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MASTER THESIS

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Implementation of a system to evaluate the dynamic balance and its assessment protocol for patient suffering from Cerebral Palsy

The Institute for Intelligent Systems and Robotics

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I would like to wish all the best for Audrey. I wish you to reach your goal, you have the work capacities and the strength to succeed. I will take your hard work and your perseverance as a model for my future.

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Abstract

This work is aimed at developing the implementation of a system for measuring the dynamic balance and its assessment protocol for patient suffering from Cerebral Palsy.

Currently, methods exist to evaluate the static balance or the gait of this kind of person as for examples force platform or quantitative gait analysis. These two methods allow to see which treatment the patient needs and how a treatment acts on him. But we lost one dimension of the daily life challenge : the dynamic balance. In fact, when someone wants to use toilets or dress alone he uses his dynamic balance. But we can see that someone who could stand alone but walk with an assistance loses his capacity to stand alone after some treatments even if it improves the gait. Therefore, we decided to study the dynamic of people suffering from Cerebral Palsy (CP).

To study their balance we have to have mean values of people with a normal development which do not exist to my knowledge on the literature. This way, we had to study a large panel of healthy people in order to create a mean and extract a possibility to make a score to compare people.

To do this analysis we will place the patient on an existing robotic device: the IsiMove. It is a dynamic posturography platform dedicated to the study of balance. It has 4 degrees of freedom (dof): 3 rotations and 1 translation which can be controlled independently or simultaneously. This way, the platform offers a large variety of dynamic perturbations motions on different axis with variable amplitude, velocity and acceleration.

Then, to analyse performances, we equipped this platform with low-profile pressure sensing the matscan, added force sensors on handles and used a motion

capture system.

At the end of this work, we succeeded in creating a good representation of posturographic result. Furthermore, the motion analysis gave us information on the chosen strategies and explained how we obtain the posturographic result.

Chapter 1

Introduction

1.1 Overview on this internship

1.1.1 Aim of this internship

This work means to show the steps for the developments of a new evaluation balance system for patients suffering from cerebral palsy using a motorised platform (ISIMOV). This project is a collaboration between a laboratory and an hospital: the Institute of Intelligent Systems and Robotic (ISIR) and the Functional Unity of Movement Analyze (UFAM). The research will be on which sensors coupled with which parameters we have to use to evaluate in the best conditions the balance in dynamic condition.
The main goal of this topic is to build an experimentation in order to answer my problems. During this work we will study the balance of people using a motorised platform.

First we will have to settled the experimentation including mechatronical works. Simultaneously we have to build a protocol based on the literature. Then, once we pass people on the platform, we will have to analyse the results using Matlab with the purpose of finding information on how people recover their balance and if it is possible to deduce a quality of balance score to classify people.

1.1.2 Presentation of the laboratory

The Institute of Intelligent Systems and Robotic (ISIR) is a laboratory attached to the university Pierre et Marie Curie (UPMC) which gathers 145 workers directed by Raja Chatila, Director of Research at the French CNRS (National Center of Scientific Research). ISIR is a multidisciplinary research laboratory that brings many researchers together around the thematic of the engineering sciences, information and the life sciences. It is around 55 professors and researchers, 66 PhD students and 24 Postdocs divided in 4 teams:

- SYROCO (Complex Robotic Systems)
- AMAC (Architectures and Models for Adaptation and Cognition)
- INTERACTION
- AGATHE (Assistance to Gesture with Applications to THErapy)

Each team has its own research field and the major research topics are: modeling and analysis of dynamics systems artificial and natural; the optimal design of interactive robotic systems; control of interactive systems; control of interactive systems; the design and signal processing systems, multimodal perceptual; Modeling human interactions - System; Neuro-computational models for autonomy; The machine learning; The adaptation of bio-inspired systems and their control. I belong to the AGATHE team which has the goal to assist human movements by the mean of a robotic device whether for medical and surgical interventions or for patient suffering from a motor impairment.

AGATHE is led by Guillaume Morel, professor at the UPMC. AGATHE research's concerns the design and control of robotic devices aimed at assisting human movements. They are finalized towards two kinds of applications: assistance to medical and surgical interventions and assistance to patient suffering from a motor impairment.
AGATHE team's main scientific objective is to develop the concept called comanipulation, which consists of realizing a task through simultaneous and colocalized actions from a human operator and a robotic system.
In order to study the motion, the laboratory has a system of motion capture the CodaMotion which use 3D Cameras and active markers, a force platform for the gait analysis or for the motion of the center of mass.

1.1.3 Presentation of the hospital

The Functional Unity of Movement Analyse (UFAM) is a pole of hospitals of Saint-Maurice created by the Dr. Michel Thétio, doctor of physical medicine and rehabilitation (MPR). It proposes some activities for the evaluation and the treatment of movement disorders as the walking and the prehension. This unity wants to receive patients for biomechanical and neaurophysiologic instrumental Analysis activities (posturography, force plateform, Quantative Gait Analysis –AQM–, . . .) and for taking over the spasticity and the dystonia (botulinum toxin injection, muscular stretching plaster, . . .).
To do all this work, there is a multidisciplinary staff composed of physiatrists, engineers, physiotherapists, care aides, a secretary (Gael Sorgniard) and health executives. This team does the link with the university structures to collaborate on research projects.

1.2 Context

1.2.1 What is cerebral palsy ?

Cerebral palsy (CP) is a physical disability that affects movement and posture. It is a permanent life-long condition, due to damage to the developing brain either during pregnancy or shortly after birth (less than 2 years old). Cerebral palsy affects people in different ways and can affect body movement, muscle control, muscle coordination, muscle tone, reflex, posture and balance. Although cerebral palsy is a permanent life-long condition, some of these signs of cerebral palsy can improve or worsen over time. By the way, Rosenbaum gave a perfect definition of cerebral palsy in a report in 2007 [1]. This disease affects 1 birth out of 500 and includes a wide range of motor or cognitive impairments. We can classify sick people in 5 levels (Figure 1.1) using a tool called Gross Motor Function Classification System (GMFCS):

- GMFCS Level I Children can walk and climb stairs without the use of a railing. They also have the possibility to run and jump but speed, balance and coordination are limited.

- GMFCS Level II Children walk in most settings and climb stairs holding onto a railing. Children have only minimal ability to perform gross motor skills such as running and jumping.

- GMFCS Level III Children walk using a hand-held mobility device in most indoor settings. They may climb stairs holding onto a railing with supervision or assistance. Children use wheeled mobility when traveling long distances and may self-propel for shorter distances.
- GMFCS Level IV Children use physical assistance or powered mobility in most settings. They may walk for short distances at home with physical assistance but outside, they are mostly transported in wheelchairs.
- GMFCS Level V Children are transported in a manual wheelchair in all settings.

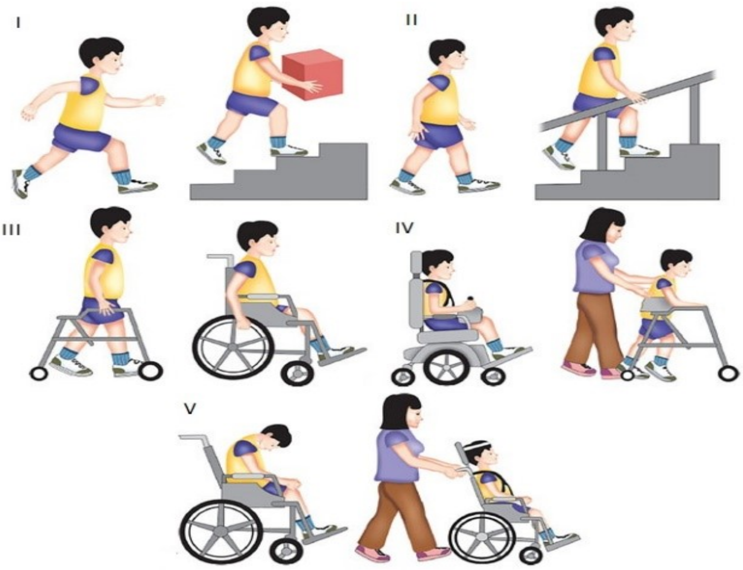

Figure 1.1: Representation Levels GMFCS

1.2.2 Which kind of treatments do exist ?

Treatments are diverse because they don't have the same goal. Now, let's present some treatments that cure the spasticity.

The most reversible and general treatments are drug therapies. Others treatments are less general as the baclofen pump which is a permanent apparatus which injects continuously the baclofen (an antispastic) directly in the cerebrospinal fluid. They place it under the skin of the abdomen thanks to a surgery. Another possible surgery is the selective dorsal rhizotomy which reduces the muscle spasticity by suppressing abnormal nerve impulse arriving from the brain. This one is not the most focal surgery; there is the selective neurotomy which is a neurosurgical solution to the localized spasticity which has been applied for several years. The past two surgical operations are permanent treatments. However, there is a possibility for patients to have a focal treatment without opting for surgery: the botunilic toxin. This treatment blocs the nerve impulse, causing muscle contractions, injecting the toxin directly in the spastic muscle. Thus induce a muscle relaxation paralyzing the latter.

Firstly, their aim is to improve their walking but some observed that their dynamic balance decrease after these treatments. So the idea is to evaluate the patient's dynamic balance at different points of their treatment in order to study their impact.
But, because this is the first time someone is asking this question, there is no knowing standards of dynamic balance. Therefore, we have to study both asymptomatic and symptomatic people.

To conclude, many treatments exist and only the AQM to evaluate their efficiency. But what is Quantitative Gait Analysis ?

1.2.3 Quantitative Gait Analysis

This analyze consists in studying movements on each joints with instrumental tools. To do so, a motion capture system is used , the Vicon, coupled with a biometrics software Nexus, a force platform and electromyograms (EMG).
The motion capture system is composed of 10 cameras infrared that emits infrared rays and receives the reflection of those rays on passive markers. The number of cameras and their position on the room is an advantage to avoid occlusion problems. Then to know the muscle activations they have simple electrodes connect to modules that send information to the computer via wifi thanks to 4 unidirectional antennas (Figure 1.2) .

The system is used in UFAM to study people's gait and detect the spasticity. It is a common analyse done to control the improvements when walking. Even if

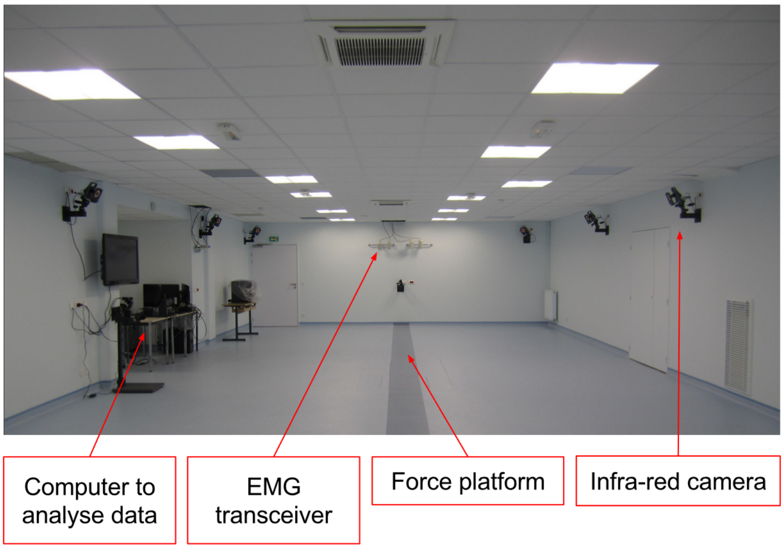

Figure 1.2: Quantitative Gait Analysis in UFAM

there are many systems which allowed to study balance, none of them provide the same analysis than the AQM. As a matter of fact, we used the Quantitative Gait Analysis as a model to build this project and create a sort of quantify analysis of balance (Analyse Quantifiée de l'Equilibre – AQE)

1.3 State of the art on the evaluation of the balance

1.3.1 What is balance?

Roughly, the balance is an even distribution of weight enabling someone or something to remain upright and steady (Oxford dictionaries).It is the ability of keeping our center of gravity aligned with the center of pressure. There is not one organ made for this task so it is done by a complex combination of different parts of our body.
Balance disorders can be due to different issues as : inner ear, eyes, neurological or musculoskeletal. Hence, it is not so easy to determinate the cause of the disorder. Doctors have different ways to evaluate it. Among all those tests, there are of course : The Berg balance Scale, the functional reach test and timed get

up and go.

1.3.2 How do we measure the balance

Posturology is the study the mecanism and dysfunctionment of the control system of posture. Maintaining the standing position is not an obviousness. It is a huge challenge anatomically and a neurophysiological feat.

Posturography in static condition

Static posturography is carried out by placing the patient in a standing posture on a fixed instrumented platform (forceplate) connected to sensitive detectors (force and movement transducers), which are able to detect the tiny oscillations of the body.
Therefore, static evaluation is based on the motion of the center of gravity (CoG) and many parameters exist. But these parameters are not robust and so clinicians try to put patients in extreme conditions or at the limit of stability. To do so they ask people to do exercises closing their eyes or on one foot or on a foam carpet.

While static posturography gives us many information, it is not enough to study the balance. Furthemore, because of problems of robustness with the parameters, there is a better solution (but more expensive) which is the dynamic posturography.

Posturography in dynamic condition

Dynamic posturography differentiates from static posturography generally by using a special apparatus with a movable horizontal platform.

Horak and Nashner begin to study the dynamic balance in 1986 with a platform surface movable thanks to hydraulic servomotors [4].
To do so, their platform gives them information on the forces position for each foot. In addition they used videotaped recordings to study the movement putting markers on the head of the 5th metatarsal, the external malleolus, the lateral condyle, the greater trochanter and the lateral aspect of the humerus. Subjects were ask to set on the platform with their weight equally distributed and their arms folded at the waist. They found out that the size of their support surface

modifies their postural movements strategies. And as we could imagine, they are using two strategies (ankle or hips strategies) and sometimes, they are using a combinations of thus two strategies.

Nowadays, 4 main dynamic platforms exist. Each platform are coupled with a specific model based on the perturbation.

The 4 main dynamic platforms are:

- EQUITEST (fig. 1.3.a), it is a platform which has a degree of freedom around one axis based on the work of Nashner [13]. Furthermore it has a mobile environment which forces people to use other sensory entries.
- MULTITEST (fig. 1.3.b) is a platform which can be used in static and in dynamic conditions, but also in a passive or an active mode, with feedback or without. It provides information about the center of gravity and the quotient Romberg for example.
- PROPRIO (fig. 1.3.c) is based on J. Allum [14]. It has 2 rotation axes, one antero-posterior rotation and the other intern-extern.
- CAREN (fig. 1.3.d), is a complete system with 6 degree of freedom. It has a force platform or an instrumented treadmill and immerses the subject in a virtual world with a big screen and a sound surround.

a) Equitest (Neurocom) b) MultiTests (Framiral) c) Proprio (Perry Dynamics) d) Caren (MOTEK)

Figure 1.3: Instrumented Dynamic Platforms

In 2000, thanks to dynamic posturography, Slijper and Latash used dynamic platform to bring to light the effect of handles in postural adjustments [5].

For their experiments, subjects stood on a force platform barefoot, feet placed at hip-width and were subject to 3 support conditions: stable, sagittal instability and frontal instability
According to their works, we can expect that the presence of handle is not insignificant.

Posturography is important but it is nothing without the right parameters to study and understand what happened.

1.3.3 Parameters and Modelling

One aim we have to do during this work is to determine parameters according to biomechanical models relying on perturbations. Those parameters are used to evaluate the balance but unfortunately, we could not achieved this task. So we used existing parameters.

Many parameters exist to evaluate the balance but they are associated to a specific model. The simplest model is the Winter [16] one which consists in considering the human as an inverted pendulum we a pivot at the ankle. But this model could not match with every disturbance. That is why it is necessary to develop our own model. To do so we will base our work on some papers:

Li and Levine proposed us a computational model of a quietly standing human [7]. But they chose a simplification considering only 2 joints in the lower limbs: a rotation at the ankle and a rotation at the hips in the sagittal plane. Hemami & al., in 2006, did a simulation of a dynamic posturography of a three-link sagittal biped model [8]. This paper will give me some indications about modelling (kinematic and dynamic). To do this simulation they use the paper of Hemami and Ozbay [9] which gives them the jacobian matrix that they utilize. These two papers consider simplified model of lower limb but, in our case, we cannot. In fact, as we said previously, we will disturb subjects in all the direction so we have to consider a more complex model of lower limbs as Kim and al. did in 2013 for their design of walking assistance lower limb exoskeleton [10]. Indeed, their model has a ball joint at the hips and at the ankle and a rotation in the sagittal plane at the knee.

1.4 Issue

Considering the existing studies, our work is to find a good protocol to apply to both healthy and sick subjects in order to quantify the balance and find, if possible, some standard. This way, it will be possible to compare and to classify the results. Therefore, we have to study and quantify the stance coordination for healthy subject first.
So we have to build a protocol, to set up the existing platform (framework, instrumentation, motion capture system) and then to do and analyze the dynamic modelling.

In the following part, we are going to see how we did the establishment of the experimentation which includes the conception and the construction of the framework, an equipment details, the work we have done on the handles and how we implemented the synchronization. Whereupon, in another part, we will talk about the protocol we had to build in order to evaluate the balance of people on our platform. To finish, in the last part, we will explain how we analysed all data before presenting you some results.

Chapter 2

Establishments of the Experiment

This chapter exposes how we build the experimentation. It includes the conception and the construction of the framework, a detail of the equipment used, the work we have done on the handles and how we implemented the synchronization. The figure 2.1 shows how we settled the experimentation room.

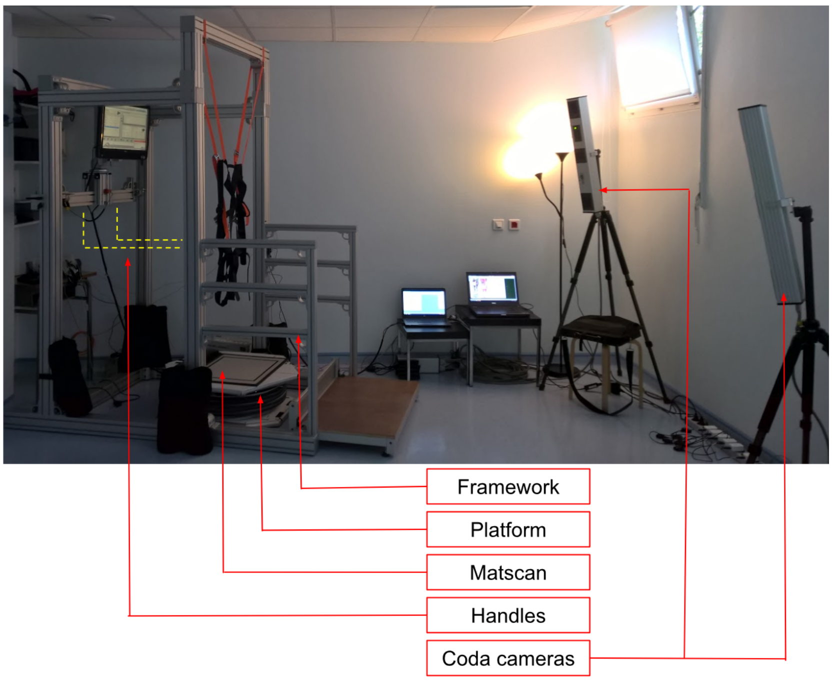

Figure 2.1: Complete Quantitative Equilibrium System

In the following section we detail each items of this experiment.

2.1 The Framework

The first structure was a design structure (cf. Figure2.2). It was made for great adult and fixed. It means that we could not adapt the position of the handles for examples.

Figure 2.2: Old Framework

Figure 2.3: New Framework

We had to create the new structure for the platform using an aluminium framework. To do so, we used the NORCAN modular structure. This solution allowed me to use Solidworks to model it using their library (cf. figure2.4).

We conceptualized this new architecture based on the existing one and several meetings with a team gathering professors and doctors. This design had to respect some specifications:

- the screen has to be height adjustable;
- the handles have to be adjustable according to the three directions;

- includes a system to hang a harness to ensure the safety
- add a shelf for the EMG
- add handles and a step to help people to step on the platform

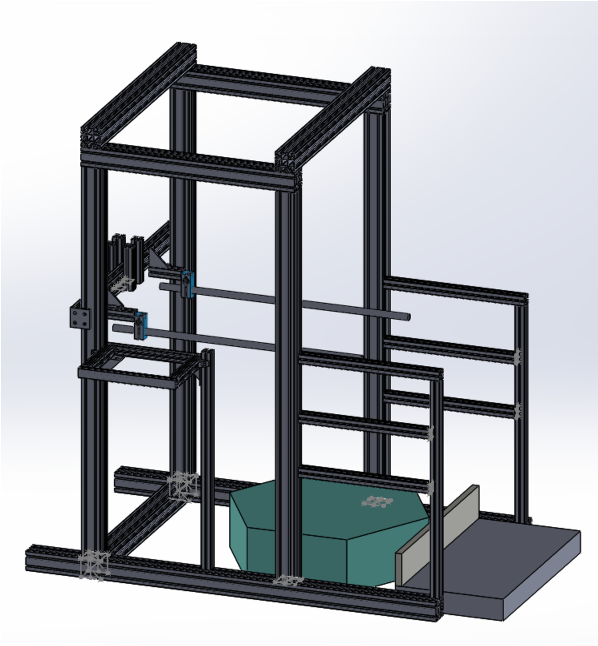

Figure 2.4: CAO of the New Framework

The idea was to adjust the height of the screen and the handles dependently and add two linear links for the handles. This addition of adjustable handles will allow us to study not only asymptomatic people but also people suffering from cerebral palsy which belong to the class I over IV of the GMFCS. Then, there were others things we had to think about, like the resistance of this structure. That is why we preferred to adopt a structure with streamline of 9x9cm. Because the other solution was to use a streamline of 4.5x4.5 cm but the bending of this beam was too high. Furthermore to avoid this construction to fall we will add ballast weights at the base of the structure (cf. Appendix F).

The figure 2.3 is the result we obtained with the 3D model.

2.2 The Platform

The ISIMOV platform (cf. figure2.5) is the central point of this project. It is a platform built and sold by the company AssistMov to the Rothschild Hospital (Paris). Before being an industrial product, it was a research project between ISIR and Rothschild..

This platform presents 4 degrees of freedom (DoF): 3 rotations and 1 translation. Furthermore, we can combine movements to create a second translation. In our study, we will use and analyse the reaction of the people under 5 disturbances [12].

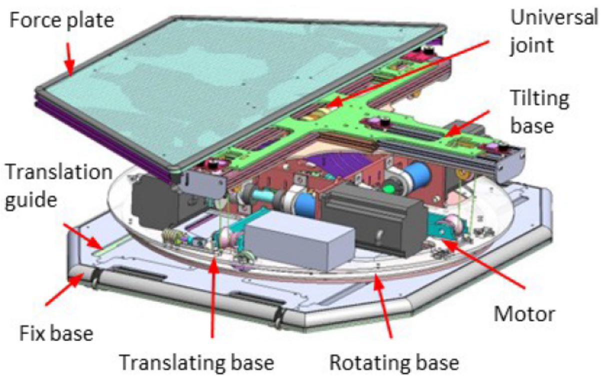

Figure 2.5: CAO – IsiMove platform

It is controlled by a computer which is also used as an interface human-machine. The software if easy to use but a little complicated to implement our own protocol.

This platform has some limits. We were asked by the constructor to avoid letting someone weighting more than 80kg stepping on it. Furthermore, we did not have to command the highest frequency or magnitude.

2.3 Matscan - The Dual Force Plate

ClassicMat Platforms [15] is a low profile foot pressure measurement platform made by Tekscan. It has many applications: gait, peak plantar pressure, weight distribution, stance timing, and balance and sway analyses, and concussion assessments. We use it to study the balance at a scanning speed of up to 100Hz.

It provides force pressure under each foot and the position or the trajectory of the center of pressure. Thanks to the FootMat software for researchers we can export data to ASCII and use it with Matlab.

2.4 The Instrumented Handles

One of my missions is to add sensors on the handles to study how much force people who will use it will apply. We will have to use either flexiforce FSR or loadcells.

FSR (Force-Sensing Resistor) are pressure sensors with a resistance varying depending on the pressure exerted upon them. Those sensors have a range from 10g to 10 kg which induces a resistance range between 2MOhm for 10g and 1kOhm for 10kg. Their active surface is made of a striated area circular or rectangular with different size possible. The choice of a type of FSR among others is determined by the nature of its utilisation and the mechanical assembly.

Load cells are force sensing modules in metal with little gauges mounted on it. They are designed to measure forces along one direction. This kind of sensors have a lot of possible range such as 0 to 5kg or 0 to 50kg. The difference between both range is their sensitivity: in fact, the sensor with the smallest range could detected smaller forces.

2.4.1 Flexiforce FSR

First we had to learn what is an FSR and how we have to use it (and code it) to add it on our structure. FSR are force sensors which have a range of detection from 10g to 10kg. They are cheap but their calibration is not easy because we have to calibrate each sensor and we think to use many of them for each hand. To code it, we were asked to use an Arduino and to store the sensor's values: we used Matlab which will get it reading the serial port because the Arduino is connected to the computer via an USB cable. An Arduino is a circuit board with a microprocessor on it; we programmed it to get the values of sensors. we connected each sensor to the Arduino via a breadboard with a 10kOhm resistance (cf. figure 2.6).

• arduino code : It reads the pins and converts it from integer to ascii to make the data transfer faster. Because we have many sensors, we put sensor values on tables.

• matlab code : It is composed of four files: one function initialize the serial pins reading; the other read the output of the arduino and converts the characters to integers; Then a main file launches those two functions and according to the sensor calibrations we have the masses corresponding to what we obtain and we have the forces. At the end, it plots the forces according to the time; and the last one stops the serial reading. Furthermore, because it is intended to be used to do clinical trials, we add a recording of the values in an excel file - easily used by a doctor for example - and also a record of the figures in a file at the name of the patient with the date of the trial enter by the practitioner.

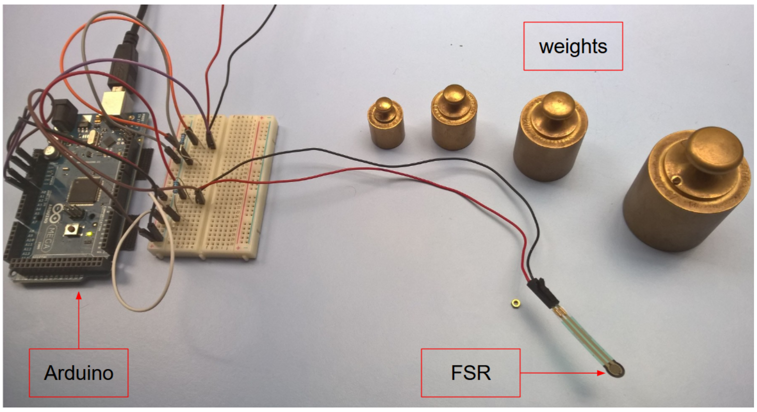

Figure 2.6: Experimentation set-up for FSR sensor

At the beginning we had to use square sensors ($4 \times 4cm^2$) but because we would like to put it on cylinder handles it was not a good solution: in fact, when we bend it, it creates resistances due to the deformation. Then we had to deal with small round sensors.

As we said before, we have to calibrate each the sensors because they don't behave the same way. To do so we used some weights (50, 100, 200, 500 grams) and collect data during 5 minutes to see how the sensors change with time. Because we are now using, small sensors we found that the best solution to detect weights on it was to use a little nut and to put the weight above. But by doing this, the force is not applied on the entire sensor but only on a crown. However, it was the best solution.

During my trials to calibrate it, we noticed that they are very sensitive: a small tremor on the table or on the floor changes the values we obtained. That is also one reason why we wait 5 minutes to take a good mean of the value.

Moreover, we had not only to calibrate it but also test the impact of the length of the cable. This is very important to know the best solution to integrate all these devices to the structure. Our conclusion is that a longer wire induces an offset on the results.

Because of the calibration problem and some people knowledge about this sensor in the laboratory, I have been asked to use loadcells instead of FSR. It was also the idea of my new supervisor.

2.4.2 LoadCell

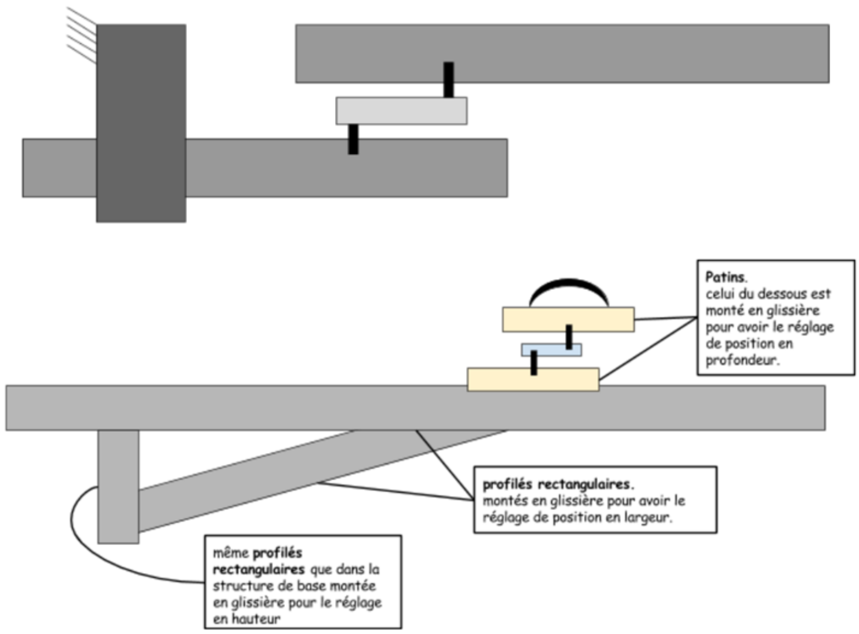

Figure 2.7: idea of a new design for handles including the loacells

It is a unidirectional force sensor working thanks to strain gauges. It is connected to a Weight Sensor Module which allows a connection to an Arduino. This way, with the related library, we find the weight exercises on this sensor. But first, as for the last sensor, we have to calibrate it. To perform that, we have to put on its extremity a known weight. Because it is connected by the same concept than the flexiforce sensor, we did not need to change the matlab code to store data. But it is not the same equipment than the other one: we cannot insert it to the structure in the same way than the FSR. For that, we proposed two solutions: one consists of adapting what we created for the fsr and the other one is a new design (cf. figure 2.7).

2.4.3 Comparison of these two methods

To know which sensor is the best in our case, we were asked to compare them (cf. appendix E). We did data acquisition during 15min for both FSR and loadcell with a weight of 500g. We had to determine which one has the better behaviour.

	FSR	LoadCell (s) – 50kg
Advantage(s)	• High range : from 10g to 10kg	• 1Loadcell = 5 FSR –only 2 LoadCell is needed – economical • Easily calibrate
Drawbacks	• Vary during the time • Calibration	• Range : from 750g to 50kg • Installation on the structure • The strain gauge stay deform a little at the end

Table 2.1: Comparison FSR–Loadcell.

In conclusion, these two sensors differ in some point: on the one hand there are the FSR which present a good range and an easy insertion in the structure and on the other hand, there are the loadcells which are easy to calibrate and economical.
We never had the answer to this question with the changes of my supervisor. Furthermore after a meeting, we conclude that we wanted forces in all the directions.

<u>“Final” solution</u>

To record the forces in the six directions, we decided to use handles with a six axes sensor force on it. This sensor is connected to an STI acquisition card which gives the forces thanks to a calibration matrix. To make it work on the structure we have to buy square aluminium frameworks to replace my handles. And then, we also have to buy a desktop computer because these acquisition cards do not work on a laptop.

So unfortunately, we could not end this part during my internship but my work on FSR will be used on another project.

2.5 Motion Capture system

Coda Motion is a motion capture system which records the position of each markers in three direction and allows us to analyse motion in 3D. It is composed of 3D cameras and active markers.
Cameras are not common cameras, it only records infrared lights. This fact causes some troubles that we had to take into account: the sun light is made of multiple kind of rays, including infrared light and if the room is illuminated by neon lights it can be a problem also because of infrared. So we had to caulk windows (hopefully for us window blinds were enough) and turn off the lights (by the way, for our case, Audrey brought an halogen lamp).
Markers are called active because they are infrared LED which will be detect by cameras. Furthermore they are connected to little battery.

2.6 The synchronization

Synchronization refers to the concept that multiple processes are launched at the same time. It is an important part because thanks to that, we could analyze the data because we could put data sensors through the platform's movements.
In this part we are going to show you the work we have done to realize the synchronization.

First of all, we list the entire device we had to synchronize:

- The platform which is the central point of this study;
- The handles which records the forces applied to the hands;
- The Matscan to store the forces on each foot and the position of the center of pressure;
- The HD-sEMG of Compiègne;
- The CodaMotion to collect the position in three dimensions of each markers.

Once we knew all we had to synchronize, we had to choose how we wanted to do it. Because we already used an Arduino (for the handles), we thought that we could use the unused pins of this device. And to start the simultaneous recording, we thought to use a button. In this way, someone could launch all the processes with just one simple button. We did it with a micro-switch button.

A micro-switch button has 3 pins: NO (Normally Open), NC (Normally Closed) and COM. The COM pin is automatically connected to the NC one. When we push the button, it switches to the NO pin. So the idea is to start the recording when someone pushes this button. So we connected the NO pin to the voltage (5V), the NC pin to the ground and the COM to a digital pin of the arduino initialized as an input. In this way, when the button is at its normal position nothing happens and when we pushed it, the NO and the COM are connected and the arduino detects an edge. After that the arduino sends an order to the other devices.

Now that we know how we will launch the recording, we had to study all the sensors and the platform to understand how they work and how to connect them to the arduino.

As for the platform, we were disturbed by the fact that the developer did not give us instructions about how the platform works and how it is connected. Consequently, we could not synchronize the platform's software with the sensors. Thus, we decided to detect the moment when the platform started to move. The first idea was to use an accelerometer working like the FSR. But because we used the CodaMotion we thought that it would be easier to put a marker on it.

When we started this part of my work, we still thought to use one direction force sensors as the FSR or the loadcells. They involved both the same procedures for recording their data: they were connected to the arduino and through the serial port the data were sent to Matlab (to analyze it). So we had the same strategy for both sensors: we added a while loop in my Matlab code, which waits until the arduino sends a flag to the serial port. Afterward, Matlab starts the acquisition.

Concerning the Matscan, it is connected to the computer through an 8 port versatek system which provides an output and an input port. Since we wanted to use the arduino as an output we had to choose the input port. As a matter of fact, the software allows us to start and to stop the acquisition thanks to external triggers.
To connect the trigger system, we needed a BNC connector, which is a miniature quick connector used for coaxial cable. But we had to connect it to the arduino. To do so, we cut one extremity of this cable to create a link between the trigger device and the arduino. We connected one part to the ground of the arduino and the other to a digital pin which will receive a voltage when the micro switch button will be pushed once to start the acquisition. It will stop when the button will be pushed once more.
The HD-sEMG works almost exactly as the Matscan. The only difference is that it needs a tension divider bridge because it cannot receive more than 3.3V whereas the arduino sends 5V.

The last challenge but not the least: the case of the CodaMotion. Surely my biggest challenge. We were looking to use the mini-hub of the CodaMotion because the experiments will take place in the UFAM. But the trigger of this hub does not work: we could either use its input trigger or its output trigger.
But one of the options of the triggering was the detection of one marker by the cameras. It sounds great but we had to make it controlled by the arduino and

not by someone. Consequently, we had to create a circuit between the battery of the markers and the LED which will be closed by the arduino. To build a closed circuit, we used a transistor.

In the following draw (figue 2.8), we show you how we connected the sensors to the arduino:

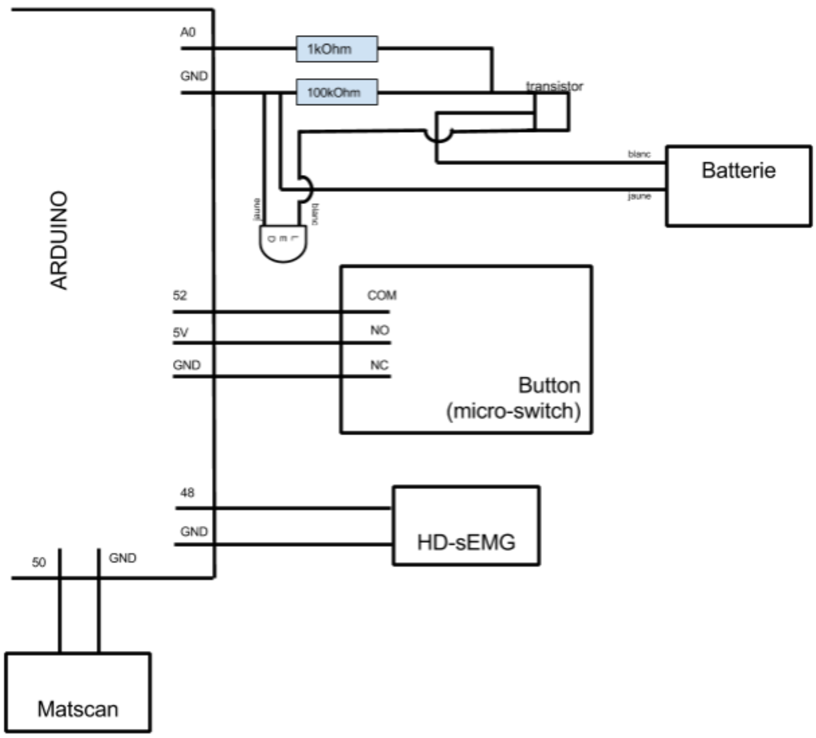

Figure 2.8: Electrical Assembly

Chapter 3

Definition and Implementation of the Protocol

The aim of this project is to study the balance for affected people. For this reason, we have to determine a score to compare their results to the result of an asymptomatic group of people which represents the "normal" behaviour.
To do so we have to study the balance of asymptomatic people and analyse their balance. Because we didn't find papers dealing with this topic we had to analyse everything and do a work of clearing.

The presented work is intended to provide a first protocol to study the dynamic balance, a first analysis of the balance and the outline of a score.

3.1 Subjects target

3.1.1 Asymptomatic group

The only constraint we had is the weight. Actually, because of the limit of the platform, we could not propose to people weighting more than 80kg. Apart from that, we had no restriction for this group, all healthy people who wants to attend to this experimentation could do it. However, if subject presents musculoskeletal weakness or pain contraindicating the participation of this study, we could refuse them. The more healthy subjects we will have, the easier will be to create a score.

3.1.2 Cerebral Palsy group

As we do not have handles yet, we could not include people belonging to the GMFCS III and IV even if there is the harness. So we could only study people suffering from cerebral palsy able to walk without any help.

3.2 Type of exercises

Considering that there is no study about dynamic balance for healthy people and the chance to have 5 degrees of freedom, we decided to disturb people in every possible direction. Furthermore, most of the balance study focus on the sagittal plane. Consequently, we have an added value because we can see what's happened in the other plane.

After deciding which movements we will do, we had to know at which frequency or magnitude to work on. To know that, we had to rely on papers. Most of them study balance at low frequency.

After many tests and discussion with doctors, we decided to have 5 levels of exercises:

1. level zero : study the static balance
2. first level : low frequency (F1) and low magnitude (A1)
3. second level : increase the magnitude (A2) and let the low frequency (F1)
4. third level : increase the frequency (F2) and let the low magnitude (A1))
5. last level : high frequency (F2) and high magnitude (A2)

This way, increasing levels of the exercises allows the subject to stop the experiment if it is too difficult for him. We can summarize the level of each exercise in the following table :

To avoid that people learn the sequence of exercise and prepare themselves to undergo some movements, we decided to create randomised exercises. To do so we created a little matlab code that would choose the succession of movement (cf. Appendix A).

	Rotation x	Rotation y	Rotation z	Translation x	Translation y
F1	0.2	0.2	0.2	0.2	0.2
A1	5	5	10	50	50
F2	0.4	0.4	0.4	0.4	0.4
A2	10	10	20	100	100

Table 3.1: Values of frequencies and magnitudes for all the platforms movement

3.3 Placement markers

We planned to do analysis of people movements. As a result, we are presenting you the system we use. In this motion capture system (CodaMotion) we need markers. So we had to know several things as what we want to see, where will be the cameras and the risk of occlusion. In fact, occlusions are the biggest problem of each motion capture system.

In our case, the structure take a lot of space in our experiment and the harness also. When we chose the harness, we kept in mind the position of the markers. That is why we opted for climbing harnesses. Considering our structure and its location in the room, the best way to place cameras was at the back of the subjects (cf. Figure 3.1).This way, we would avoid the occlusions due to the structure and we would not block the access to the patient.

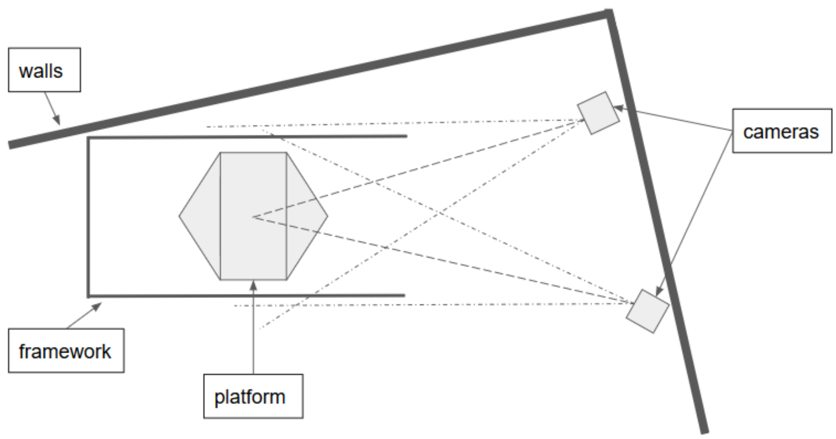

Figure 3.1: Camera positioning

To place markers, we had two solutions : the first was to place markers on anatomical landmarks and the second was to use clusters. Each methods present advantages and drawbacks. For example, clusters are easier to place on subjects but anatomical landmarks are closer to the articulation centers. To make a choice between those two methods, we made tests on one leg (cf. Figure 3.2). The result of this study shown that clusters is too far from the reality. This is due to their positioning which is approximate and to the fact that lower limb muscles are big : it creates non-existent angles and rotations. Anatomical landmarks is therefore a better solution. Furthermore, there is the problem of the sliding skin : actually, the model assumes that the segments are solid and shows the skeletal movements, but markers are on the skin and between the skin and bones, there is soft tissues which would deform. This is called soft tissue artefact.

Figure 3.2: Test cluster/anatomical landmarks

Since we wanted to know the position and the movement of the ankles, the knees and the hips, we placed markers on anatomical landmarks concerned (cf. Figure 3.3) : the head of the fifth metatarsal, the calcaneous, the medial and the lateral malleous and epicondyle, the greater trochanter and the posterior superior iliac spine (PSIS).

Figure 3.3: Markers positioning

3.4 The execution of a session

A session is a long process composed of many steps. Each step is important for the comprehension of the study and to ensure the security of the people.

1. They have to read information about the experiment. In fact, Audrey had prepare many information papers that people had to sign. There were papers made for parents of healthy children and PC children and also for healthy and PC adults;

2. We took some physiological measurement of the lower limbs in order to compare our results with an existing scale;

3. Apply the sling;

4. Place the coda markers on joint positions and the HD-sEMG on two muscles of the stronger leg : the gastrocnemius and the tibialis anterior;

5. Now, the subject is ready to take place on the platform, we attach the harness and the exercises can begin.

Before each exercises, we repeated what will happen and the same directive which were :

- Try to keep the feet at the same place : the figure 3.4 shows how we place the feet of people who can do it;

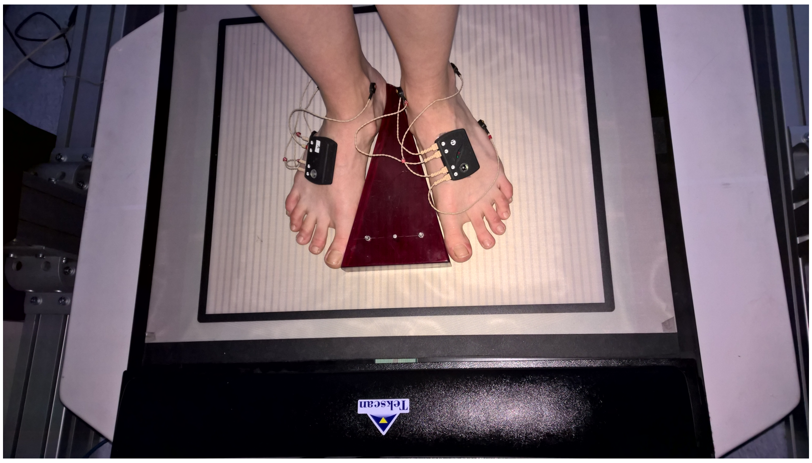

Figure 3.4: Feet Position

- Look at a fix dot on the screen.

Between every exercise, we had a break which corresponds to the acquisition time of both matscan and the coda motion (overall). During this break, we asked everyone if they need to rest a little by moving their feet or if they need to sit, especially for people who suffer from Cerebral Palsy.

At the beginning we needed 1h for a healthy subject and at the end only 45 minutes. And for a person with cerebral palsy we needed from 1h30 to 2h. This is due to the fact that we used the Berg Balance Scale.

Generally, people like this kind of exercise which change their clinical practice customs. But we also had negative feedbacks which were expected and wanted in order to improve our protocol.
For everybody, the time spent on the platform is too long – even for healthy people. This was due to the acquisition time. We could not do anything to change or improve the situation because it was not our duty. As a consequence of this, we offered people to sit or rest a little between exercises.
Furthermore, the feet position was not intuitive and was challenging to maintain. For this second point, doctors told us that we should not use this pattern because what is true for static is not always true for dynamic. So for the future work we are thinking of just asking to people to put their feet according to the width of their iliac spine.

When our measurement campaign was done we could conclude about the process cycle. In our opinion, we think that the protocol is long to be a part of their own clinical process but each step is important. Moreover, it is easier to be at least two, in order to prepare quickly the patient for example.

Chapter 4

Analyse

In this section we will present you how we processed all the data and we will present you results we obtained for a healthy subject and for a subject who suffer from cerebral palsy. In order to process data in a proper way, we decided to classify data for each movement of the platform. Hence, we found the moment when the platform starts to move thanks to a coda sensor placed on the platform and another one placed on the framework. We checked the distance between those two points and when it exceeded a threshold – determined by experience –, we concluded that the platform started to move. Then we cut the sequence according to the protocol we applied. Furthermore, we organized all the parameters we compute on an excel file named donnees.xlsx in which each subject has his own page and where we put some information we need to compute parameters and also the mean value.

To process data we have a main file on matlab which launchs an interface where we can choose the subject and the exercise we want to analyse. Then it launches 2 other files which process the data for the posturography and for the kinematic.

4.1 Posturographic Data

4.1.1 Data recovery

The Matscan's software is presented in this way (figure 4.1):

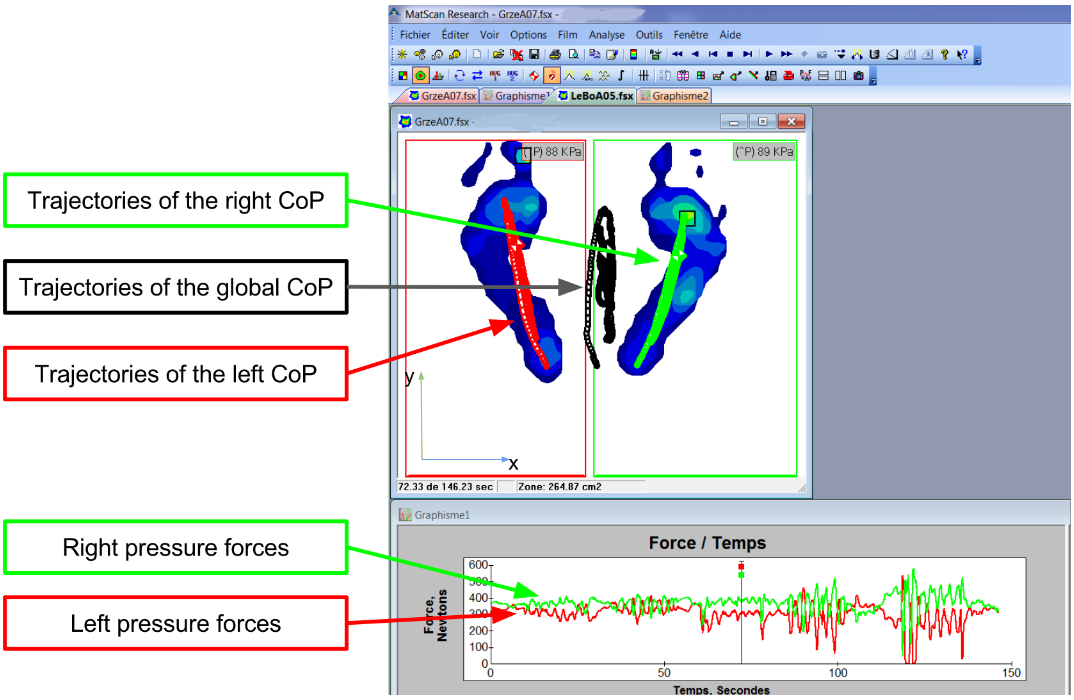

Figure 4.1: Screenshot of Matscan's Software

It allows us to recover the forces under each foot and also the position of the center of pressure for each foot and the one related to the projection of the center of gravity. Before doing that a calibration of the sensors is required. The software propose different kinds of calibration. we used the one called "étallonage par image" which uses a moment (an image) during the recording were we know exactly the weight applied to it. Because the first exercise was static, we thought that it was the best way to do it without disturbing the protocol and adding a step to our routine. Once It was done for one exercise we just had to save it and download it for the others.
After doing so, we chose to gather all data on an excel file which has the same pattern for each subjects in order to facilitate the data processing with matlab.

4.1.2 Processing

To process data we have the file matscan.m which will compute parameters for each movement of a given exercise and a given subject. Moreover, it also plots and saves posturographic graphs such as the statokinesigram for example (A statokinesigram is the layout of a line connecting the successive positions of the center of pressure during the recording).

What we had in mind at the beginning was to develop our own parameters based on our biomechanical model. Because of a lack of time, we could not do it this way, so we decided to use existing parameters, even though it was made for static posturography. There are lots of parameters we can compute from posturographic measurement. Considering our experimental conditions and the pathology under study, we focused this analysis on the most relevant.

Parameters computation

- length of the statokinesigram : corresponding to the length travelled by the center of pressure during an exercise. We can easily understand that if a person keeps his position, his center of gravity will not move. As a result his center of pressure will not move and so the length of the statokinesigram will be near to 0 ;

- elliptic area : the area of the ellipse of confidence containing 90% of the sampled positions of the center of pressure (Tagakwe A., 1985). If this area is big, this means that the subject travelled a large distance with his center of gravity to recover his balance ;

- LFS : it is a coefficient which represents an energy expenditure. It is the quotient between the ellipse area and the length of the statokinesigram. So the closer to 0, the better the result ;

- mean values of the CoP (Center of pressure) coordinates according to x and y axis : thanks to that we can see if the subject is symmetric and if he uses more his heels or his toes ;

- mean value of forces apply on each feet : with this parameter we can see if the subject is symmetric or not ;

4.1.3 Representation

The idea was to represent the previous parameter in order to have an overview of the subject's capacities quickly and easily. The representation of the statokinesigram or the forces according to the time were not the right solution to fit with those conditions. Therefore, we choose a radar representation. In this representation we can put all parameters on a same graph and also put a mean value and superpose graphs.

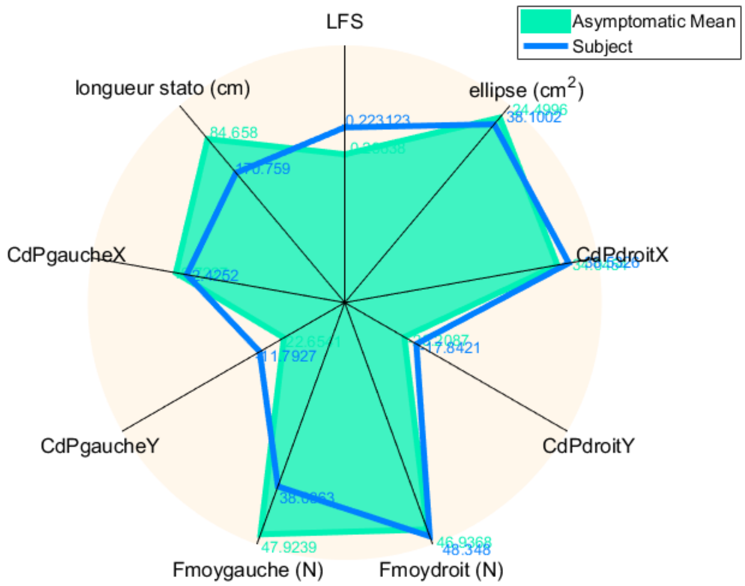

Figure 4.2: example of a Representation for Posturographic Data

The Figure 4.2 shows us an example of a representation in radar. The green area represents the mean posturography parameters for a group of healthy subject. The blue line is the result of one subject. we program this radar in order to have the best result at the circumference of the circle and the worst at the center. The bigger the area is the better the subject is. And we have such representation for each platform movement of each exercise.

4.2 Kinematic Data

Kinematic data are provided by the Coda Motion. It corresponds to the position according the three axis of each sensors. The software gives us a .txt file easy to use with matlab thanks to the command [data,delimiterIn]=importdata(fichier).

4.2.1 Data recovery

Sometimes, the sensor could not to be seen by the camera for example because of a motion of the platform (the medio-lateral translation). In this case, CodaMotion's software can provides us data with an interpolation. But we decided to use an interpolation function with matlab instead of using the one of coda. This helped to know when there were occlusions because instead of having values there were NaN.
So when we used the command importdata we have a cell array which disassociate the words and the numbers. Then, to use the data easily, we split each columns. After that, we use a function to interpolate the data to change the NaN and we replace the one at the beginning and at the end of each vectors by 0. We used the representation of the figure 4.3 to know if we can trust in the knimatic result or not.

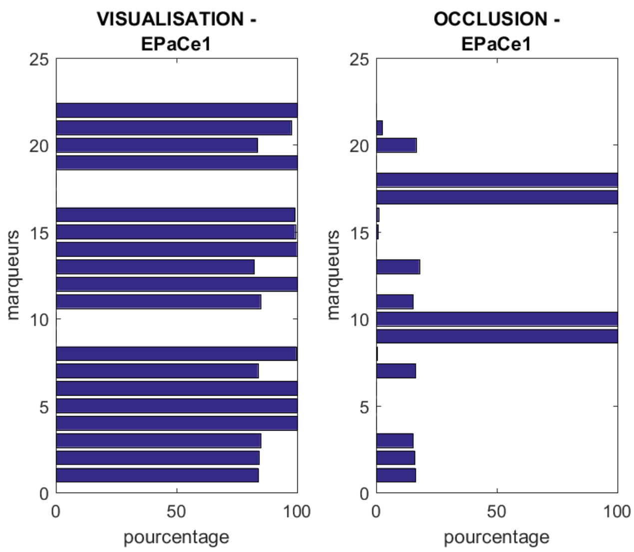

Figure 4.3: Example of a representation for the occlusion

4.2.2 Processing

Get the frame

The idea was to create a reference frame for each segment of lower limbs. To do so we needed a plan and so 3 points for each segments (that explains the choice of the markers). With those 3 points we have 2 vectors and we can compute to have the orthogonal and then we find the third orthogonal using one of the first vectors.

Once we have the reference, we have normalised it. In order to do so we used the Gram-Schmidt orthonormalisation which is a recursive algorithm (cf. Figure 4.4).

$$\begin{aligned}
\mathbf{u}_1 &= \mathbf{v}_1, & \mathbf{e}_1 &= \frac{\mathbf{u}_1}{\|\mathbf{u}_1\|} \\
\mathbf{u}_2 &= \mathbf{v}_2 - \mathbf{proj}_{\mathbf{u}_1}(\mathbf{v}_2), & \mathbf{e}_2 &= \frac{\mathbf{u}_2}{\|\mathbf{u}_2\|} \\
\mathbf{u}_3 &= \mathbf{v}_3 - \mathbf{proj}_{\mathbf{u}_1}(\mathbf{v}_3) - \mathbf{proj}_{\mathbf{u}_2}(\mathbf{v}_3), & \mathbf{e}_3 &= \frac{\mathbf{u}_3}{\|\mathbf{u}_3\|}
\end{aligned}$$

Figure 4.4: Gram-Schmidt process

Get the angle

Now we have the reference frame for each segment. Hence, we can use rotation matrix to find the rotation angles according to the 3 axis and for each time t.

Considering the following rotation matrix between 2 frame at time t,

$$\begin{pmatrix} a11 & a12 & a13 \\ a21 & a22 & a23 \\ a31 & a32 & a33 \end{pmatrix}$$

The following equation give us the value of the angle for the time t by identification:

$$q1x(i) = atan2(a32, a33) \tag{4.1}$$

$$q1y(i) = atan2(-a31, sqrt(a32^2 + a33^2)) \tag{4.2}$$

$$q1z(i) = atan2(a21, a11) \tag{4.3}$$

Filtering

The signal obtained was noisy, so we had to use a filter to improve the result and suppress the noise.
First we compared what we obtained with the matlab function smooth and a Butterworth (low pass filter) and we concluded that with the right parameters a butterworth is more efficient than a smooth. But even after this filter we had some weird peaks which were presents without any explanation so we try other filter and found that an outlier removal using Hampel identifier was the best solution.

Hampel creats an upper and a lower envelopes of the signal rejecting a predefined number of points. Then we take the mean of those 2 envelopes and get the signal filtered. The number we had to choose is the number of neighbors on either side of the sample. To choose it we look at the disturbing peak and saw that there was approximately 45 points. That is why we chose 45. When we chose this parameter we had to pay attention to not choose a number too high. In fact, it will, for sure, just flatten the signal.

4.2.3 Representation

we have two kinds of representation for the kinematics data :

1. The representation of the motion for 1 subject according to the time (figure 4.6);

2. A representation to show the mean value of a population : multiple box plots (figure 4.5).

The first one allows to have an overview of the strategy used by the subject. The second one allowed to see the mean minimum and maximum values of joints for example for the group of healthy subject.

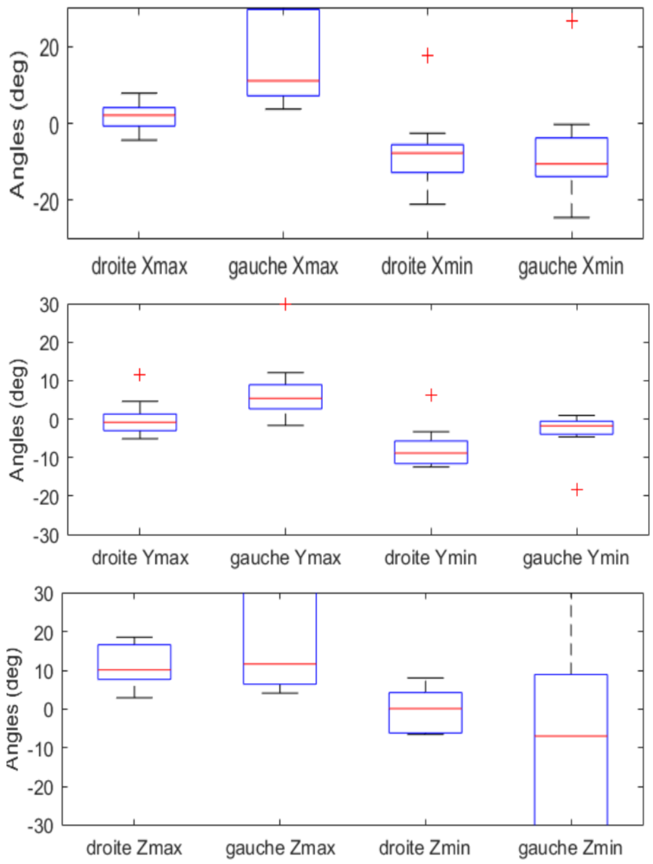

Figure 4.5: Example of a representation for the multiple box plots

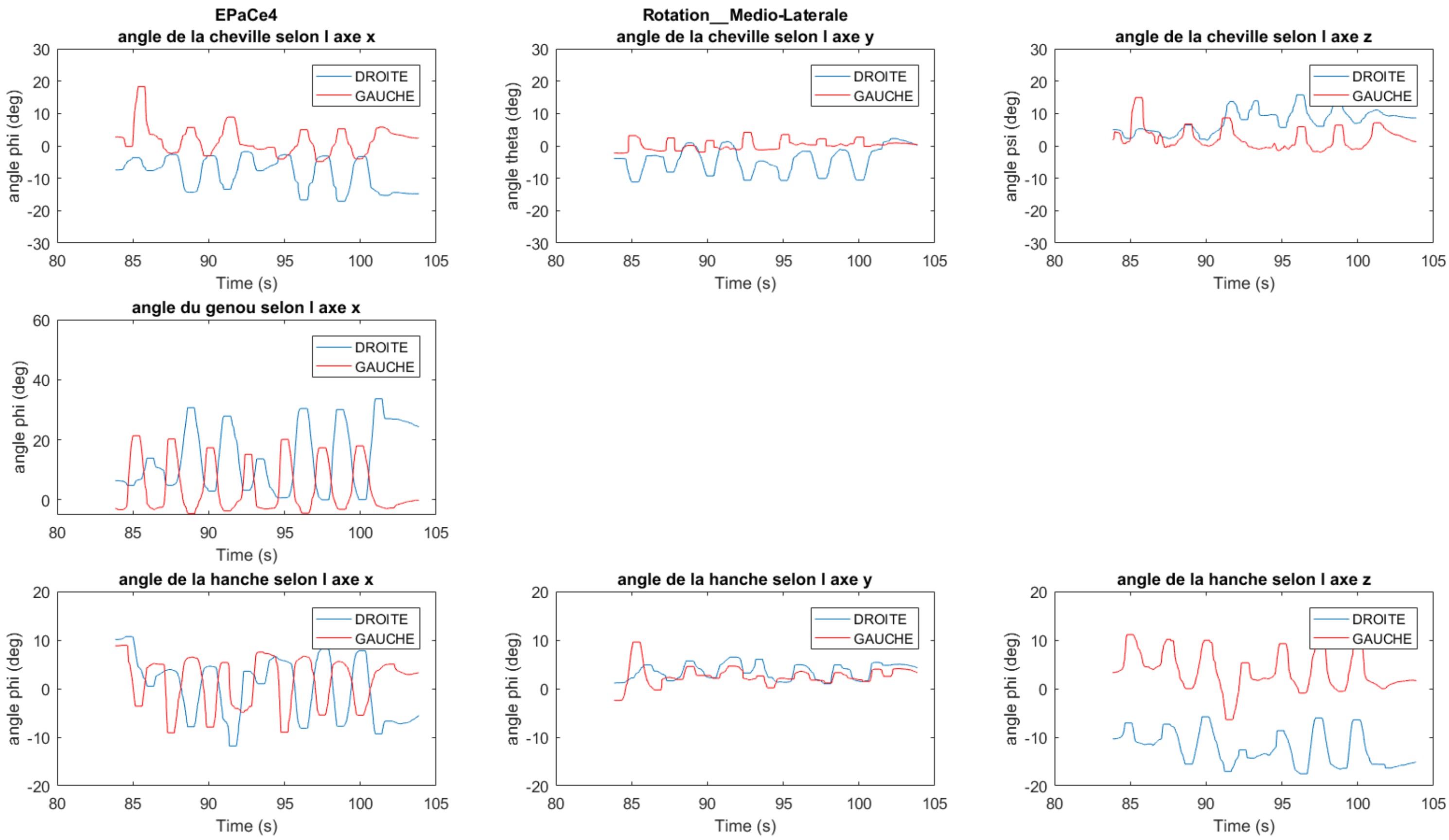

Figure 4.6: Example of a representation for the kinematic data

4.3 Mean values of the Healthy group

The idea of this work was to create a score to compare easily a subject with "normal" values. So we had to do the mean of all the values of our healthy group in order to have a "normal" pattern.

We had the chance to have more than 20 subjects (most of them healthy). but the problem was that we did not have a strong population for a precise range of age. So we selected a dozen people from 20 to 50 years old to make our panel. Nevertheless, the mean result we will present in this part will not be the mean values of this entire population of healthy people. In fact, for the Coda Motion data, we have many times problems with occlusions. And when one point is missing all the processing failed because every frame is related to the other.

For example, when we have the same result as the Figure 4.7, we cannot treat the values: whether we have bad results whether the code cannot run.

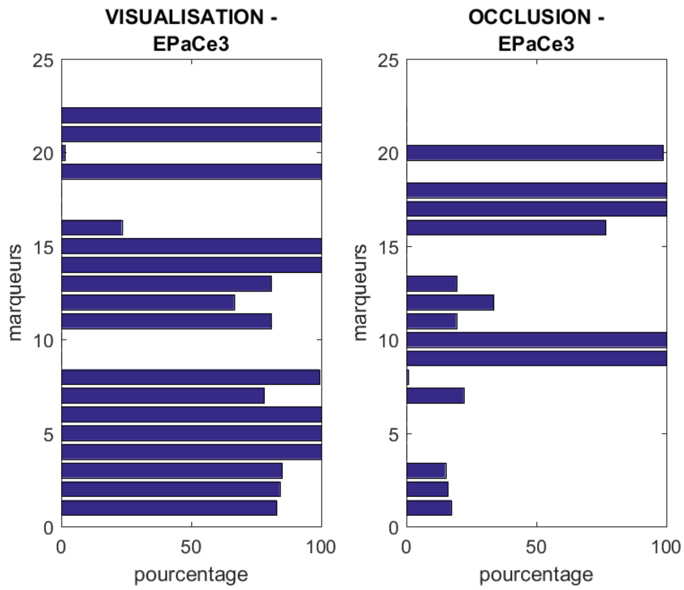

Figure 4.7: Case of bad occlusions

In this case, the left great trochanter and the left medial epicondyle are missing. As a consequence, we could not compute the frame of the pelvis and the one attached to the left thigh.

Regarding the posturographic data, it will be the mean value of few people because the data extraction was a very long process.

Posturographic healthy means

To have a reference value for posturography, we just took parameters for each subjects we had information about and take the mean. Then we had to create the radar in order to have an easy and functional representation.

We decided to choose hypothetical and unreachable values for the periphery and the center of the radar. For example, the best value for the length of the

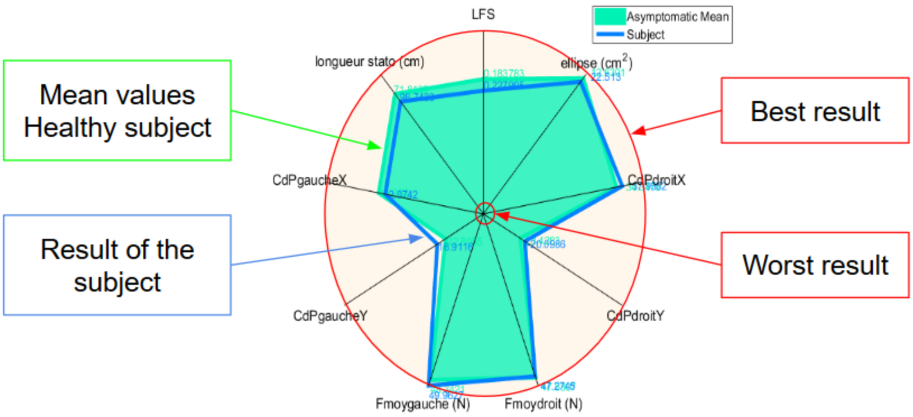

Figure 4.8: Overview of radar representation

statokinesigram is 0 and the forces apply on the feet is 50% of their total weight. And when we plot it on a radar, we print it with a colored area. This way, we can easily see the level of the subject when there is a graph plots in same time. (cf. Figure 4.8 & Appendix D)

Kinematic healthy means

To have the value of the kinematic data of this panel, we took the mean values of 13 normal developed subjects and we put it on the spreadsheet "donnees". And then we plot the multiple box plots (figure 4.9). This representation is interesting because we can see the trend about the manner people use their joints.

What is a multiple box plot ?

It is a proper way to represent graphically depicting groups of numerical data through their quartiles.

It shows :

- The low line indicates the minimum value;
- The upper line indicates the maximum value;

- The difference between those two lines is the total range which shows the dispersion of the values
- The line in the middle is the median value

So we can deduce that if the body of the boxplot is big, meaning that the values are heterogeneous

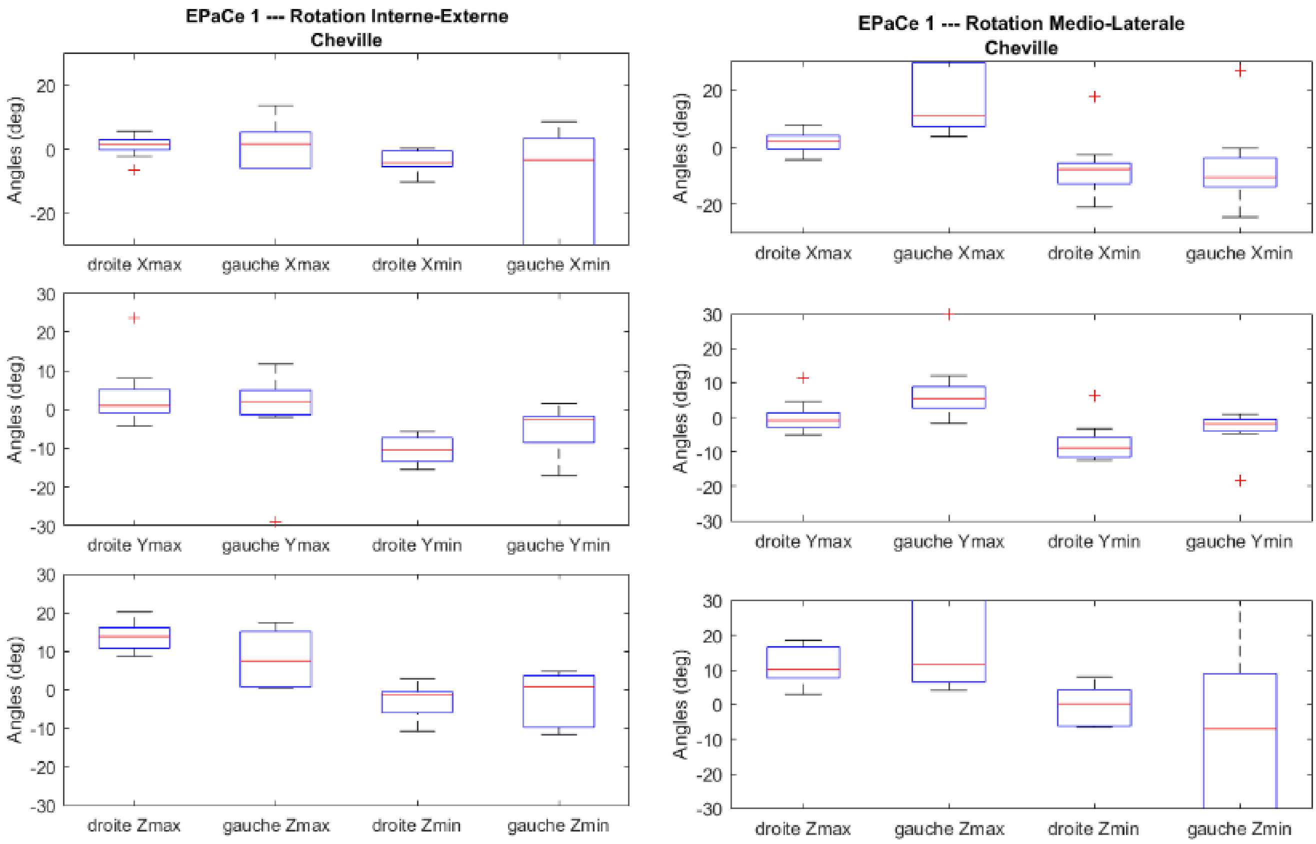

Figure 4.9: Example of representation for kinematic data mean

4.4 Analysis of a CP Subject

We will focus this last part showing you the analysis of the result we obtained for a subject who suffers from cerebral palsy. Let us focus this work on one movement of the platform, the Medio-Lateral Rotation. we choose this one because it seems to be the movement for which results are not wasted by technical issues and they bring to light many information.

The subject was an adult, GMFCS I. His cognitive abilities were pretty good. It means that he can focus on the exercise and understand easily what we ask him to do. Furthermore, when we apply to him the Berg Balance Scale he obtained the highest score. So, he is not a weak CP patient.

When he did the exercise, we could see that he was shaking more than a healthy subject. But the surprise according to the movement or the acceleration of the platform was the same. And he did not need to use handles or the support of an assistant.

4.4.1 Posturography

The Figure 4.10 is the footprint of our subject. We can see that he has slightly flat feet.
When we saw him doing the exercise we concluded that he was a strong subject but we wanted to see if the results confirmed what we stated.

Now take a look at the appendix D which presents the posturography results of our subject. As we can see on the radar, he was constantly pretty good and we would go so far as to say that sometimes he outperforms the average values. For example, if we look at the second level (EPaCe2) for the antero-posterior rotation, he has a lower energy cost than the average. The question we have to ask now is How can he do that in spite of his handicap ?

The Figure 4.11 present all the posturographic result of our subject. We can see that he is part of the lower mean concerning the LFS (energy cost) and presents an asymmetry between the force applied under the right and the left leg.

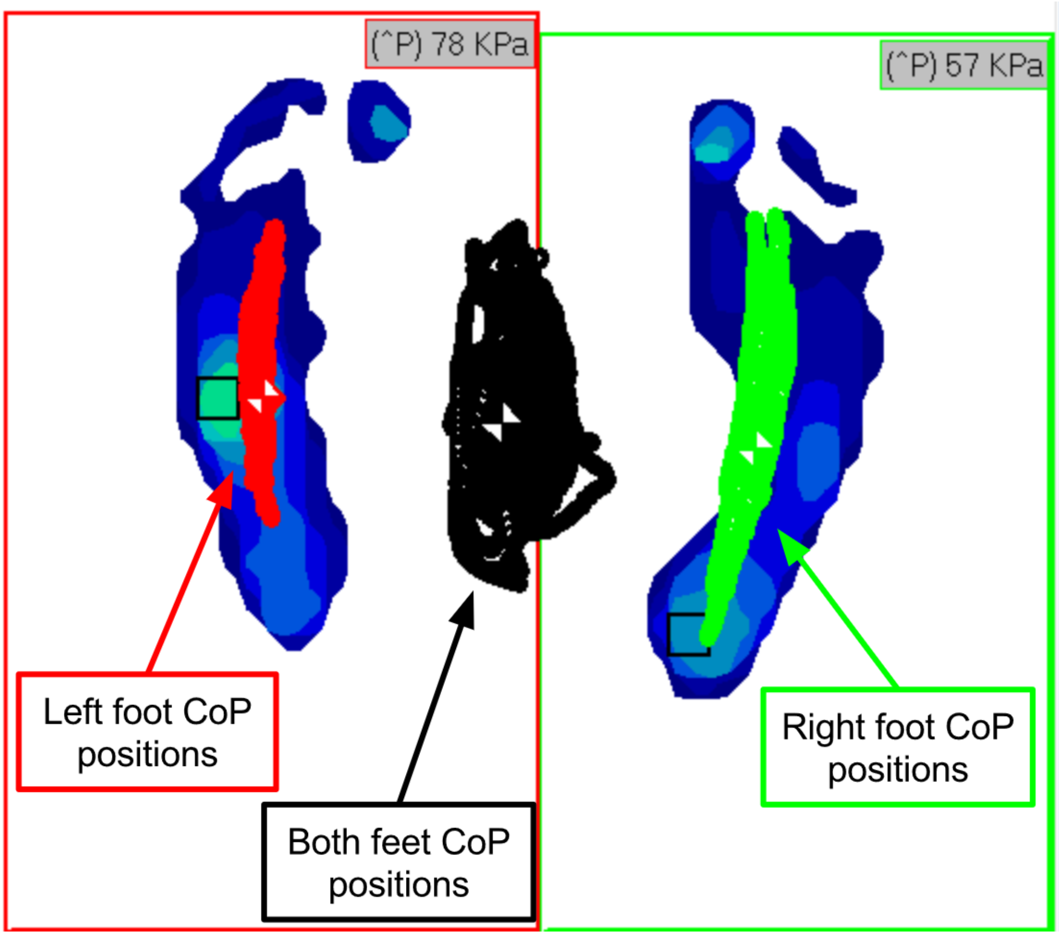

Figure 4.10: Footprint of our subjects'feet

As a matter of fact, the posturography results show us if a subject is good or not and can highlight his weakness but we do not learn about the strategy he uses to achieve such a result. That's why the following part is important.

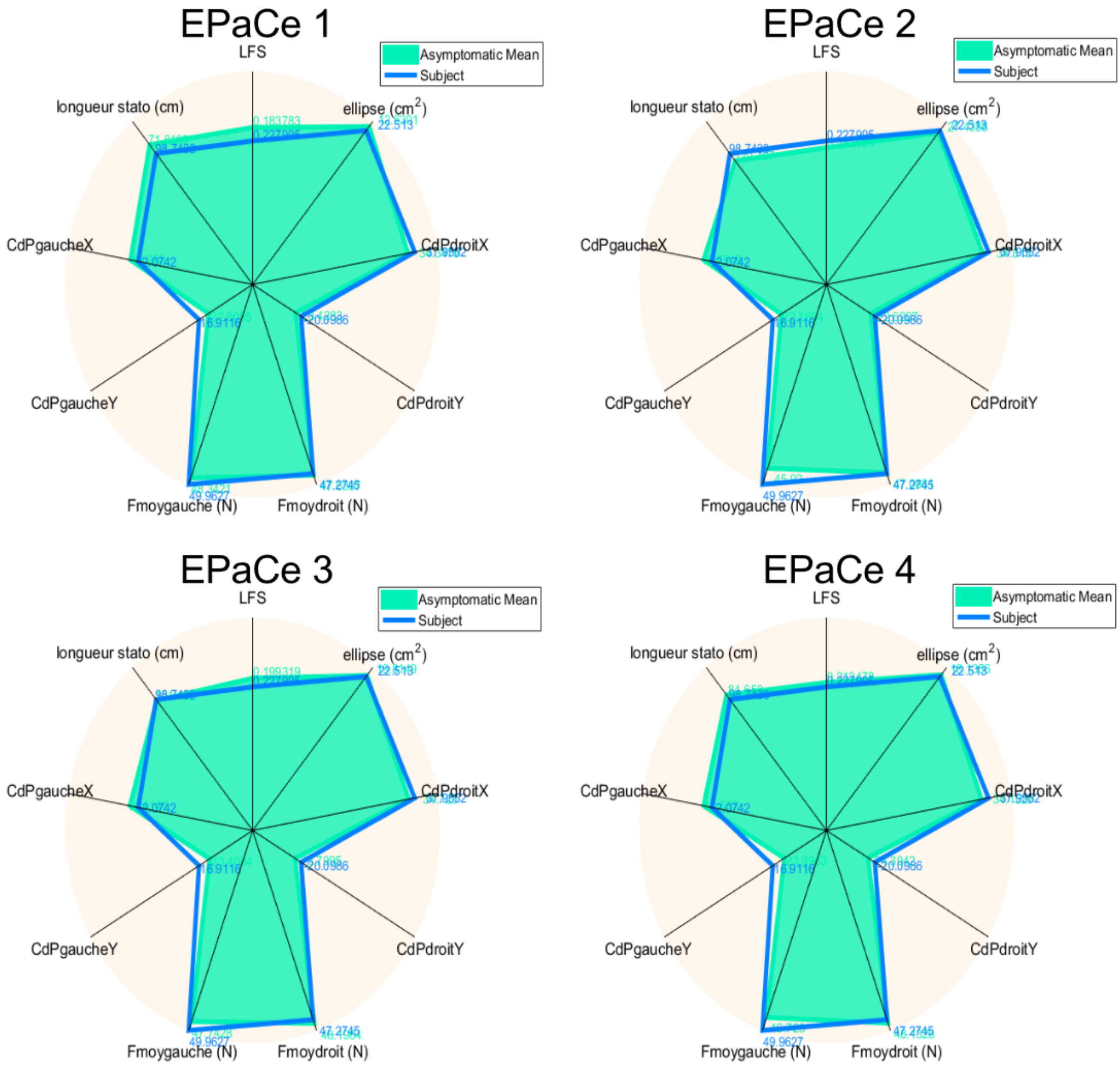

Figure 4.11: Posturographic results of the CP subject – Medio-Lateral Rotation

4.4.2 Kinematic

In this part we want to focus the analysis on the Medio-Lateral Rotation movement because it is the most relevant results on his strategy.

EPaCe 1

EPaCe 1 is the sequence of the 5 platform movements at low frequency and low amplitude.

The figure 4.12 shows that both the healthy patient and the patient who suffers from cerebral palsy, use their ankle at the same range.

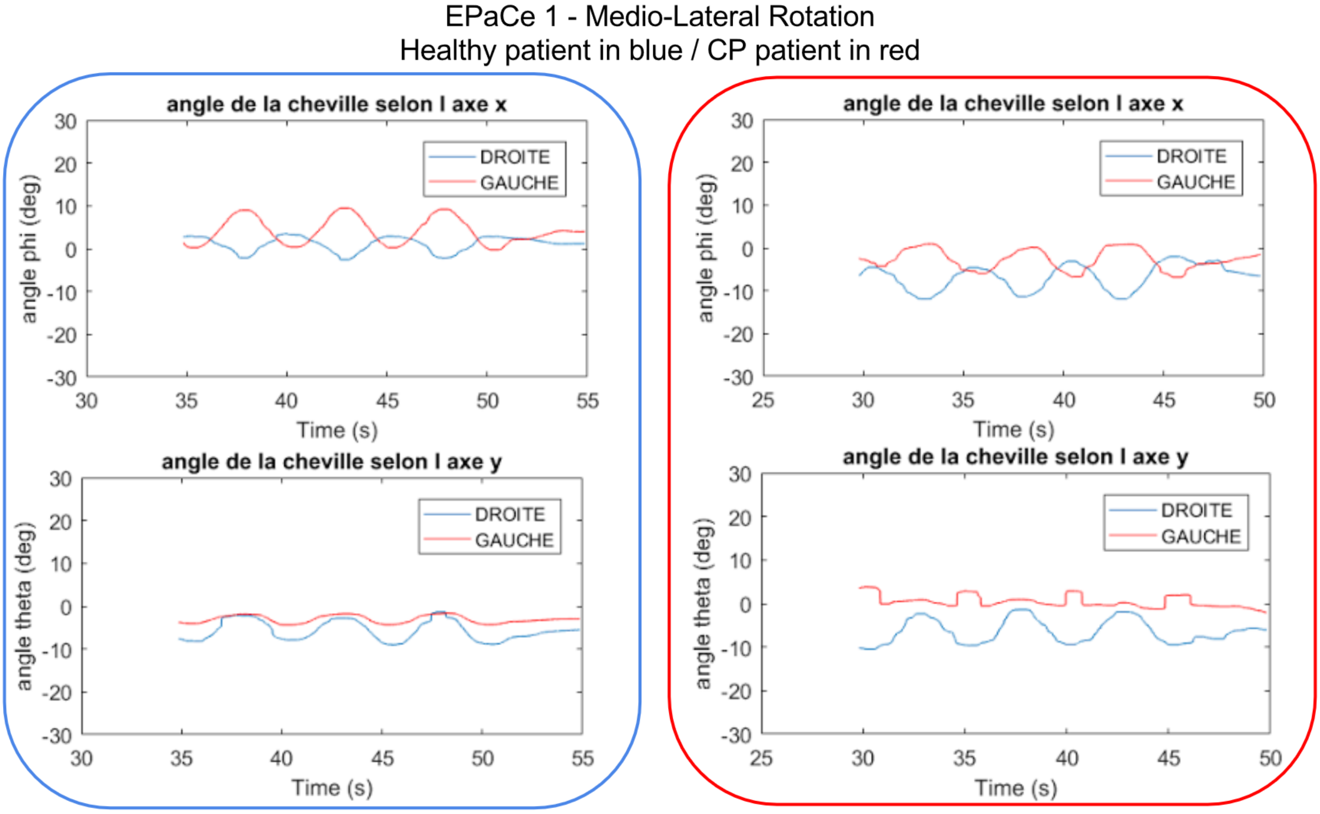

Figure 4.12: Comparison of the motion analysis of a CP patient with a healthy patient focusing on the ankle

However, the figures 4.13 and 4.14 prove that they did not have the same strategy. Actually, the CP patient use more his knees and his hips than the other.

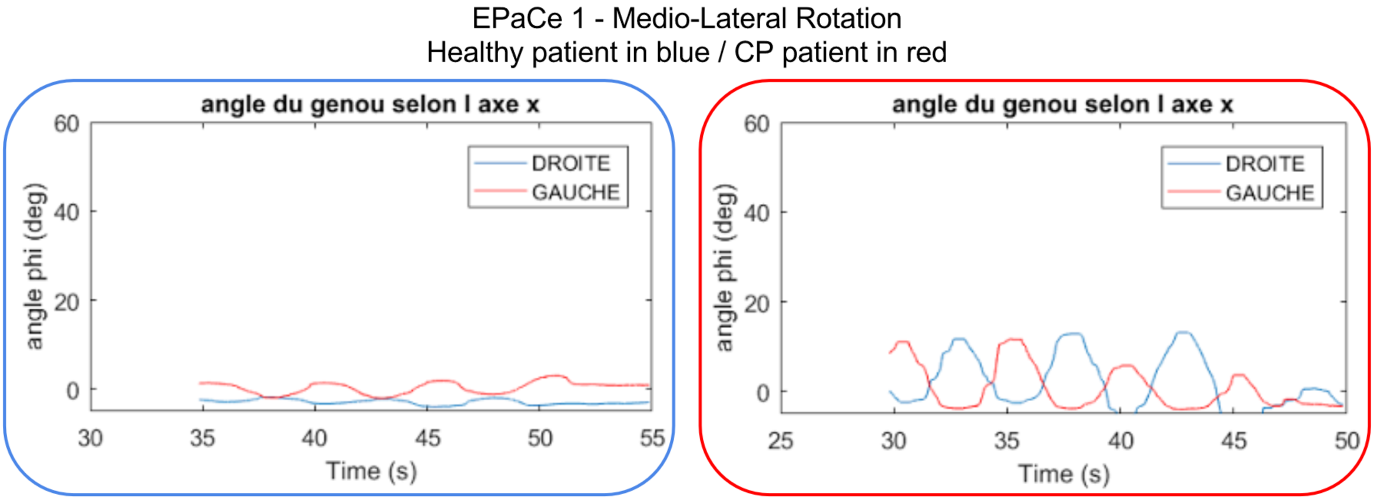

Figure 4.13: Comparison of the motion analysis of a CP patient with a healthy patient focusing on the knee

So to succeed the exercise properly, meaning keeping his balance without falling, he uses in this case the same strategy as one of the subject of the panel (ankle strategy) but in another ratio. Furthermore he uses his knees and his hips to compensate his difficulties.

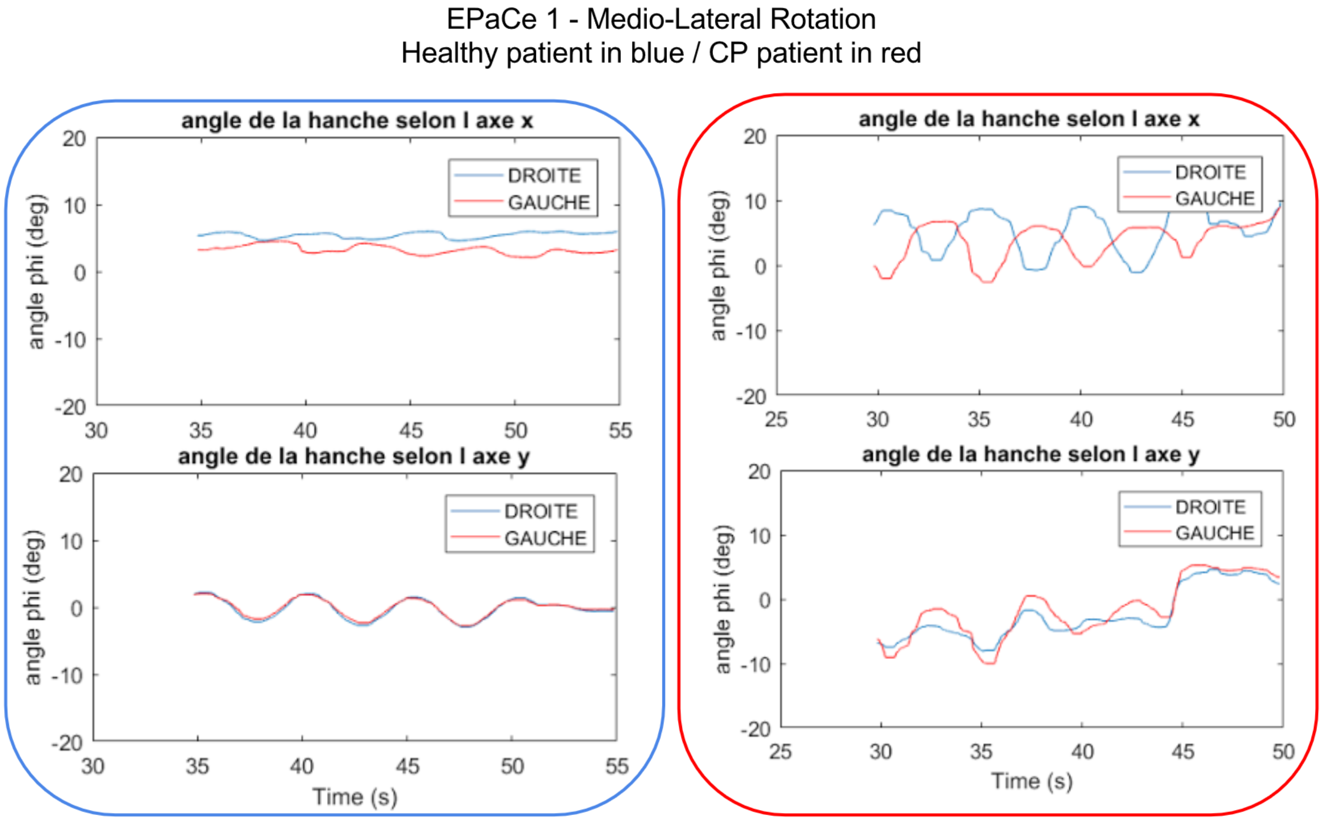

Figure 4.14: Comparison of the motion analysis of a CP patient with a healthy patient focusing on the hips

EPaCe 2 – EPaCe 3

Just to remind you the meaning of EPaCe2 and EPaCe3. Those are both intermediate level of exercises. The first one (EPaCe2) is the one where we increase the motion amplitude and let the movement at a low frequency. The second (EPaCe3) is the contrary: we increase the frequency and let the movement with a low amplitude.

First, what it is interesting in the figure 4.15, is that we can see the increase of the amplitude or the increase of the frequency.

Then, now that the level increased, is it clear that he has a leg stronger than the other : The right leg. He recruits more his right leg.

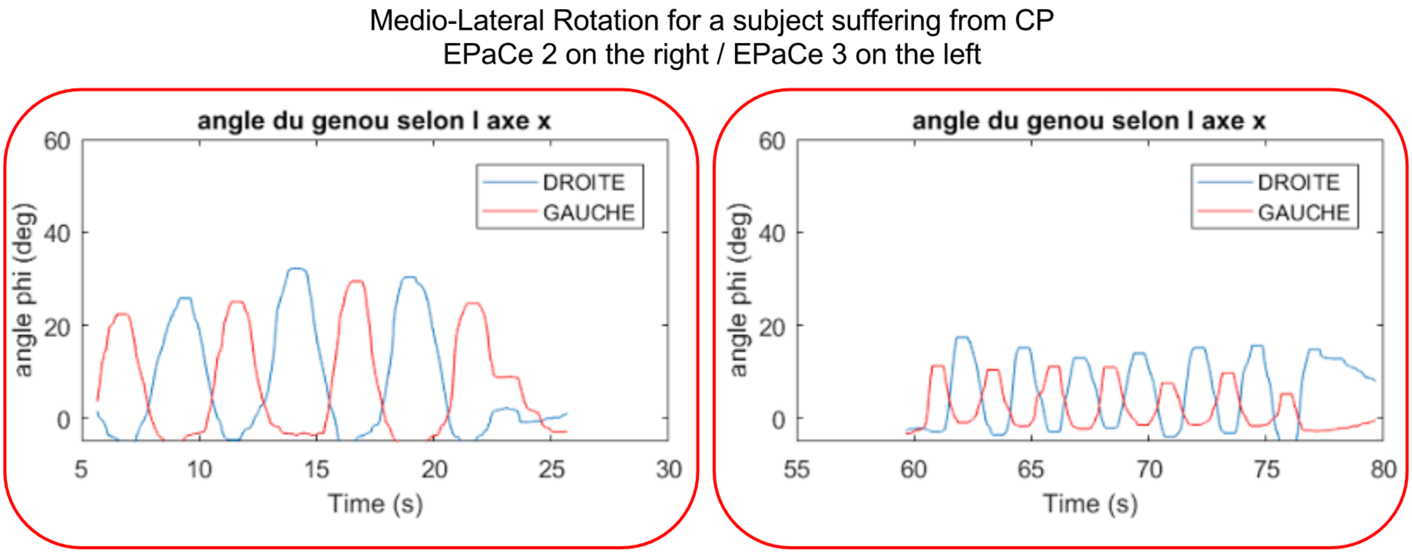

Figure 4.15: Comparison of the motion analysis of a CP patient between 2 different exercises

EPaCe 4

This exercise was the combination of the two intermediate level. We can see that it was much more difficult than EPaCe 1 for him. But also if we compare with a healthy subject. There are the same issues than for EPaCe 1 but in another proportion (figure 4.16).

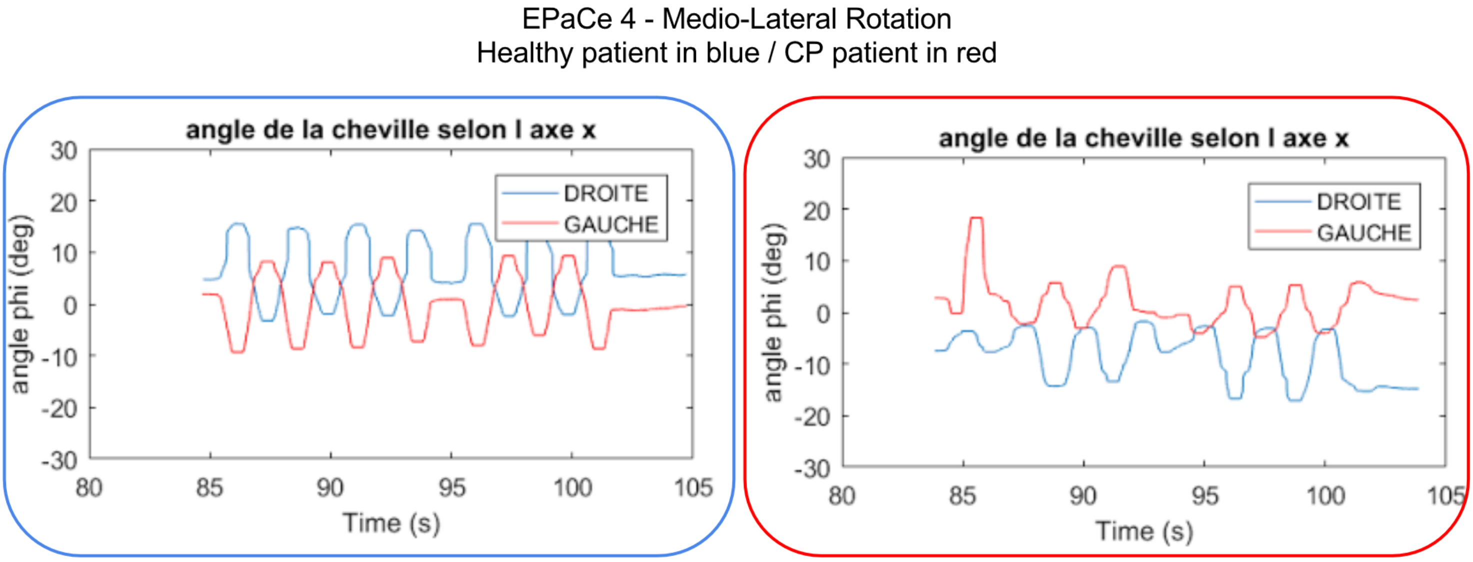

Figure 4.16: Comparison of the motion analysis of a CP patient with a healthy patient focusing on the ankle

In addition, if we focus on the results according to the x axis – even though there are movements according the other axis too –, we can see a difference of strategy between those two subjects (figure 4.17). on one hand we have the healthy subject who uses mostly his ankles to keep his balance. And on the other hand, our CP subject uses mainly his knees and his hips. We could expected the kind of results because it is the main conclusion of many paper on the literature which deal with balance topic.

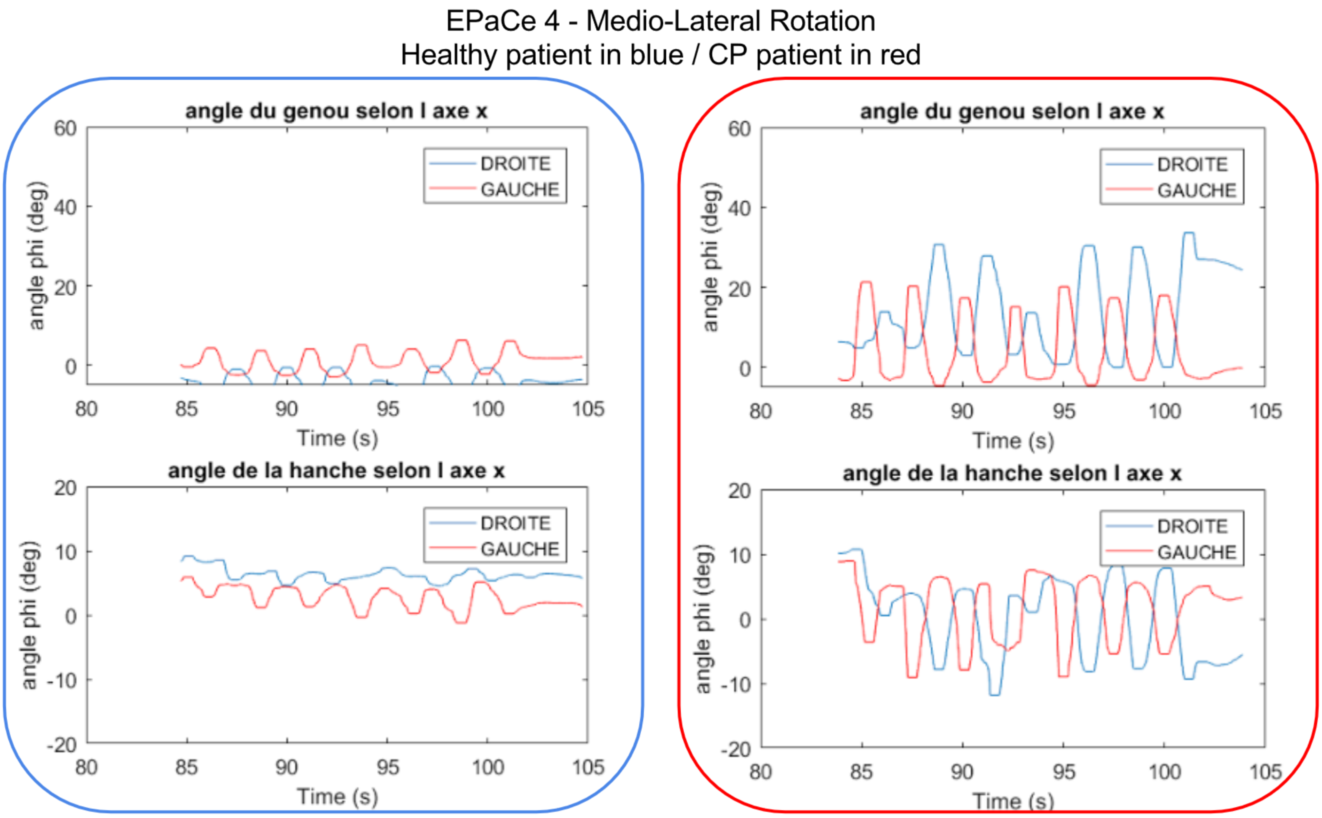

Figure 4.17: Comparison of the motion analysis of a CP patient with a healthy patient focusing on the knee and the hips

4.4.3 Overlaps between conclusions

Now we saw both sides of my work, let's come to the conclusion. Because as we said before, we cannot understand well what is happening if we do not cross-check our conclusions.

So with the matscan we saw that our subject is an average person with an average energy cost (LFS) and an asymmetry between his two legs. This asymmetry is confirmed with the result of the coda Motion. Furthermore, we saw that he has a complicated strategy to recover his balance (knees and hips) instead of using an easier one.

To conclude with this analysis, we can say that this subject has good posturographic parameters but to achieve this he has to use a different strategy than the one a healthy subject can use.

Conclusion

In Conclusion, this internship ends on an operational balance measurement system almost over (it misses the handles) coupled to a judicious protocol.

This first work shows that those two points (the platform and the protocol) were well thought: in fact, the results highlight the necessity to combine the chosen sensors (motion capture and dual force plate) with the perturbations.

For this first measurement campaign, we used the matscan and the Coda Motion. Unfortunately, after a change direction for the instrumented handles, we could not offer a final solution to get that information within the 6-month internship. So this is something that remains to be done for the following work. Furthermore, even if the protocol has been proven its evidences during this work, it should be require to change it. In fact it may be a little too long for people and if they decide to change the cameras, they will have to adapt it to this new method.

Finally, this work underlines the relevance to study kinematic data which completes the posturographic data in the apprehension of the using strategies. Indeed, our CP patient results show that even if we feel that need to have a strong subject with the posturographic results, that can be the fact of many compensation due to their handicap that can be reveal by the kinematic data.

During this internship, I experimented different features of the researcher work:

- Set up a protocol;
- Set up an experimentation;
- Approach companies in order to treat with them;

- Order equipments and manage a budget;
- Attend formations and seminaries.

I think reached most of my goals. I could learn a lot about FSR, loadcell and Arduino. Apart from that, I regret not having enough time to finish my dynamic model that I did not present in this report. It is a shame because the inverse dynamic model could gave us information about the energy cost of the muscle recruitments. Moreover, with this model, we could have custom parameters which depend on the disturbances. Because the one that we used are based on the CoP position which have a known the bounds of relevancy. Unfortunately, I could not extract mean values while gathering the entire population of our study largely due to occlusion problems. Otherwise, in my opinion, my internship went well and I think that we succeeded to clear a little the field for the following work.

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Appendix A

Experimental Protocol

In the following page, you have the experimental protocol we did during all this first session. It was the same for all subjects in order to facilitate the data processing.

Protocol experimental

ID	Ex_Name	Duration	
1	Pause	5	
2	Rx_00	30	
3	Rx_00	30	
4	Pause	20	85
	PAUSE		
5	Tx_BfBa	20	
6	Pause	5	
7	Ry_BfBa	20	
8	Pause	5	
9	Rx_BfBa	20	
10	Pause	5	
11	Rot_90	7	
12	Ty_BfBa	20	
13	Pause	5	
14	Rz_BfBa	20	
15	Pause	10	137
	PAUSE		
16	Ry_BfHa	20	
17	Pause	5	
18	Tx_BfHa	20	
19	Pause	5	
20	Rx_BfHa	20	
21	Pause	5	
22	Rz_BfHa	20	
23	Pause	5	
24	Rot_90	7	
25	Ty_BfHa	20	
26	Pause	10	137
	PAUSE		
27	Rot_90	7	
28	Ty_HfBa	20	
29	Pause	5	
30	Tx_HfBa	20	
31	Pause	5	
32	Ry_HfBa	20	
33	Pause	5	
34	Rx_HfBa	20	
35	Pause	5	
36	Rz_HfBa	20	
37	Pause	10	137
	PAUSE		
38	Rx_HfHa	20	
39	Pause	5	
40	Rz_HfHa	20	
41	Pause	5	
42	Tx_HfHa	20	
43	Pause	5	
44	Ry_HfHa	20	
45	Pause	5	
46	Rot_90	7	
47	Ty_HfHa	20	
48	Pause	10	137
	total	633	sec
	total	10,55	min

Appendix B

Marker Positions

This is how we put markers for every subjects in order to simplify the data processing.

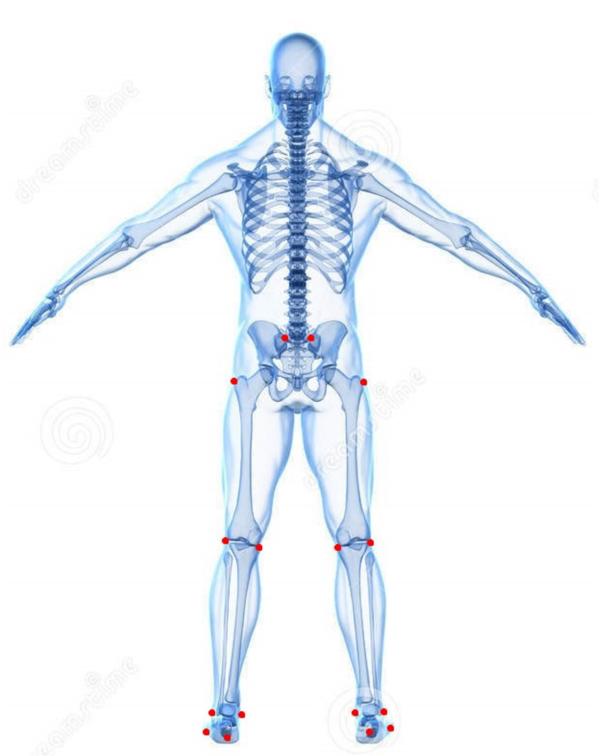


Figure B.1: Markers positioning

Position des marqueurs coda

Boitier	n°	marqueur n°	x	y	z	Position
A	0	1	2	3	4	tête M5 - pied droit
	1	2	5	6	7	malléole latérale droite
	2	3	8	9	10	malléole médiale droite
	3	4	11	12	13	épine calcanéenne droite
B	0	5	14	15	16	tête M5 - pied gauche
	1	6	17	18	19	malléole latérale gauche
	2	7	20	21	22	malléole médiale gauche
	3	8	23	24	25	épine calcanéenne gauche
C	0	9	26	27	28	
	1	10	29	30	31	
	2	11	32	33	34	épi-condyle latérale droite
	3	12	35	36	37	épi-condyle médiale droite
D	0	13	38	39	40	grand troch droit
	1	14	41	42	43	EIPS droit
	2	15	44	45	46	EIPS gauche
	3	16	47	48	49	grand troch gauche
E	0	17	50	51	52	
	1	18	53	54	55	
	2	19	56	57	58	épi-condyle latérale gauche
	3	20	59	60	61	épi-condyle médiale gauche
F	0	21	62	63	64	pour la synchro
	1	22	65	66	67	plateforme 1
	2	23	68	69	70	plateforme 2
	3	24	71	72	73	plateforme 3

Appendix C

Explication of the code

I gave those 5 pages to the team at the end of my internship to make it easier to follow my work after I left.

---- EPaCe ---- Codes Matlab ----

main.m

1. ouvre une interface pour choisir le sujet à étudier et l'exercice
2. affiche un diagramme qui montre les occlusion durant l'acquisition coda et l'enregistre dans le dossier du sujet en utilisant le code **occlusion.m**
3. lance l'analyse du coda en lançant le code **analyse_coda.m**
4. lance l'analyse du matscan en lançant le code **matscan.m**

occlusion.m

Pour chaque marqueur :

1. on vérifie si il y a une valeur NaN suivant au moins un axe
2. si tel est le cas on considère cela comme une occlusion et on augmente de 1 le compteur.
3. à la fin ça nous donne une valeur qui correspond on nombre de fois ou le capteur a été occulté et on trouve le pourcentage des occlusions (occ).
4. On soustrait cette valeur à 100 pour avoir le pourcentage qui correspond à la détection des capteurs par les caméras (visu).

Puis on les affiche.

analyse_coda.m

Ce code permet de calculer les paramètres cinématique, il les enregistre dans le fichier excel donnees.xlsx. De plus, il affiche les graphes correspondant et les enregistre dans le dossier du sujet. Le tout pour chaque exercice séquencé par mouvement.

1. fait appel au code **cotedroit.m**
2. filtre les angles calculé dans le code précédent
3. passe les angles de radian en degré
4. idem pour le coté gauche en faisant appel au code **cotegauche.m**
5. on retrouve dans le tableau donnees.xlsx le moment où on a appuyé sur le bouton au début et à la fin.
6. Pour Chaque exercice :
   a. on séquence l'exercice
   b. affiche les graphes à l'aide de la fonction **Affiche_coda** et les enregistre dans les dossiers des sujets en format png
   c. calcul des min,max,mean des données et on les enregistre dans le fichier excel donnees.xlsx à l'aide de la fonction **parametres_coda**

analyse_coda0.m
même chose que le précédent avec les codes:

- **cotedroit_j0.m**
- **cotegauche_j0.m**

et les fonctions:

- **Affiche_coda**
- **parametres_coda**

cotedroit.m Calcule les angles de la jambe droite
cotedroit_j0.m Calcule les angles de la jambe droite pour les sujets du premier jour
cotegauche.m Calcule les angles de la jambe gauche
cotegauche_j0.m Calcule les angles de la jambe gauche pour les sujets du premier jour

1. télécharge le fichier coda .txt qui se trouve dans le dossier du sujet
2. extrait les données pour chaque marqueur
3. interpolations des valeurs pour changer les valeurs NaN dues aux occlusions en utilisant la fonction **fixgaps**
4. remplace les valeurs NaN du début et de la fin qui ne peuvent pas être interpolées par 0
5. Création des repères pour chaque segment du membre inf
6. Orthonormalisation de Gram-Schmidt
7. interpolation pour retirer les NaN en utilisant la fonction **fixgaps**
8. Pour chaque temps, calcul des matrices de rotations et identification des angles (ref. Siciliano)
9.

Utilisation du code **bassin.m** pour calculer le repère du bassin pour la jambe droite et la jambe gauche car il s'agit d'un seul "solide" qui devrait avoir le même repère indépendemment du côté étudié

bassin.m

1. 2.extrait les données pour chaque marqueur
2. interpolations des valeurs pour changer les valeurs NaN dues aux occlusions
3. remplace les valeurs NaN du début et de la fin qui ne peuvent pas être interpolées par 0
4. Création des repères pour chaque segment du membre inf
5. Orthonormalisation de Gram-Schmidt
6. interpolation pour retirer les NaN

matscan.m
ce code permet de calculer les paramètres de posturographie, il les enregistre dans le fichier excel donnees.xlsx. De plus, il affiche les graphes correspondant et les enregistre dans le dossier du sujet. Le tout pour chaque exercice séquencé pour chaque mouvement.

1. extrait les données de posturo du tableau que j'ai créé au préalable au nom d'identification du sujet.
2. on retrouve le moment où on a appuyé sur le bouton au début et à la fin.
3. Pour Chaque exercice :
    a. on séquence l'exercice
    b. affiche les graphes à l'aide de la fonction **Affiche_posturo** et les enregistre dans les dossiers des sujets en format png
    c. calcul des min,max,mean des données et on les enregistre dans le fichier excel donnees.xlsx à l'aide de la fonction **parametres_posturo**

analyse_matscan
Analyse_matscan calcule les moyennes des données de posturo pour les sujets asymptomatiques et les enregistre dans le fichier excel donnees.xlsx grace à la fonction **Parametres_radar.m**
Il le fait pour chaque mouvement séparement et pour chaque exo

compare_posturo.m
Ce code permet d'afficher les diagrammes en radar avec la "norme" et le sujet étudié

1. récupération des valeurs moyennes des sujets asymptomatiques dans le fichiers excel donnees.xlsx
2. récupération des données de posturo du sujet étudié
   NB: study_subject contient l'identification du sujet que l'on souhaite étudier
3. affichage des radar en utilisant la fonction **print_radar** pour cahque exercice et pour chaque mouvement de plateforme

---- EPaCe ---- Fonctions Matlab ----

Affiche_coda

Affiche_coda(donnees, temps_debut,temps_fin,sujet,exercice, mouvement)

Affiche_coda affiche les graphes du coda et les enregistre dans le dossier approprié

donnees: récupére les valeurs des angles
temps_debut : début de la séquence à afficher
temps_fin : fin de la séquence à afficher
sujet, exercice et mouvement permettent de classifier (dans l'affichage et dans l'enregistrement) les différents plots

parametres_coda

parametres_coda(donnees,temps_debut,temps_fin,sujet,exercice,plagedroite,plagegauche)

Calcule les paramètres liés à la cinématique et les enregistre dans le tableur excel donnees.xlsx.
On calcule les valeurs min, max et moyenne de chaque articulation
donnees permet de récupérer les valeurs des paramètres à afficher
temps_debut et temps_fin permettent de séquencer les graphes par mouvement de plateforme
sujet et exercice permettent de classifier (dans l'affichage et dans l'enregistrement) les différents plots
plagedroite et plagegauche permettent de ranger les données correctement dans le fichier excel

Affiche_posturo

Affiche_posturo(sujet,donnees, temps_debut,temps_fin,exercice, mouvement)

Affiche_posturo affiche les graphes de posturographie et les enregistre en png

donnees permet de recupérer les valeurs des paramètres à afficher
temps_debut et temps_fin permettent de séquencer les graphes par mouvement de plateforme
sujet, exercice et mouvement permettent de classifier (dans l'affichage et dans l'enregistrement) les différents plots

parametres_posturo

parametres_posturo(sujet,donnees,temps_debut,temps_fin,plage)

parametres_posturo calcule et enregistre les données posturographique

donnees permet de recupérer les valeurs des paramètres à afficher
temps_debut et temps_fin permettent de séquencer les graphes par mouvement de plateforme
sujet et plage permettent de ranger les données correctement dans le fichier excel

calcul des paramètres

→ la longueur du chemin parcouru par le CdP
→ Ellipse contenant 95% des positions du CdP mesurées
→ le LFS
→ La moyenne des coordonnées du CdP suivant X
→ La moyenne des coordonnées du CdP suivant Y
→ moyenne des forces sous chaque pied

les valeurs des forces sont entre 50 et 0 : 50 correspond à 50% du poids appliqué sous le pied 0 correspond à 0% ou 100%.

Parametres_radar

Parametres_radar(exercice,mouvement, plage)

ParametreMoyen_radar calcul les valeurs moyennes min et max de posturo des sujets asympomatique et les enregistre dans le fichier excel donnees.xlsx

exercice permet de classifier correctement les valeurs dans le fichier excel
mouvement permet de retrouver les bonnes valeurs
plage permet de l'enregistrer au bon endroit

print_radar

print_radar(fig, P)

affiche la représentation en radar
le vecteur L à pour première colonne les valeurs centrales du radar et en deuxième colonne les valeurs périphériques
str correspond à la légende des rayons du radar
cette fonction utilise la fonction **radar**

Appendix D

Posturography result

This appendix is an overview of the posturographic data. In green it is the mean results for the healthy panel and in blue it is the result of our subject who suffer from cerebral palsy.

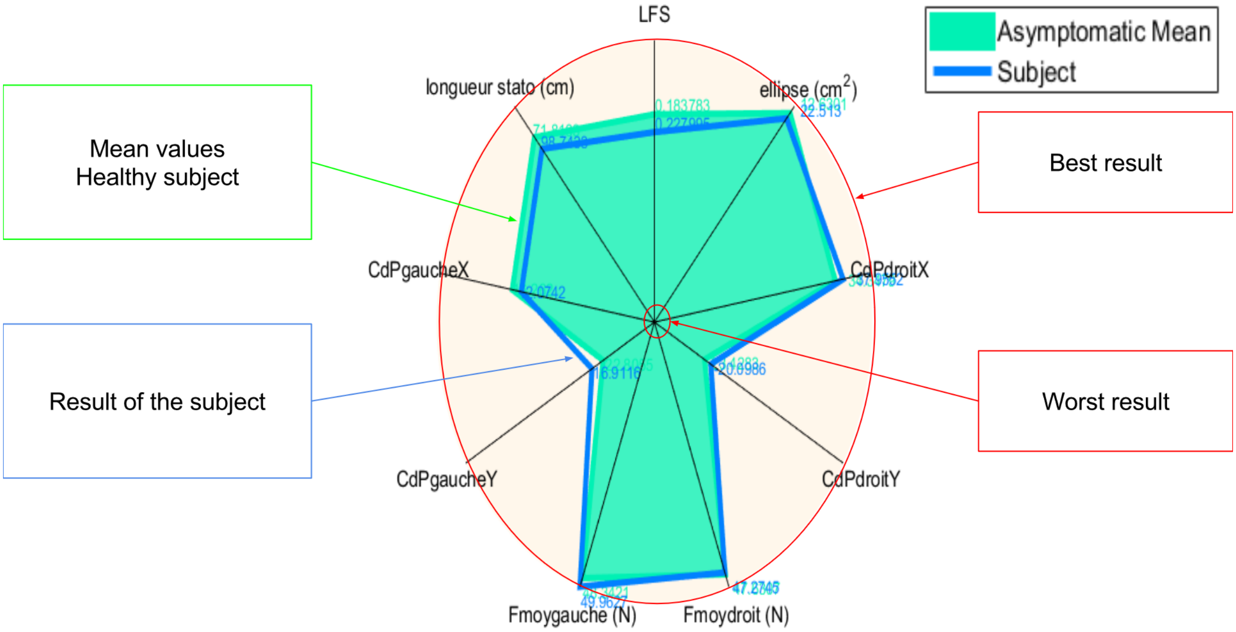
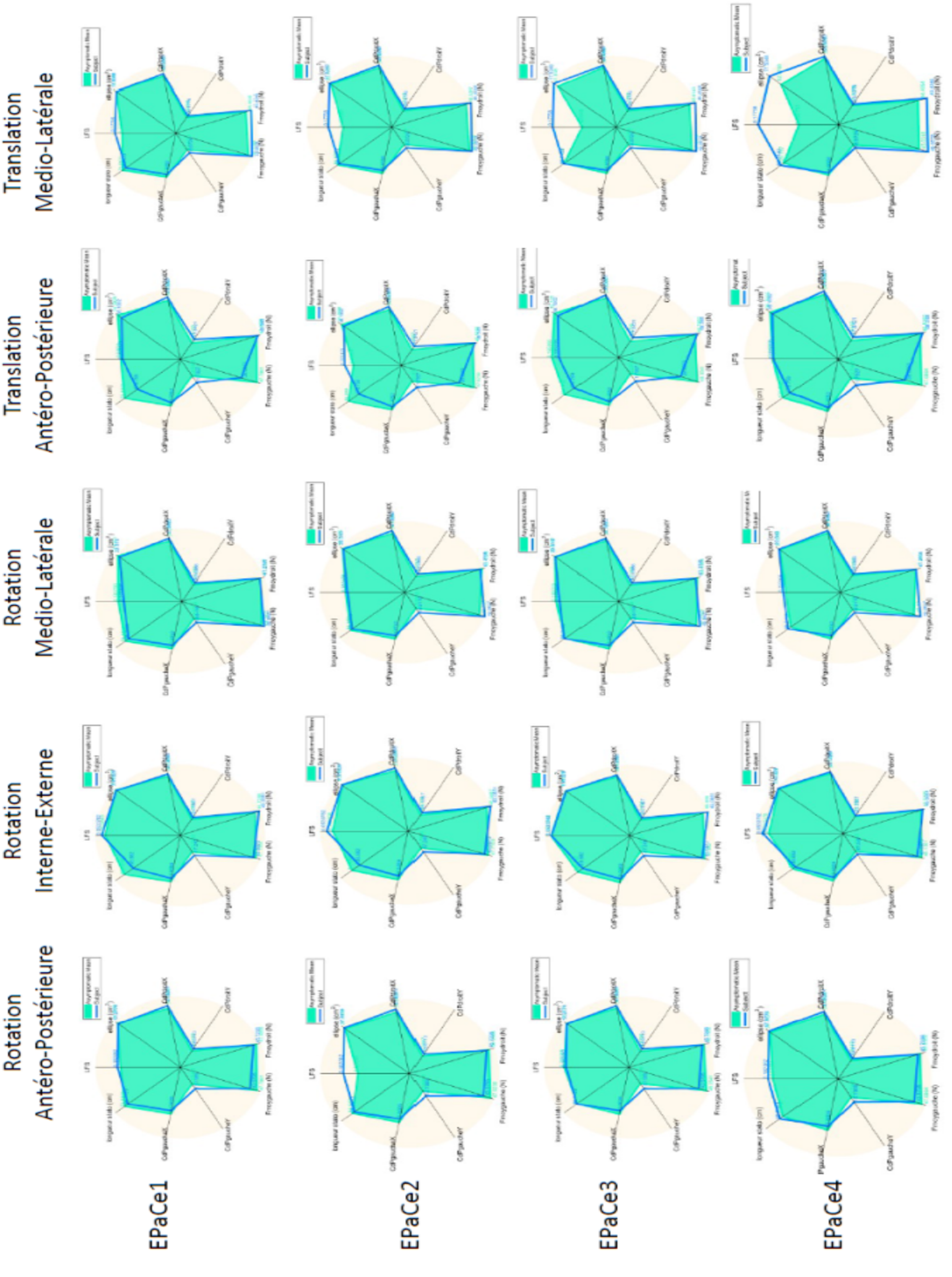


Figure D.1: Reminder Signification of the Radar Representation


Translation Medio-Latérale
Translation Antéro-Postérieure
Rotation Medio-Latérale
Rotation Interne-Externe
Rotation Antéro-Postérieure
EPaCe1
EPaCe2
EPaCe3
EPaCe4

Appendix E

Comparison between FSR and Load Cell

In the following pages there are the results of some tests we proceed to find which sensor was the best to record the vertical forces on handles.

Comparison between FSR and Load Cell

Question : Quel est le meilleur des capteurs entre FSR et Load Cell ?

- sensibilité ?
- linéarité ?
- répétabilité ?
- avantage(s)?
- inconvénient(s)?

Comparaison des capteurs avec un poids de 500g :

1. Acquisition des valeurs des capteurs à vide
2. Positionnement le poids dessus
3. Acquisition des poids durant 15 min environ
4. Retrait du poids
5. Acquisition des valeurs des capteurs à vide pour voir s’il retrouve leur 0

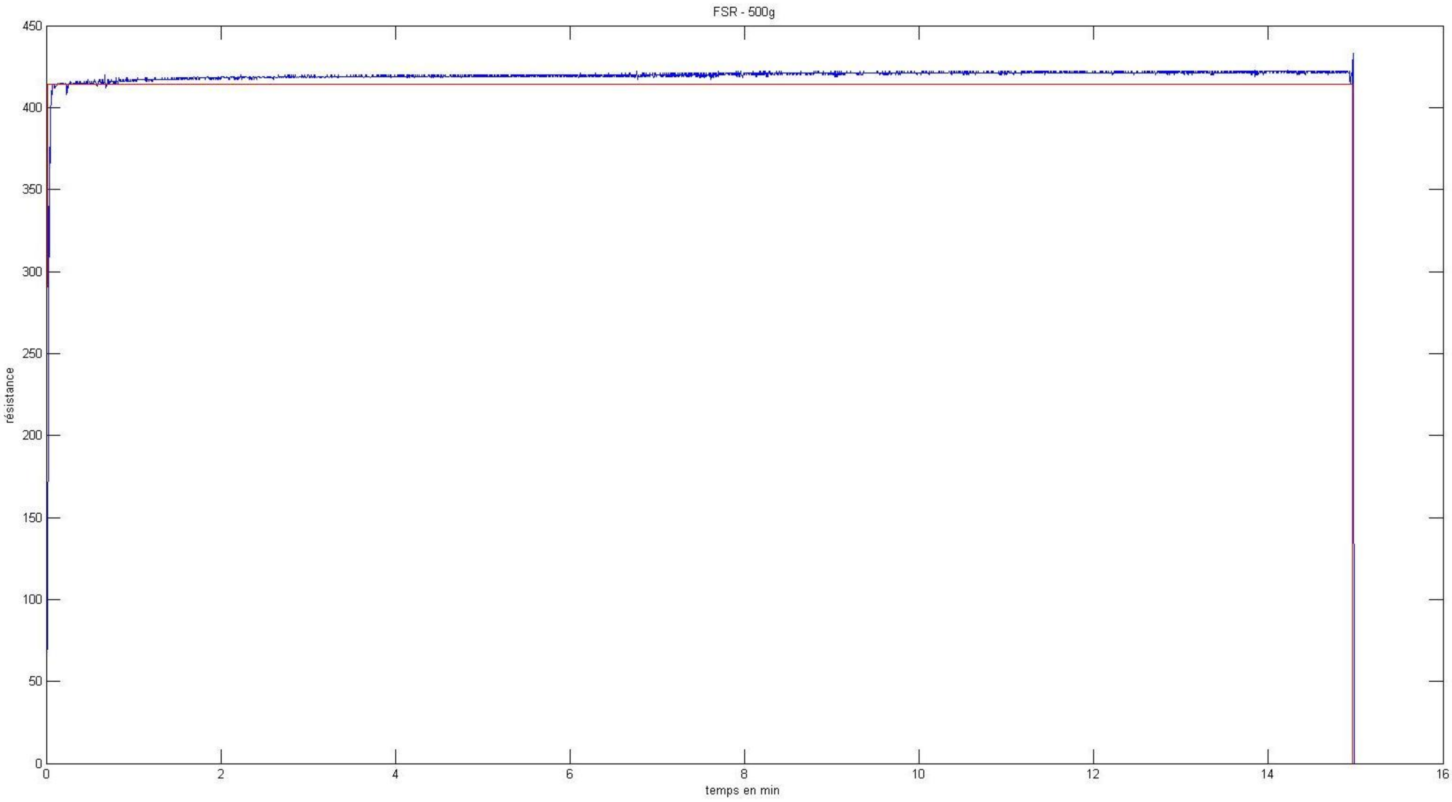
Ci-dessous les graphes globaux des comportements des capteurs :

1er graphe : valeurs obtenus avec un FSR et un poids de 500g

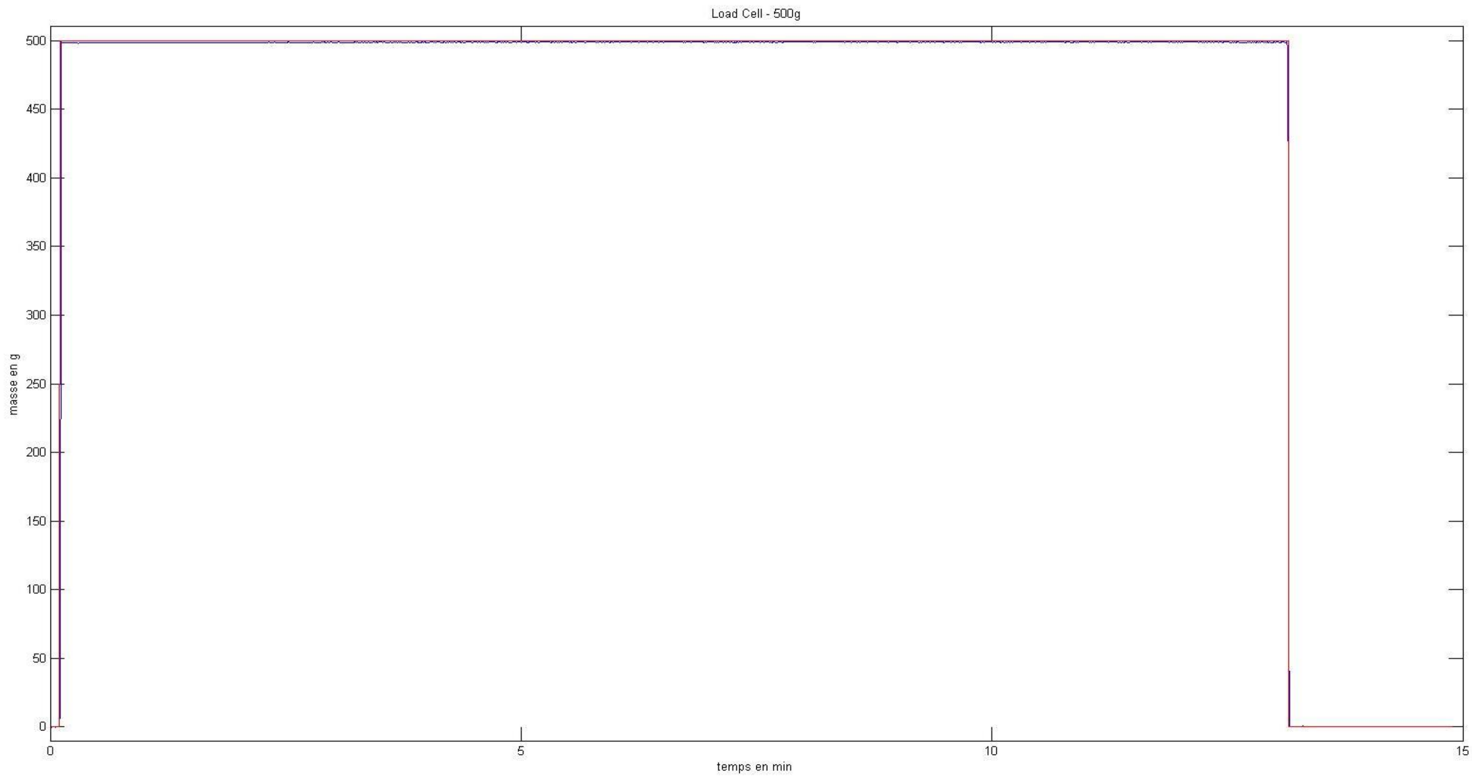
- en bleu : valeurs obtenues (résistance)
- en rouge : première valeur obtenus lorsque j'ai posé le poids pour mettre en évidence l'augmentation des valeurs au cours du temps.

2éme graphe : valeurs obtenus avec une load cell et un poids de 500g

- en bleu : valeurs obtenues (masse en g)
- en rouge : valeurs que l'on devrait obtenir.



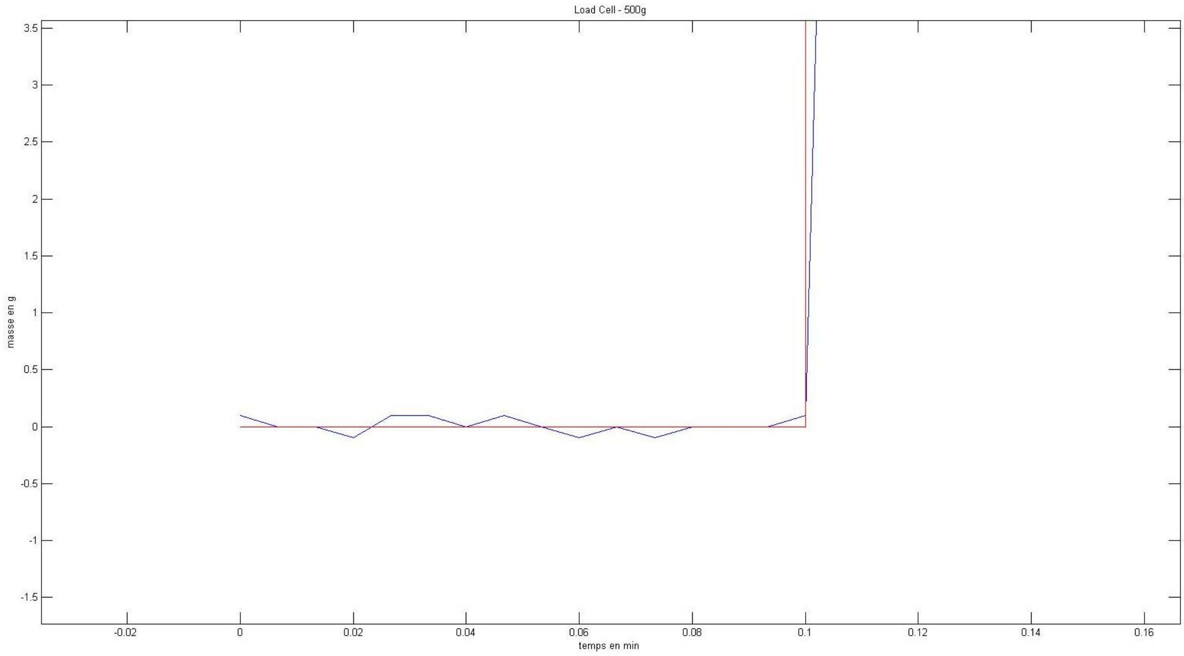
FSR - 500g
résistance
temps en min
0
50
100
150
200
250
300
350
400
450
2
4
6
8
10
12
14
16


Load Cell - 500g
500
450
400
350
300
250
200
150
100
50
0
masse en g
0
5
10
15
temps en min

Pour mieux voir ce qu'il se passe, on va comparer les comportements selon différentes sections :

1. le zéro du début

Les premières valeurs du FSR étaient 0 contrairement à la load cell qui nous donne des valeurs variant entre -0,1 et 0,1 (cf. ci-dessous)



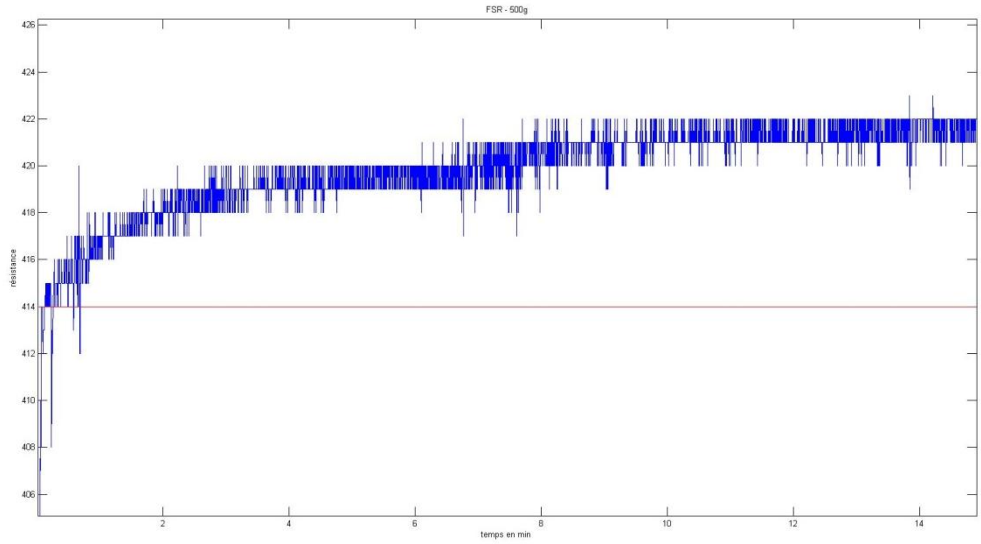
2. l'ascension

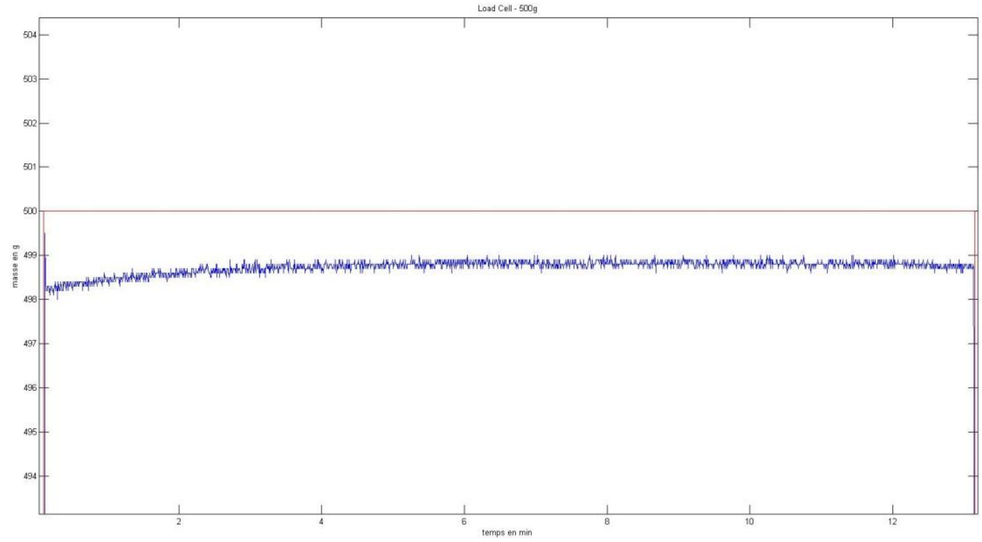
Bonne réactivité pour les deux capteurs

3. la précision sur la valeur du poids

On remarque que les valeurs du FSR augmentent au cours du temps alors qu'elles sont à peut près constantes pour la load cell.

De plus, le FSR présente beaucoup de bruit et de variation, la load cell est plus linéaire.



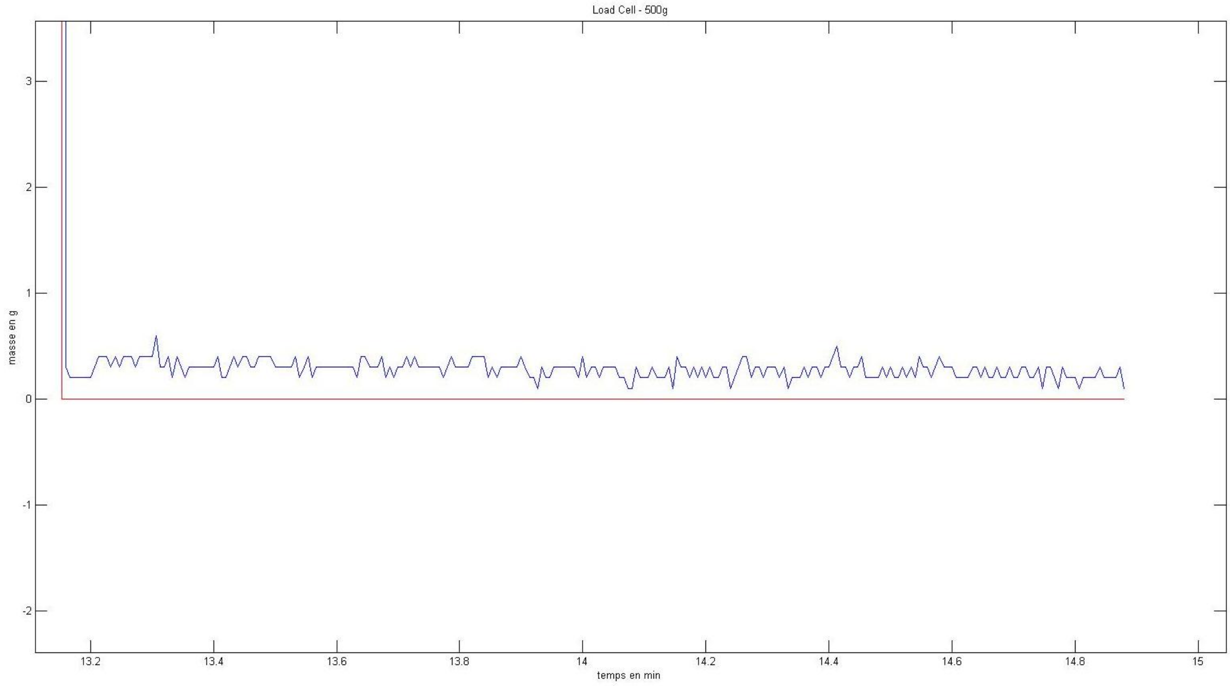


4. la descente

Bonne réactivité pour les deux capteurs

5. le zéro de la fin

Dès le poids retiré, on retrouve des valeurs nuls pour le FSR et une oscillation pour la load cell. Cependant, cette oscillation ne se fait pas autour de la même valeur que celle du début : on obtient une oscillation décroissante entre 0,4 et 0,1.



AVANTAGE DES LOAD CELL :

- pour 5 FSR 1 seule load cell suffit. (load cell à 50kg)
  - ⇨ seulement 2 load cell nécessaire (économie ?)
- calibration : 1 paramètre à changer

INCONVENIENTS :

- montage des capteurs sur la structure
- le comportement de la courbe sur la phase finale peut être dû au fait que les jauges mettent du temps à rependre leur forme initiale
- load cell de 50kg sensible à partir de 750g

AVANTAGE DES FSR :

- sensible de 10 g à 10kg

INCONVENIENTS :

- variabilité au cours du temps
- étalonnage

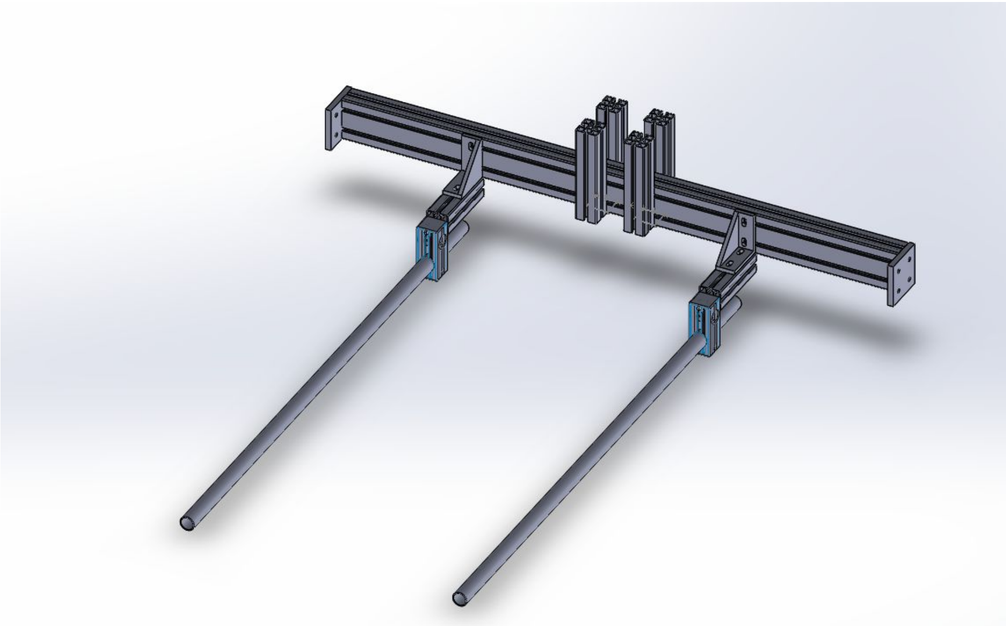
Appendix F

Description of the framework design

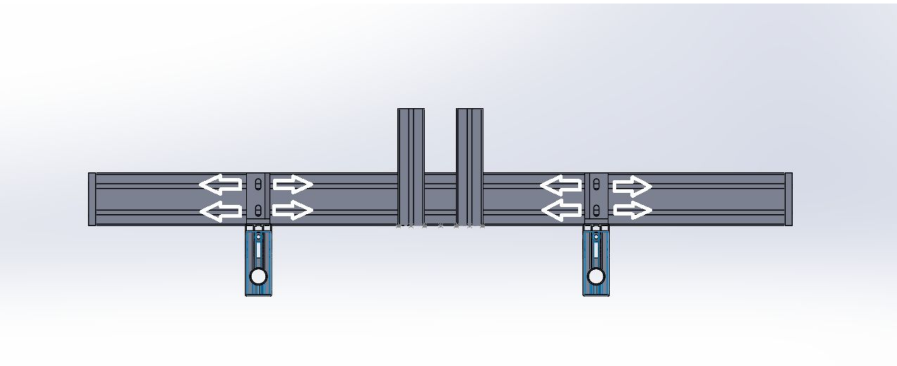
In the following pages you can find some explanations about the framework.

3D plan of the framework

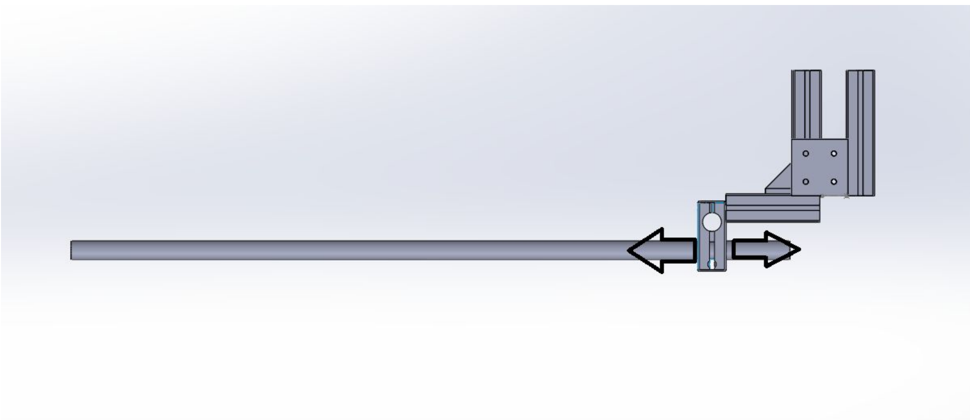
Bati



Support _ Bras _ écran

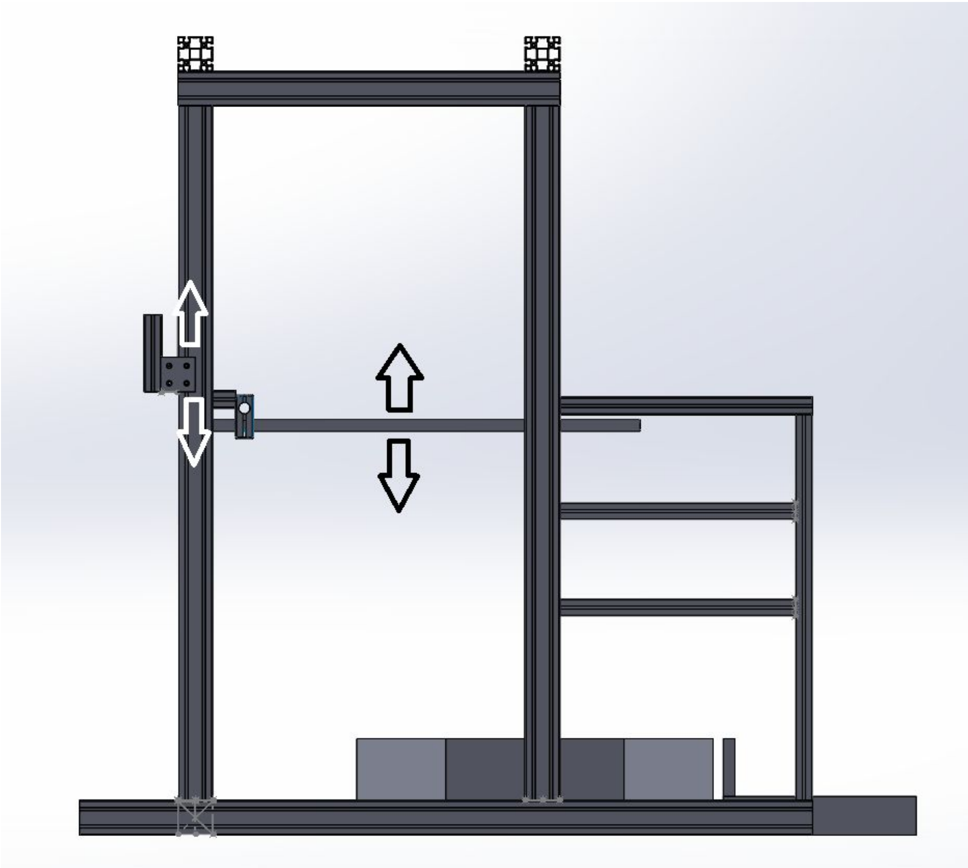


Slide links in order to adjust handles according to the patient.



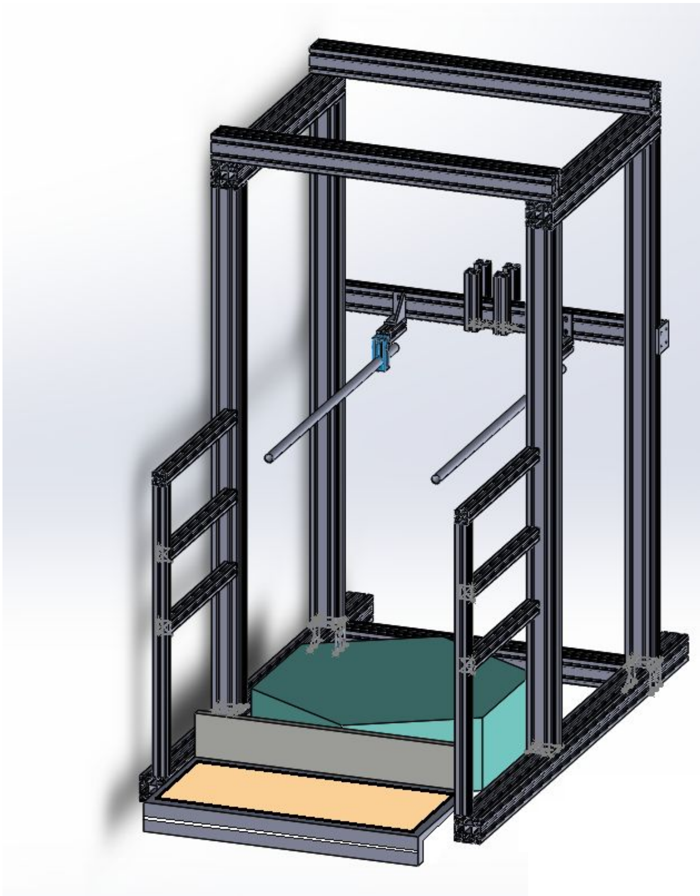
Particularités

Same kind of link to adjust the height of the screen and the handles.



Particularités (suite)

Final framework :

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