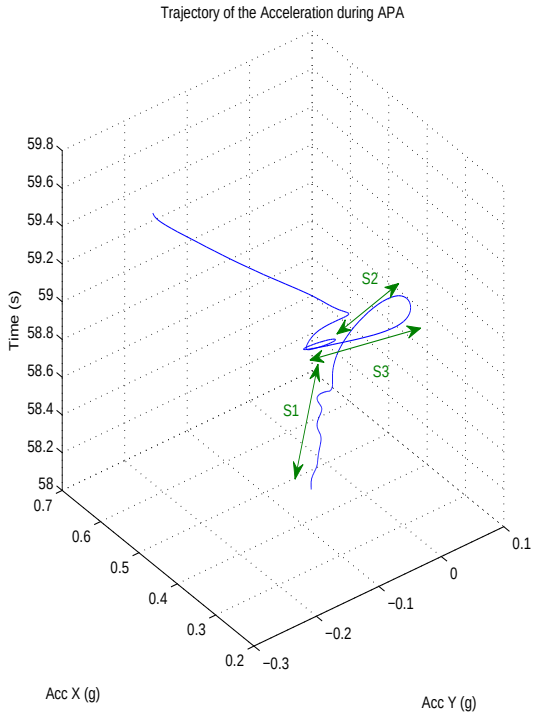

Figure 3.23: Trajectory of acceleration when patient steps with the right foot.

The behaviour of the gyroscope signals is very similar to the accelerometer signals but this case we are measuring a turn forward or backward and toward right or left.

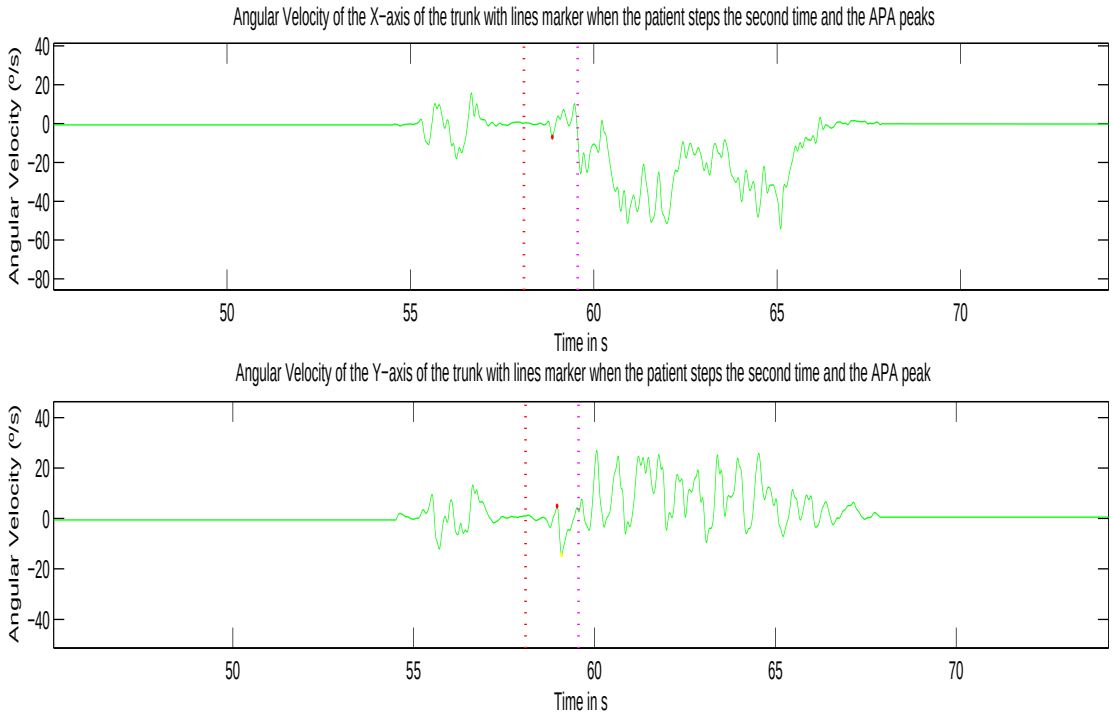

Figure 3.24: Angular Velocity when patient steps with the right foot.

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 PCA

One of the most difficulties inherent in multivariate stadistics is the task of the features extraction to obtain the most relevant information from the original data and represent that information in a lower dimensionality space.

PCA is a qualitative rigorous method for achieving this and it has been widely applied in gait analysis both for the reduction of redundant information and the interpretation of multiple gait signals[40].

This method attempts to represent the data efficiently by descomposing a data space into a linear combination of a small collectionof bases collection of bases consisting of orthogonal axes that maximally decorrelate the data[31].

Given set of centered N-dimensional training gait samples $x_j, j = 1, ..., Mx \in$ such that R_N and $R = \sum_{k=1}^{M} x_j = 0$

Where M represents the number of gait samples and N is the number of input values. The x_j vectors are aligned in the data matrix X. Also, the data have to be center so it's necessary to extract the average of the each set.

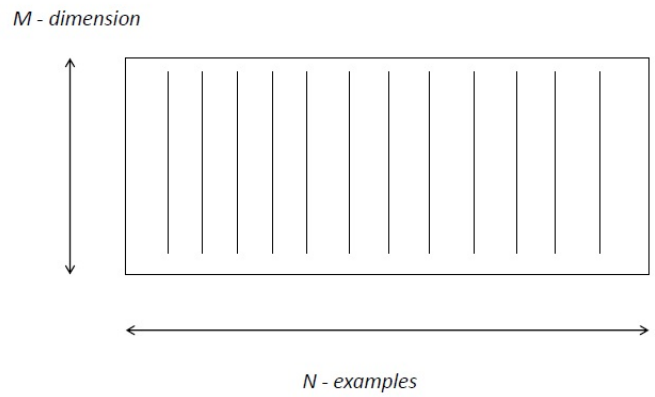

Figure 3.25: Data matrix X with M rows and N colums.

The projection of the j-th vector x_j onto the vector 'u' can be calculated in the folowing way:

$$p_j = \overrightarrow{u}^T \overrightarrow{x}_j = \sum_{i=1}^{N} u_i x_{ij} \tag{3.2}$$

We want to find a direction 'u' that maximizes the variance of the projections of all input vectors. That funtion to maximize is:

$$J^{PCA}(\overrightarrow{u}) = \sigma^2(p_j) = \frac{1}{M}\sum_{j=1}^{N}(p_j - \bar{p})^2 = ... = \overrightarrow{u}^T C \overrightarrow{u} \tag{3.3}$$

Where C is the covariance matrix of the data matrix X.

$$C = \frac{1}{N}\hat{X}\hat{X}^T$$

Using the technique of Lagrange multipliers, the solution to the maximization problem is to compute the eigenvectors and eigenvlues of the covariance matrix.

Thus, we have to solve the following eigvector problem:

$$\Lambda U = C^{'} U \tag{3.4}$$

In such a way the orthonormal matrix U contains the eigenvectors $u_1, u_2, ...u_N$ in its colums and the diagonal matrix Λ contains the eigenvalues $\lambda_1, \lambda_2, ..., \lambda_N$ on its diagonal.

The eigenvalues and the eigenvectors are arranged with respect to the descending order of the eigen values, thus $\lambda_1 \geqslant \lambda_2 \geqslant ... \geqslant \lambda_N$

Therefore, the most variability of the input random vector is contained in the first eigenvectors. Hence, the eigenvectors are called principal vectors.

So U can be used as a linear transformation to project the original data of high dimension into a space of lower dimension.

$$P = U^T \bar{X}$$

In terms of gait feature extration by choosing the first two eigenvectors, PCA can directly perform the dimensional reduction[31]. We can use this new information to do a classification. Tha classification can be achieved through a SVM which separates a given set of labelled training data with a hyperplane that is maximally distant from the two classes [41].

3.4.4 Feature extraction

Automated recognition of gait pattern change is important in medical diagnostic. Thus, in this section we are going to extract and evaluate different gait features as well as methods to obtain them. Feature extraction is a important to do a good classification of patterns. The main goal in this chapter is to obtain the relevant information from the platform and inertial sensors synchronised previously and carry out a study comparative between them.

One the one hand we try to figure out whether there is a correlation between the features of both systems and determine if we can use the inertial sensors to characterise the movement without another measure auxiliar platform. One the other hand we want to extract useful features that we can use to do a classification between patients and therefore it can be used for diagnosis.

o do this, we will use the data obtained after the synchronisation between Force Plate and Gait Watch signals. Using this signals lets us extract the information easily and compare them.

The next step is to determine when the second step happens. We used as a reference the point when the patient touched the platform to do the synchronisation. However, in

this case we have to identify when patient carried out the second step to go down from the platform. We need this part of the signals because it is when we can see the displacements of the center of pressure. To obtain these limits of the signals we use the LTSD algorism. This is applied over the acceleration signal so we can determine the beginning of this period for each cycle. The end of the interval is the point when the patient go down and touch the ground ,i.e when there is not pressure signal over the platform. Thereupon, we apply a low pass filter to the Gait Watch signals, i.e signals of the accelerometers and gyroscopes in the trunk. This allows us to delete the low frequencies of these signals due to the noise of the sensors and get the features properly. Specifically it has been used a low pass filter with a cutoff frequency of 2 Hz.

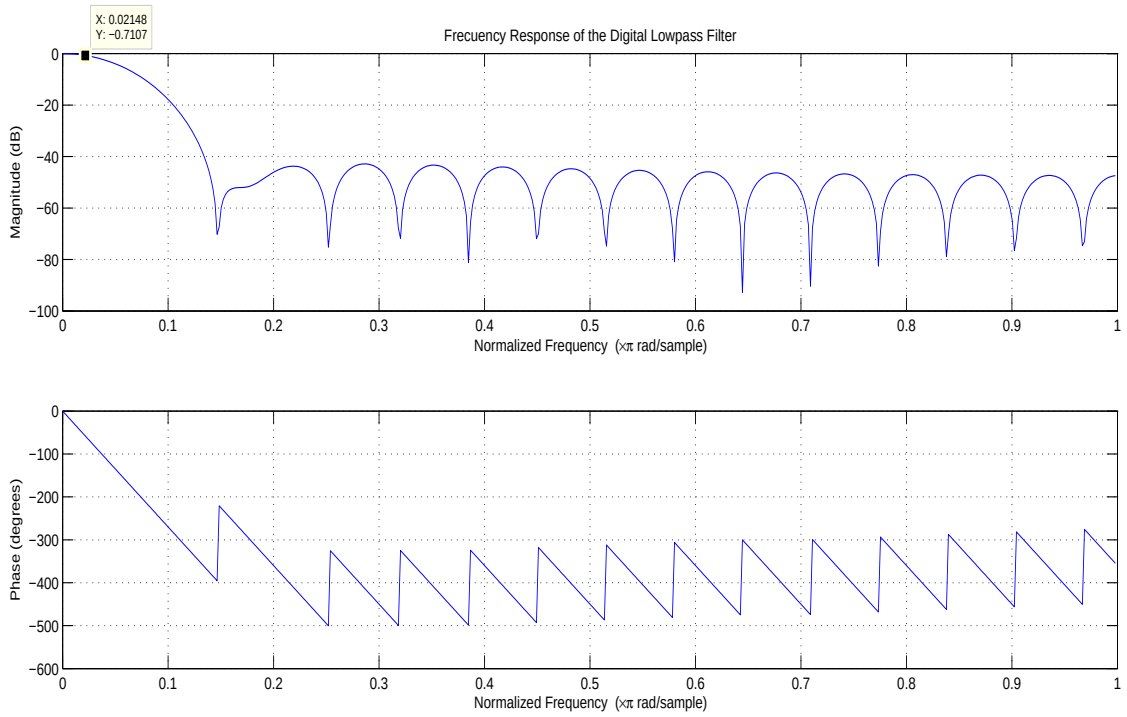

Figure 3.26: Lowpass Filter with a cutoff frequency of 2Hz

One the signals have been filtered, we will do the average of all repeat. Typically, the experiment is repeated several times to do a ratio and obtain a single signal for each patient. As we said before, the protocol is repeated about ten times so we have to synchronise this cycles and realise the mean of all them. First of all, we need determine when the patient steps with the right of left foot. This is important for the signals in the medio-lateral direction because the sing of the signals is the opposite. Thus, if patient does the step with the left foot, the signal will be invert before doing the mean. This fact is detected seeing the last values of the center of pressure because this gives us information about the locatitation of the feet. When the patient starts to step with left foot, last value of the cycle of ML- COP

is positive because the step finishes the pressure is located in the right foot. However, if the patient starts with right foot, the last value of the ML-COP cycle will be negative.

To align the signals, we use cross-correlation between them. The cross-correlation is a mesure of similarity fo two signals as a function of the lag of one relative to the other[42]. For discrete function as our case, the cross correlation is defined as:

$$(f * g)[n] = \Sigma_{m=-\infty}^{\infty} f^*[m]g[m+n] \tag{3.5}$$

Where f^* denote the complex conjugate of f and n is the lag.

Using this method, we can determine the point where the signals are more similar. After this, we can interpolate them and carry out the average between them.

At this point, we have six signals per patient: the center of pressure in the antero-posterior and medio-lateral direction, the acceleration in X and Y axis and the angular velocity in the same axes. Therefore, the next step is extract the features of them.

We was analysing the Gait Watch and Forceplate signals in the above chapter and determining the most interesting episodes in these signals. So, the first features that we will obtain are the peaks in COP, acceleration and angular velocity. we can see this in the following figures:

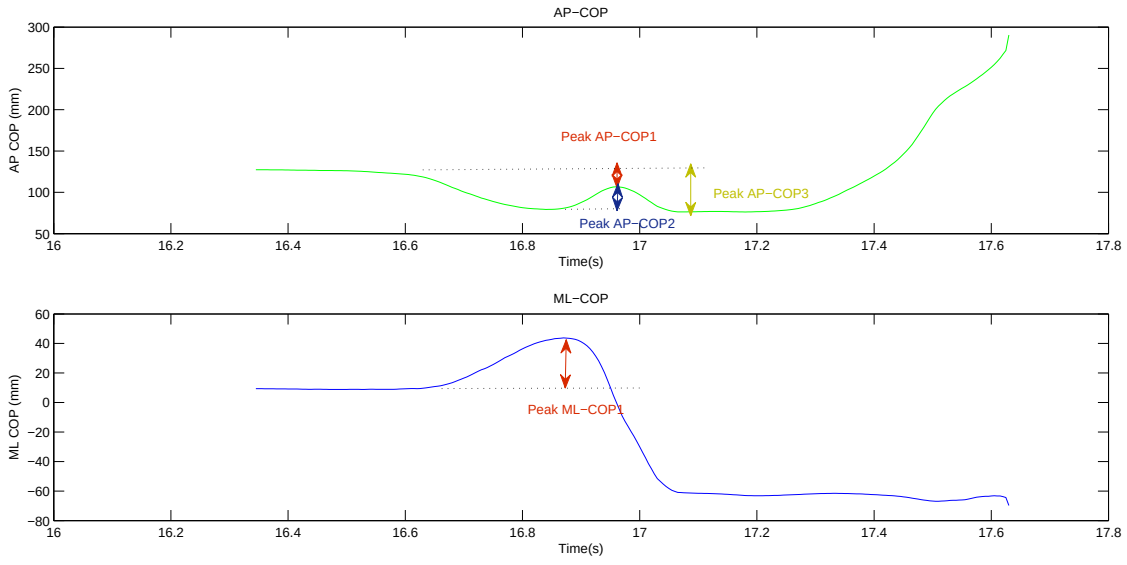

Figure 3.27: Peaks in the Center of Pressure signals .

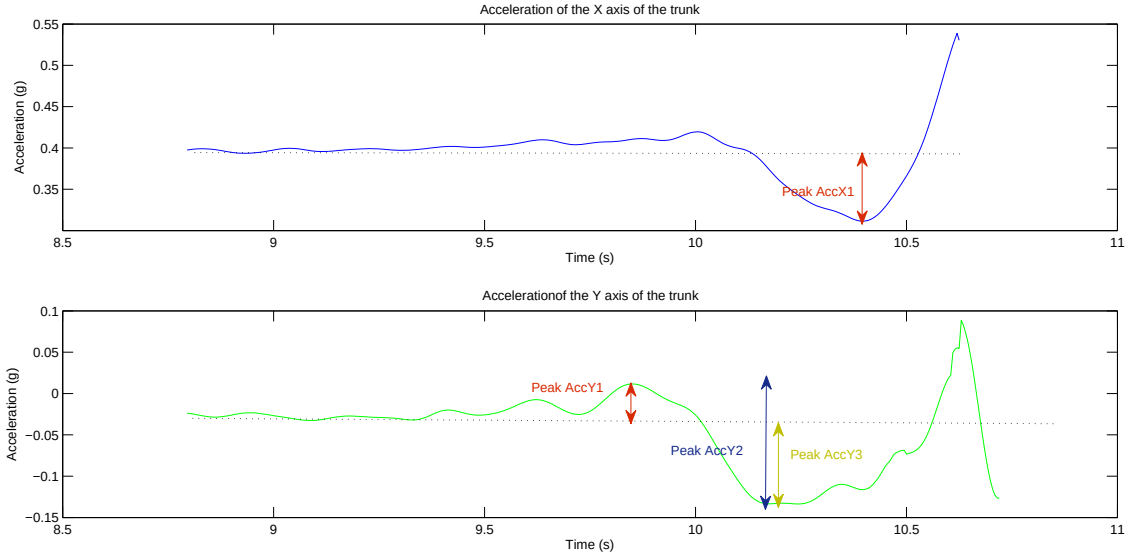

Figure 3.28: Peaks in the Acceleration signals .

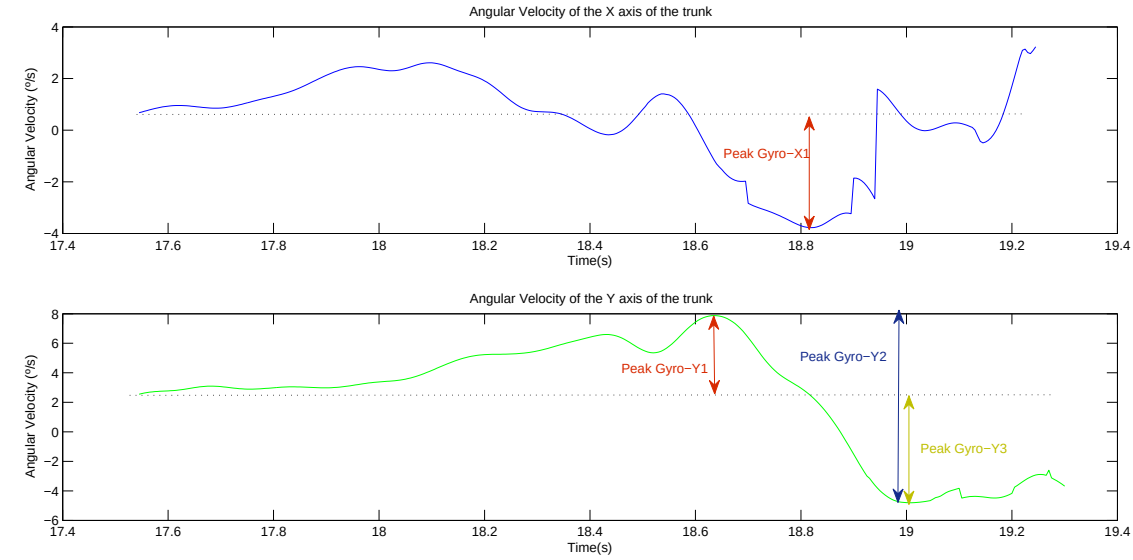

Figure 3.29: Peaks in the Gyroscope signals.

Hereafter, we will calculated the APA duration in each system because it would be able to be a appropiate parameter to compare. Also, the majority of these features have been used in others studies [10] so it can be a right way to measure the movement.

Now, we are going to apply PCA algorithms to obtain the most significant information

about human movement. This method allows us to minimise the redundant information performing the dimensional reduction.

We applied PCA twice: in the signals of the Antero-posterior direction (AP-COP, X-Acc and X-Velocity) and of the Medio-lateral direction (ML-COP, Y-Acc and Y-Velocity). So far, we have the projection in the orthogonal space, three eigenvectors and three eigenvalues. The corresponding eigenvectors are ranked in a descending order of eigen values and by choosing the two first eigenvectors PCA directly performs the dimensional reduction, that is, the class of three dimensional gait data is described by low-dimensional features containing only two principal components.

The two first eigenvalues of the covariance matrix accounts for 98% of the variance. This indicates that we only need to take the two first eigenvector to have the significant information of the data. Also, if we see 3.30 3.31 we can determine that the important information, i.e the information with more variance is defined with the COP and Angular Velocity signals. This is because the acceleration and angular velocity signals are very similar and one of them is not necessary, i.e it does not give us added useful information.

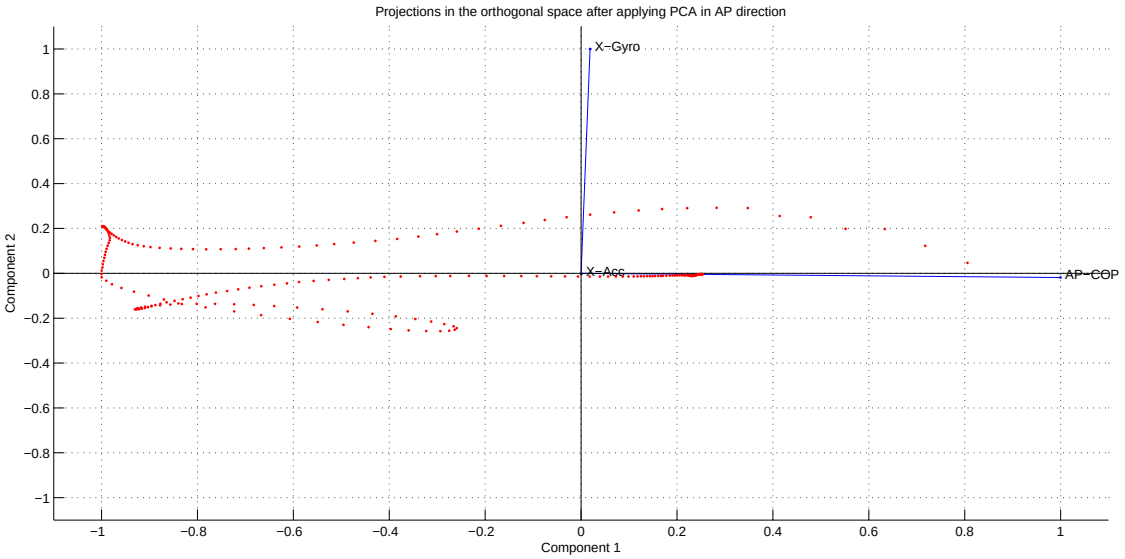

Figure 3.30: Projections in the orthogonal space after applying PCA and eigenvectors in Antero-posterior direction.

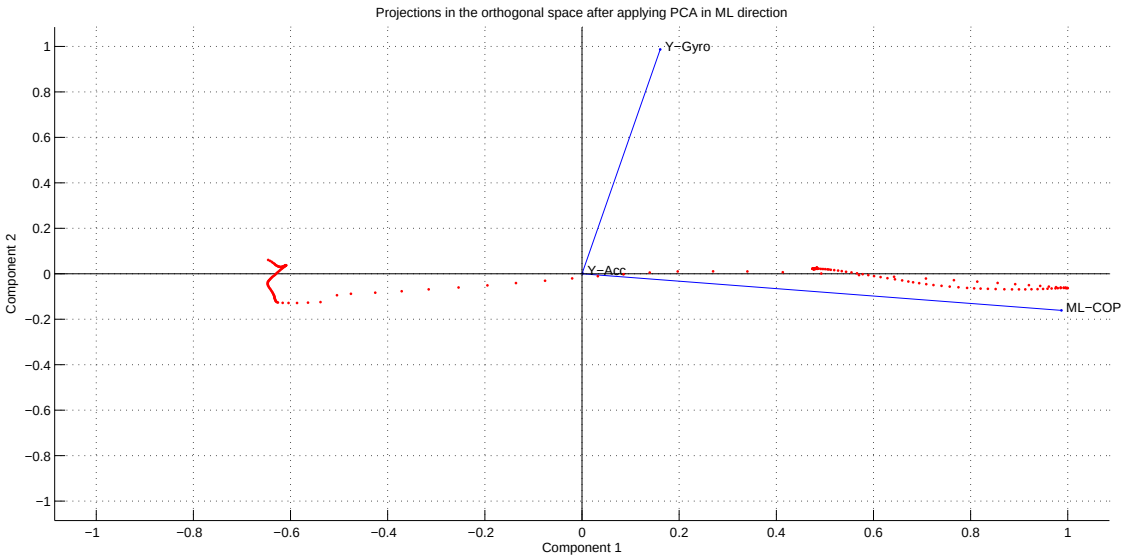

Figure 3.31: Projections in the orthogonal space after applying PCA and eigenvectors in Medio-Lateral direction.

The next step is to obtain the same features of the new signals. Now, we have four signals per patient: two components for AP direction and two ones more for ML direction. The characteristics extracted in this case are the same than with the originals signals.

Finally, we apply PCA between patients. Our data base is reduced because we only have five patient. So, our matrix data has five columns where each one has the COP, Acceleration and Angular Velocity concatenated. As in the above study, the two first components account the most of variability and this representation in the space indicates us the movement relation between patients, i.e whether the movement is similar between them. This allows us to know if it is possible to do a classification afterwards and what components are appropriated to do it. In the Antero-Posterior direction, the projections are located in the right part of the orthogonal space. People analysed in this study are patients with different level of the disease. Therefore, the second component would be able to be useful to differentiate patients with parkinson's disease. Also, it is possible that the first component can be used to differentiate between control subjects and do a classification 3.32.

In the Medio-Lateral direction the data are more dispersed. This indicate that the movement changes a lot between patients. However, almost all eigenvectors are pointing toward the upper half of the space3.33.

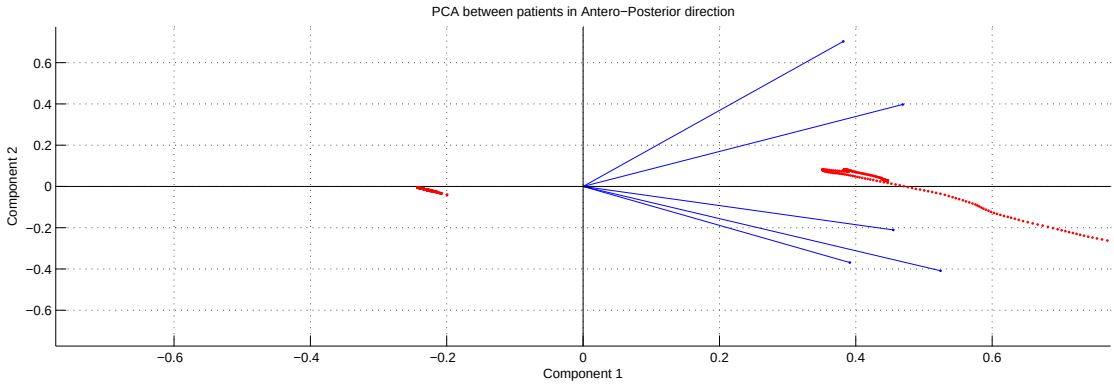

Figure 3.32: Projections in the orthogonal space after applying PCA and eigenvectors in Antero-posterior direction between patients.

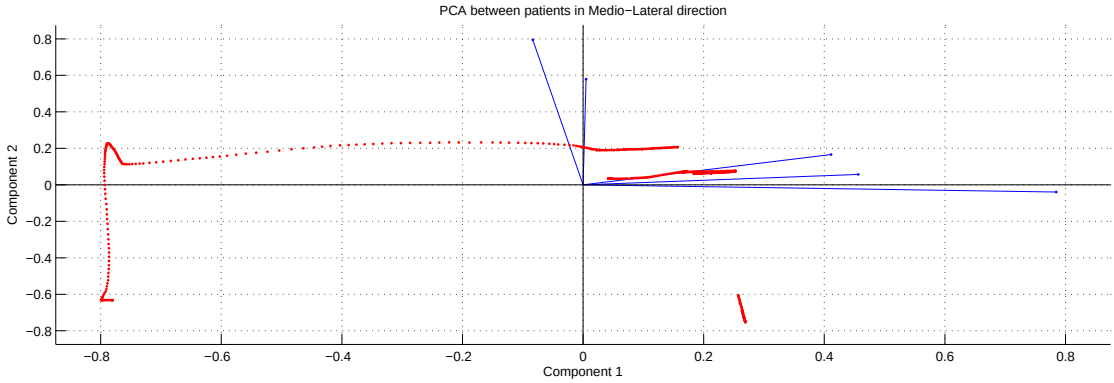

Figure 3.33: Projections in the orthogonal space after applying PCA and eigenvectors in Medio-Lateral direction between patients.

3.4.5 Results discurssion

One the APA features have been calculated, we will do the correlation between them. Firstly we are going to do a comparative study between FP and GW in the Antero-posterior direction. We calculated the correlation between the APA peaks detected in the COP signal 3.27and the the peak calculated in the acceleration and angular velocity signals3.283.29. The results of this correlation are showed in 3.34. If we analyse these values of correlation, we can determine that the feature of the gyroscope have a higher correlation with the features of the COP signal. The first peak of the COP and the peak of acceleration and angular velocity signals account a positive correlation with a significant value. Also, in the center of presure, the most interesting feature is the first peak, i.e when patient has momentum to step because the correlation with the acceleration signal as well as the angular velocity achieve the highest values.

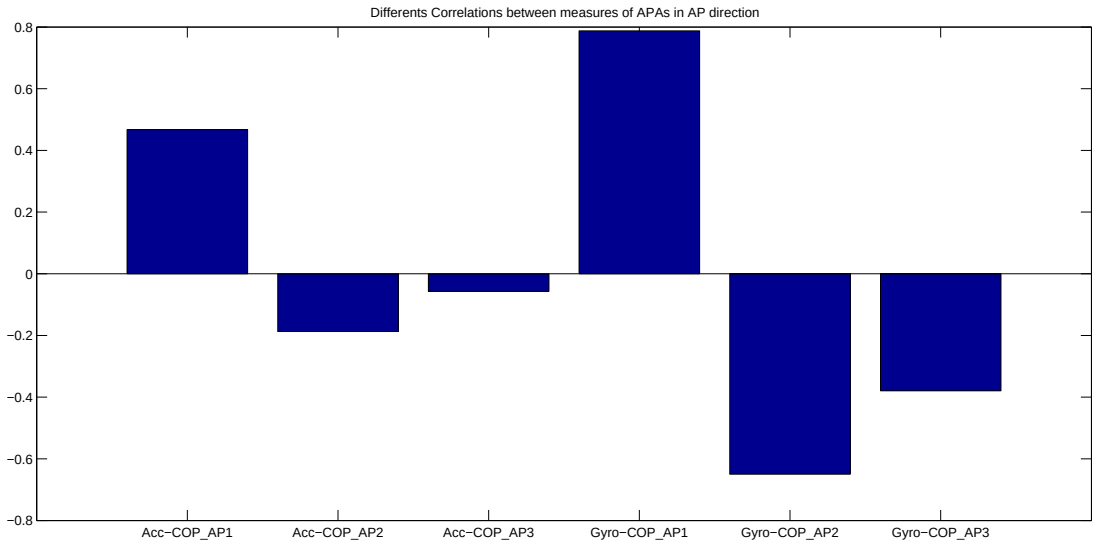

Figure 3.34: Correlation between features in the AP direction.

Then, we will compare these signals in the medio-lateral direction. In this case, all correlations are positives and a lot of them with a considerable value. However, we can identify that the most interesting signals in this directions are the signals from the accelerometers. We did the correlation between the peaks detected in the ML-COP and the rest of the features obtained from the acceleration and angular velocity signals. Therefore, the most interesting features of these signals are the height of the negative peak as well as the distance between both peak int he signals 3.35. The correlation is higher than 0.8, so this indicate that the accelerometers can give us a useful information as the center of pressure.

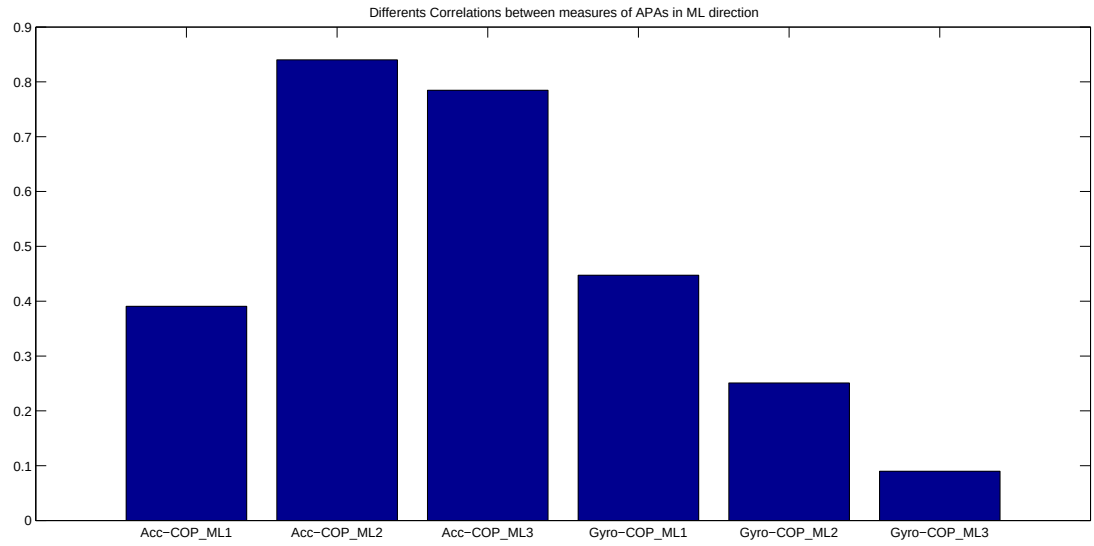

Figure 3.35: Correlation between features in the ML direction.

If we pay attention in the APA duration3.36, the correlation between COP and Acceleration and COP and Angular Velocity is negative. This doesn't make sense because it should be positive. Thus, we determine that there is not correlation between them. Even so, there is correlation between the APA duration in accelerometers and gyroscopes.

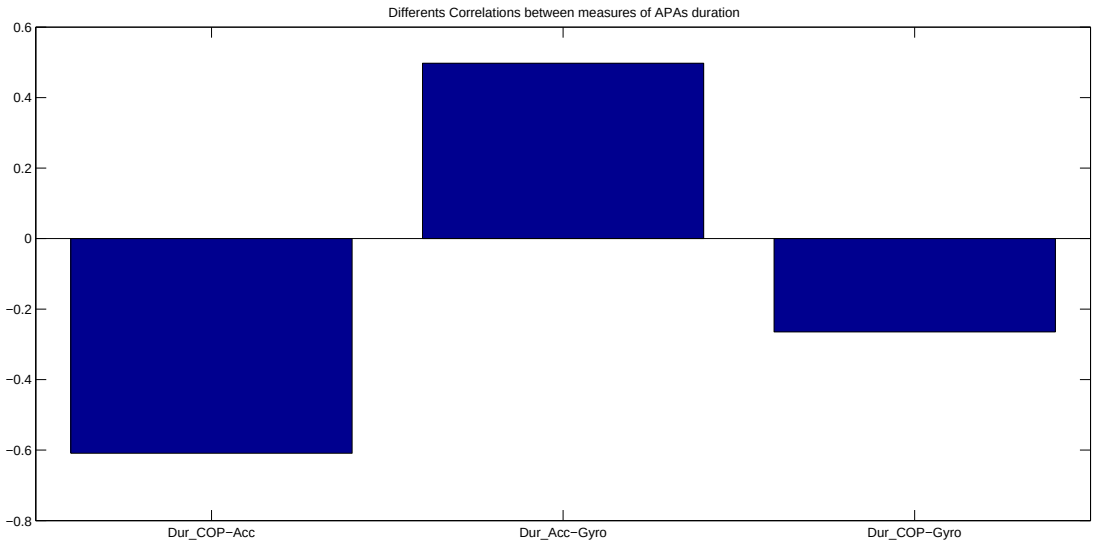

Figure 3.36: Correlation between APA duration.

Finally, we are going to see the correlation after using the PCA method. In principle, these features are more accurate because we removed the useful information and we have less and more interesting data. Whether we observe 3.37, the first three values are the correlation between the three APA peaks detected in the first component (analogous to COP signal) and the APA peak of the second component (analogous to angular velocity or acceleration signal) in the AP direction. The most significant value is the correlation between the negative peak in the first component and the peak of the second component.

In the ML direction, we do the correlation between the APA peak of the first component and the three features of the second component. The higher values is the correlation between the peak of the first component and the distance between both peaks of the second component being this a negative correlation3.37.

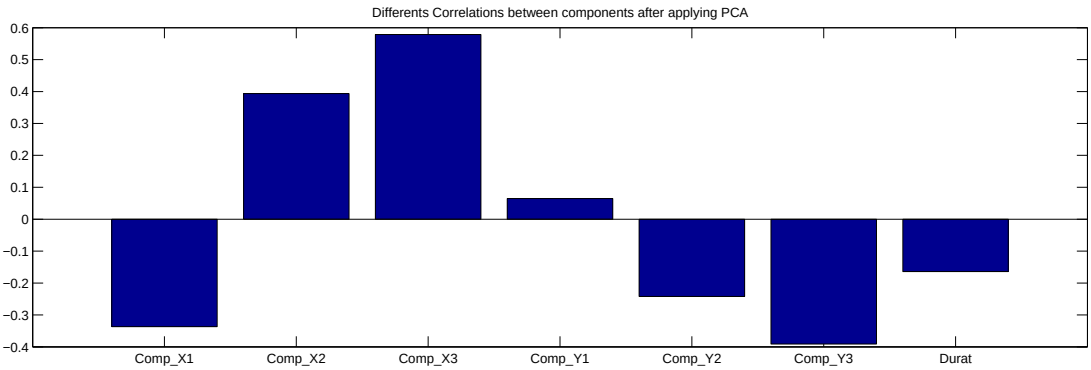

Figure 3.37: Correlation between features after applying PCA.

Chapter 4

Gait Watch and Qualisys Optica motion tracker

4.1 Introduction and chapter's structure

After explaining and comparing both systems Gait Watch and Force Plate, we proceed now to do analysis of te differences and similarities between Gait Watch and Qualisys Optical motion tracker.

It has been demonstrated that Qualisys System is a accurate system to analyse the body movements and it can be used in several applications. However, this system has a lot of constraints like the possibility of application scope.

Thus, we are going to do a comparison with Gait Watch system, a system based in inertial sensors being more potable and cheaper. Along this chapter we will explain how the pitch has been calculated using Qualisys System. This will be what we will compare with the angles obtained through inertial sensors.

4.2 Computing Euler angles using Qualisys System

To compute the Euler angle, the subject is wearing two infrared markers per segment placed in both thighs and shanks. The infrared optical cameras emit infrared light and this reflects in the markers placed over the body allowing to know the position of the markers.

The pitch angle of such segment is computed between the vector defined by the upper and lower markers and the vector normal to the Earth's surface. To be able to compute it we first have to define a third point which has the same X coordinate as the lower marker and the same Z coordinate as the upper marker. This will define a right triangle in which one of the contiguous cathetus is normal to the Earth's surface and the hypotenuse is defined by

the line between the upper and the lower point. Therefore, by calculating the arctangent we can easily find the angle of the right triangle, which is, in turn, the pitch angle[4]. We can see this in 4.1

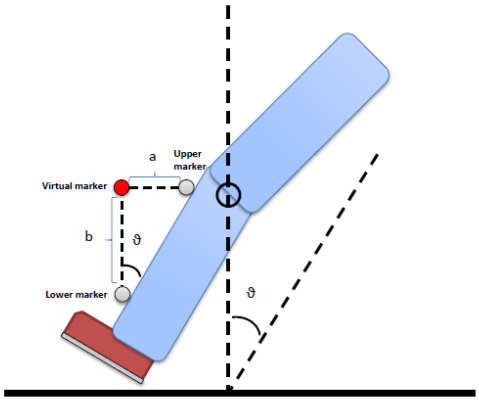

Figure 4.1: Diagram of the pitch computation using the Qualisys System [4].

Thus, the pitch angle is computed as follows:

$$\theta_{QS} = arctang(\frac{a}{b}) \tag{4.1}$$

$$a = \sqrt{(x_{upper} - x_{lower})^2 + (z_{upper} - z_{upper})^2} \tag{4.2}$$

$$b = \sqrt{(x_{lower} - x_{lower})^2 + (z_{lower} - z_{upper})^2} \tag{4.3}$$

where $[x_{lower}, z_{lower}]$ and $[x_{upper}, z_{upper}]$ are the coordinates of the projections of the lower an upper markers in the XZ plane, respectively.

4.3 Feature extraction

4.4 Results discurssion

Chapter 5

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.

5.1 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.

5.1.1 Neurological and Muscular diseases

Parkinson's disease is the second neurodegenerative disorder more frequent after Alzheimer[43]. According to the Parkinson's disease fundation, PD is a chronic and progressive movement disorder, meaning that symptoms continue and worsen over time[5]. Many as one million Americans and 60,000 Spaniards and 10 million people worldwide live with Parkinson's disease. Also, there is a large number of cases that go undetected [7].

Primary motor signs of Parkinson's disease include trembor, bradykinesia, dyskinesia and disorders in the posture and gait. Bradykinesia is the term for defining slow execution of the movement, tremor is the term used to define repetitive periodic movements within a certain frequency range and dyskinesia is a movement disorder which consists of effects including diminished voluntary movements and the presence of involuntary movements .Inertial Systems could be used to detect these disorder and help to diagnose and monitor them [7].

Another disease associated to the central nervous system is **Multiple Sclerosis (MS)**. MS is an autoinmune disease characterize bay scar tissue resulting from the repair of damage to the myelin sheath that surronunds neurons. MS affects approximately 2.5 million people worlswide. Symptoms of MS are unpredictable but may inlcude fatigue, visión problems, loss of balance and coordination, or depression. Also, Individuals with MS often have por balance control that is especially apparent during dynamic task suach as gait initation. Hence, Inertial Sensors may be a useful tool to detect these symptoms [25].

Cerebral palsy (CP)is important to be mention because it is a movement disorder appears in early childhood. CP is a neurodevelopmental condition caused by non-progressive brain lesión, can occur before, during or shortly after birth. Children diagnosed with CP demonstred increased muscle activity to sustain posture, agonist/antagonist co-contraction, impair postural control, inadecuate force production, and restrictive voluntary ans selective control of movement[2].

These impairments nor only interfere with performance of functional activities, but also with opportunities ans/or willingness to participate in leisure, community ans achool activities.

Impaired postural control in CP includes difficulty organizing compensatory postural adjustments (CPAs) and anticipatory postural adjustments (APAs) [2]. For that purpose, consideration should be given to the use of Inertial Sensors to monitor this disease in dialy life.

5.1.2 Sleep disorder

Sleep disorders cause an unrestful sleep and important repercussions in some cases such as sleepiness and psychiatric and cardiorespiratory secondary disorders[44].

In order to diagnose them, we can use inertial sensors to monitor changes that occur during sleep. In addition, it is a good option to do this cheap and portable, in such a way that patient can move freely while they are being monitored[7].

Also, the information gathered can provide information of the cardiac, respiratory, and snoring activities of patients sleeping[44].

If we use all of this at home, it is possible to provide a tool to sleep specilists for knowing the behaviour of the patient when they are sleeping, what sleep cycles are more affected and improve their medical treatments.

For example, some of the patients with **Epilepsy** suffer as tonic-clonic nocturnal seizures. These seizures may go unnoticed to the patient, thus, during the control sessions with the doctor the patient could not tell the doctor these episodes. To avoid such a situation, the patient may sleep with an attached MIMU so nocturnal seizures can be detected and stored in the memory, allowing the doctor to notice that nocturnal attacks are happening[7].

5.2 Dialy activities

Providing new wereable technology for medical and surgical **rehabilitation** services is emerging as important option for clinicians and patients. Wereable technology like inertial sensors provides a convenient platform to be able to quantify the long-term context and physiological response for individuals[45].

In the first phase of the reabilitation program the patient have to move to the medical center for treatment. However, the second phase patient have to do low intensity exercices to stregthen the muscles. This last task doesn't require continuous supervisión, thus, MARG systems can avoid the overcrowding of rehabilitation centers and patient can do the exercise at home comfortably[7].

In addition, doctors can then supervise the sessions carried out by the patients by remotely checking the logs. Also, they could detect differents activity states, for example, knowing whether a person is sleeping, driving or doing exercise[7].

Fall detection is a important aspect during daily life of elderly people . It is very clear that falls are a serious health issue and that systems automatically detecting a fall and calling for help could be of great help to solve it.

Moreover, there are applications for the motion analysis in **sport activities** by attaching

sensors like accelerometers and gyroscopes onto the athletes ‘ body segments. For example, for a swimmer, the discrimination of the swimming styles and the segmentation of the underwater stroke phases could be achieved. In addition, the physiological response was also detected on the wrist acceleation when the swimmer was fatigued in analsis method the intensive training situation[46].

5.3 Business plan

5.3.1 Executive Summary

SmartManagement claims to improve the quality of life of elderly people and with motion disorders. This system can detect falls and call emergency ambulance service as well as gathering data from the inertial sensors to analyse the postural adjustment and the differents movements and activities during the day. This information will be sent to a server, so the doctor can access this information doing a medical monitoring of the patient and changing the treatment whether it is necessary.

To do this, we will use inertial sensors attached over legs, trunk and arms. This devices are more wearables and cheaper than other systems for gait analysis. This lets us making a cheap and comfortable design for our customers. The signal processing will be carried out by application in android that will communicate with the devices. At the same time, this application will transmit this information to the server.

The Gait analysis with inertial sensor is a innovate field specially in Spain where there are not companies in the market developing this kind of products. Population get older and their necessities grow being their monitoring and self-reliance increasingly important. There are international companies such as ‘Gaitup’ whose main goal is to assessment of the gait and fall detection. This is a important competence but firstly we will focus in domestic market and also we will provide improvements in price, communication and services.

To achieve that, we will contact with hospital and old people’s home as well as public institutions because we pretend that users only pay a portion of the cost of the product. Also, we want to find private investors providing them publicity in return for a investment. We plan to establish presence in Internet and social networks to show our product. With this, people will be able to know what we do and how can improve their lives, those of their relatives and other loves one.

We can see a visual summary of this using a Model Canvas [Second appendix].

5.3.2 Company Description

SmartManagement is a technological-based company whose objetive is the implementation and development of completed system to monitor elderly people with motion disorders. The company is currently developing a research work and seeking to stablish its corporate identity in the medical product field.

Our method for developing businesses is 'lean starup', so the product is not closed, but we recieve information from our customers to improve the prototipe and provide their requirements.

The main motivations why this Project are impacts are: - As population age, health expenditures tend to grow rapidly since older persons usually require more health care in general and more specialized services to deal with their more complex pathologies(Stadistics from DESA, World Population Ageing 2013[47]).

- Globally, 40 per cent of older persons aged 60 years or over live independently. This indicate the necesity of continuous assistance(Stadistics from DESA, World Population Ageing 2013[47]).

- One of the most causes of disability and health problems in old age are falls and immobility (Stadistics from DESA, World Population Ageing 2013[47]).

- For the elderly who fall and are unable to get up on their own, the period of time spent immobile often affects their health outcome. Muscle cell breakdown starts to occur within 30-60 minutes of compression due to falling. Dehydration, pressure sores, hypothermia, and pneumonia are other complication that may result[7].

The objetives of the company are as follows: - Improving the quality of life fo elderly people. - Making a Custom-made desing so it will be different and fit for each people. - Avoiding the overcrowding of old people's home and hospitals. - Increasing the length of home stay where old people used to be more confortable. - Helping elderly people as well as people with motion disorders, increasing their self-reliance. - Establish a medical advisory board.

5.3.3 Market Analysis

Over the past few decades the increased level of public awareness concerning healthcare, physical activities, safety and environmental sensing has created an emerging need for smart sensor technologies and monitoring devices able to sense, classify, and provide feedbacks to users' health status and physical activities, as well as to evaluate environmental and safety conditions[article]. This makes the project more interesting and specially timely.

The potential customers of SmartManagement are both domestic and foreign although

we will focus in the last one.

Domestic customers include hospitals, elderly people and people with motion disorders like Parkinson Disease or Cerebral Palsy. Also, we have to considers the key partners like public institutions, suppliers or University where there is a great research in this field. The foreign market includes many of the above segments but also includes key distributors such as inertial sensors distributor.

This kind of products aren't marketed in Spain. However, there are some institutions and companies working in similar investigations. Telefonica together with UPC (Polytechnic University of Cataluña) had developed a inertial sensors-based system for monitoring Parkinson's motor symptoms[48].

In the international market, there are several companies developing products for gait analysis and activity monitoring. The main competition is a Swiss company called 'Gaitup'[49]. This comany was founded in 2013 in with the will to make products and solution for evaluating health and performance, based on wearable sensor technology.

Gaitup develops products like 'Gait Analysis' whose goals are evaluation of the treatment, fall risk and motor symptoms assessment and feedback to the patient. Also, 'Activity monotoring package' allows the identification from long-term data,healthy status and evaluation in home environment.

However, **SmartManagement** is not only focused in the product, but also it seek the confort and the necessities of the custumers. Thus, it is realised a custom-made desing and adapted to economic status of our customers. Also, another added value is the realization of courses to teach the operation and advantages of the product.

Intel and Michael L.Fox Foundation is working in wearable technology for Parkinson disease. They announced the development of sensor technology and analytics platform for Parkinson's treatments and monitoring[1]. Although it is focused in Parkinson disease, it could be expanded to other diseases or fields. Also, this indicate the importance of this types of project and its social impact.

5.3.4 Organization and Management

SmartManagement will have a CEO, who will be in charge of managing. Also, the company will have the next structure:

- **Hardware Department**: this department is in charge of the design of the devices, i.e the types of sensors, their positions and market study of inertial sensors and new trends.

- **Software Department**: this department is divided in two more. One of them will realise the signal processing and data analysis. The sencod one will carry out the mobile application to gather and process the data in real time and send a urgent message whether

this is necessary(for example, a fall).

- **Communications and servers Department**: data will be processed and sent to a Server for the doctor is able to obtain the results for adjusting the treatment.

- **Marketing Department**: All information about the project will be shown in social networks. We consider the activity in social networks is very important and one way to show the importance of this project and its possibilities. In addition, we will make a Web Site that will be used to contact us and show our products and services.

- **Administration Department**: this department will be in charge of the administratives topics such as possible investors, legal issues and economics tasks.

Figure 5.1: Diagram with the differents departments in the company.

5.3.5 Product Line

The following is a brief explanation of the production process:

- Assembling and configuration of inertial sensors. To do that, first we will obtain MEMs from ACAL bfi. Although there are a lot of supplier can provide these devices, we finally choose this one because it offers a great variability and quality in its products.

- The next step is to use the signals from inertial sensors to carry out the signals processing and extract the main information to characterise the gait and others aspects such as falls or

problems in the movement.

- At the same time, we initially will do a application for mobile phone in Android and when this works properly, we would like to expand to iphone as well. The final idea is that everybody can use our product.

- Then, we have to control the communication between inertial sensors and Smartphone as well as the communication between the mobile pone and cloud. We have to differentiate between the normal data transfer and urgent call. In the the first one, the data transfer between the Smartphone and cloud will send information to the server for afterwards the doctor can use this information and adjust the treatment of the patient. In the second one, the process is different because the mobile phone calls automatically to emergency department when person is at risk for fall or other similar situation.

- Once we have a first prototype we are going to apply the 'lean startup' method. Some companies begin with an idea for a product that they think people want and after long time the company realise that customers don't care about the idea. For this reason, we want to establish a feedback with our customers before of setting the final product, so business will grow with maximum acceleration.

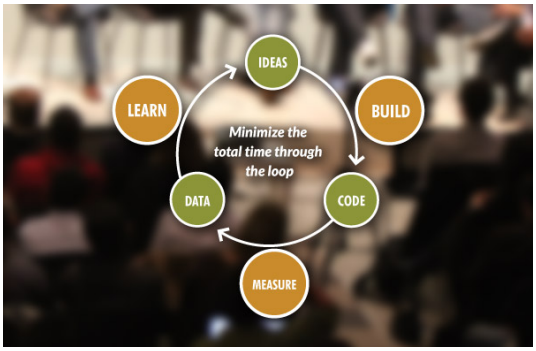

Figure 5.2: Process of the 'lean startup' method.

5.3.6 Marketing and Sales

We will leverage a marketing and sales campaign because we are aware of firsts sales will be possible with a strong presence in social networks. The marketing strategy will have two phases. The first one is as follow:

- Publicity in Internet. We will advertise on our Web Site and we also want to invest in google publicity for reaching people.

- Building of Web Site. We will create a Web Site where we are going to show the description of our product and its possibilities to improve the quality of life for elderly people. Also, our customers will be able to buy the products here or contact us.

- Publicity off-line. It will carry out using informatives meetings to show the advantages of this project. In addition, we will visit hospitals and old people‘s home to inform personally.

- Marketing on-line. Social network such as ‘twitter’ and ‘Facebook’ are a useful tools to advertise our products. Also, we pretend not only to show our advances but also keeping them actives publishing regularly. We will use’ linkedin’ for providing employment and building a network outside contacts. In addition, we will create a blog to give suggestion elderly people with motion disorders because we want to transmit our social engagement as well.

- Presence in conferences, trade fairs and exhibitions.

Regarding sales strategy, these will sell on-line on the WebSite. However, we are aware most of elderly people don’t use technologies, so we will use the hospitals and old people’s home to distribute the product. Also, we could send the product to their homes directly whether it is necessary.

5.3.7 Finaltial projections

Smart Management will be funded by a initial investment from the stockholders of the company and public institutions. It is important to develop awareness of the importance of this fact and obtaining grants to make the product.

We will need public grants because we consider that elderly people shouldn’t pay a lot for this devices, so a part of the price will be funded by foundations and government and another by the user.

In addition, we are going to find investors for the project. They will be able to receive publicity and partners from our company. Thus, other goal for the company is to create a good relationship between partners and investors.

An amount of money achieved will be for hardware, software licenses, accommodation and marketing. The rest of the money will set aside for salaries of our employees. At the beginning the salary of the stockholders will depend on the company economy. After two or three years this will be adjusted, so they will have a fixed wage.

5.3.8 SWOT Analysis

Figure 5.3: Table of the SWOT Analysis.

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Appendices