Universidad de Alcalá
Escuela Politécnica Superior

Grado en Ingeniería Telemática

Trabajo Fin de Grado

Android-based application for monitoring the rehabilitation of patients with breast cancer

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2021

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FECHA: Enero 2021

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January 20, 2021

Acknowledgements

Gracias a mi familia por permitirme tener la oportunidad de formarme, no solo en España sino además haberlo hecho en el extranjero en múltiples ocasiones. Gracias a ellos por darme todo el apoyo y el ánimo necesario durante los peores baches y las mejores alegrías, sé que sin ellos esto no hubiese sido posible.

Además, doy gracias a la carrera por haber cruzado en mi camino a personas tan maravillosas, mis amigos. Somos una gran familia, son los que más me entienden con el sufrimiento y presión que tiene la Ingeniería, pero además los que más disfrutan conmigo las alegrías. Gracias a ellos por hacer toda la etapa universitaria más amena y divertida. Pero sé que esto no acaba aquí, nos quedan muchas más aventuras por vivir juntos.

Por último, no podía olvidarme de uno de mis pilares fundamentales durante toda esta etapa, mi pareja. Gracias por apoyarme en todo, por celebrar todas las noticias buenas, pero también, por aguantarme en mis caídas y levantarme de ellas con más fuerza.

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Resumen

Hoy en día, el cáncer es una enfermedad muy común. Los pacientes necesitan mucho apoyo psicológico, una rutina terapéutica y un gran seguimiento por parte del personal sanitario. Acerca del cáncer de mama, éste tiene una alta probabilidad de ser superado en comparación con otros tipos de cáncer. Esta enfermedad conlleva, en muchos casos, la extirpación de la mama afectadaa lo que requiere rehabilitación para recuperar la movilidad en la zona.

En este proyecto, vamos a desarrollar una aplicación basada en Android para el teléfono móvil con el fin de ayudar a los médicos y pacientes en la rehabilitación desde casa. Con la ayuda de esta aplicación y algunos sensores que los pacientes tienen que colocar en sus brazos, será posible monitorizar los ejercicios y proporcionar una retroalimentación sobre el desempeño. Esto les ayuda a recuperarse evaluando el ejercicio inmediatamente. De esta manera, se pueden mostrar los errores en la ejecución de estos.

Summary

Nowadays, cancer is a very common disease. Patients need a lot of psychological support, a routine and a lot of follow-up by healthcare personnel. Focusing more on breast cancer, it has a high probability of being overcome compared to other types of cancer. This disease leads, in some cases, in a breast removal, which leads to rehabilitation to recover mobility in the area.

In this project, we are going to develop an Android-based application for the mobile phone to help doctors and patients in rehabilitation from home. With the help of this application and some sensors that patients have to place on their arms, it will be possible to monitor the exercises and to provide a feedback about the performance. This helps them to recover by evaluating the exercise immediately. In this way, errors in the execution of the exercises can be shown.

Key words

- Breast cancer
- Android application
- Sensors
- Bluetooth
- Firebase

Chapter 1

Introduction

1.1 Motivation

The rehabilitation is the care that patients receive in order to maintain or to improve their capacities. These capacities are needed for their daily life, and can be physical, mental or cognitive. They can be lose by an illness, or by a secondary effect of a medical treatment.

The rehabilitation general objective is to help patients to recover their capacities or their independence. But depending on the patient, the objectives will be different as they have different problems, and causes.

There are different types of rehabilitation treatments, some of them use machines, devices or sensors, but other ones not. So depending on what kind of rehabilitation the patient is going to need, the rehabilitation is developed in different places, such as an hospital, an rehabilitation center or at home [1].

At the first stages of the rehabilitation process, the patients go to the centers, so they are under the supervision of an expert. Patients are supervised by the experts. Depending on how the patients improve, the experts will take in consideration if the patients can go home or if they has to come back. In case the patients are sending home, they will have to continue doing exercises in order to get the full recovery.

Usually, doctors give patients instructions (printed on a paper) of the exercises that they have to performed at home. But when patients are at home, most of them do not remember the correct way of doing the exercise, or with how much speed should be done. Indeed, they do not know if they are doing right or not because there is no one checking on them.

The project is focused on patients who suffer breast cancer removal, where the rehabilitation is really important for the patient. It helps to restore arm and shoulder movements, as these parts are tauter after the surgery. In addition, after the breast removal, the affected area of the chest or arm may become inflamed, this is because some lymph nodes have been removed, so, in consequence, there would be fewer lymph nodes to filter out the lymphatic fluid, which causes the inflammation of the area. So, if patients want a full recovery, all the exercises have to be done perfectly and periodically.

1.2 Global Overview and Objectives

This project is developed in the University of Alcalá in the framework of the FrailCheck project, advised by physiotherapist from both University of Alcalá and Ramon y Cajal Hospital.

The main objective is to provide a mobile application to the patients to assist them in performing the rehabilitation exercises. The patients have the exercises with all the instructions in an app. By means of this app, they can watch a video showing how to do the exercise, so they are guided during all the workout, but they also have a timer to control the time.

The project is focused on patients who have suffered breast cancer removal, so does the application. Doctors have to register their patients with their username, which is the ID, and a default password. Patients which are previously registered by their doctors are the only ones who can enter into the application. Figure 1.1 shows a diagram of the project.

The application is divided into different parts, one where the patients choose the stage, and other one with the exercises to be done. There are a few recommendations showing the correct order to perform the exercises (first of all stage one, then stage two, and finally stage three), but this is not mandatory, the patient can change it depending on his/her necessities. Usually, at the next stage, the exercises will start to become harder until they get to the final stage. When this last step is completed, it will be stated that the patients have reached their final target. For example, if the final goal is to reach an arm amplitude movement of 90 degrees, the patients will start with a reduced amplitude degree, increasing it stage by stage.

In order to have the records of their exercises, some sensors are going to be used, they are called IMUs (Inertial Measurement Units). As this sensors have to be placed by the patients, an image is going to be provided within the app with the concrete spots where the sensors should be located. Once they are placed in the patient's body, they have to be connected via Bluetooth with the application, so the data that is picked up by them is stored in a database (using Firebase). In addition, the application will show an immediate feedback to inform the patients if the exercise was developed right or not. In case that it is not, the patients will have to repeat the exercise, until they get a positive feedback.

Doctors can see their patients improvement by accessing the database through Firebase. So they can give their patients a feedback about the improvements and failures at the next appointment.

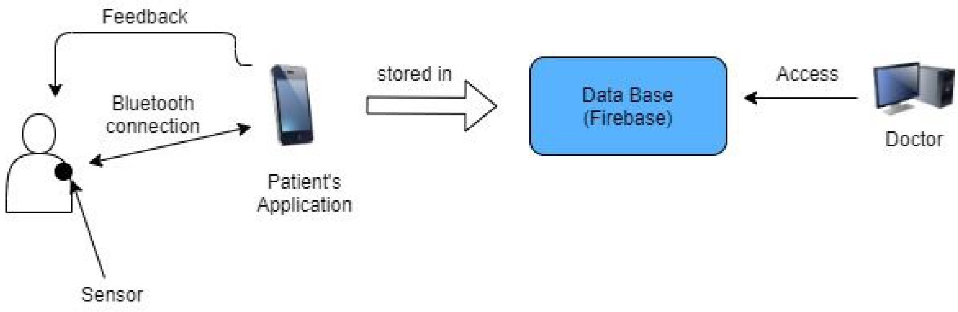


Figure 1.1: Overview

1.3 State of Art

1.3.1 Health Applications

The advance of medicine has always gone hand in hand with technology. In this context, the challenge of engineers has always been to provide the necessary technology to support health experts in improving diagnoses or the precision of operations. For example, with the help of cameras, machines, etc. In the same way, the emergence of smartphones has led the growth of application for both patients and doctors.

For example, IDoctus [2], which is developed for doctors, is an application that provides access to a big database full of information about diseases. Doctors can check symptoms and treatements of diseases looking into this database. IDoctus helps to get a more precise diagnosis. On the other hand, there are applications focused only on patients. For example, another tool called Universal Doctor Speaker [3], helps patients to understand better what their doctor just told them. It works like a translator, but in addition, it also helps patients to know which health problem they could have with their current symptoms.

Moreover, there are also a lot of applications aimed at doctors and patients. For example, ConsultorioMovil [4], it is developed as a chat between patients and doctors. Patients can receive automated telemedicine, care and monitoring services during their medical treatments. They can ask for an appointment through the app, or they can even consult their personal medical file. On the other hand, doctors can register new patients through the app or through the web, so they can check their medical files.

In times of pandemic, this last example of application is really useful. Patients having online appointments, it reduces infection risk.

Furthermore, there are a lot of applications which are developed to treat one specifically disease, instead of making a general health application.

1.3.2 Cancer and Rehabilitation Applications

Nowadays, there are a lot of studies and applications about cancer. Among all types of cancers, this project focuses on breast cancer, a disease that happens more frequently to women than to men. However, there are studies which show that during the first five years after the diagnosis, the mortality is higher in men than in women [5].

As this is a very common disease, there are a lot of applications and articles which try to help the patients along their paths. That help focuses on their physical recovery, on their mental health, or even on the previous detection of the disease (which helps to decrease the mortality).

For example, one of those articles [6] explains an application where the patients are connected with their doctors. Patients upload any relevant information or anomaly that they have noticed. With that information, the application automatically scores the risk of breast cancer. Doctors can read that information about their patients, so they can assess them. This will potentially encourage people to do more frequently self-examinations.

Another example on how to help patients is: assist them following a diet and doing sport, i.e. to have a correct lifestyle according to their necessities [7]. This study explains the fact that exists a variation in breast cancer incidence and in the mortality rates depending on geographic factors (involving regional and cultural differences in diet and lifestyle). Although, there are already many applications that do this function (establishing diets, workout plans, etc), these are not suitable for people with special medical conditions. This article focuses on specific dietaries, workouts and mental plans for breast cancer patients. These plans depend on the stage of their treatment.

Moreover, the importance of the mind in the whole disease process should not be overlooked. These kind of patients need a lot of emotional support, their mental attitude is crucial to overcome the illness. To help them during all the path, the application Contigo has been created [8]. This application focuses on emotions and it cares a lot about explaining how the process is going to be, so the new patients can understand everything and stay calm. It is a guide where sixteen women talk about their personal experiences encouraging others that are going through the same.

Once a disease has been diagnosed, there exists a rehabilitation process, which starts at the hospital, but later on it takes place at home. When patients leave the hospital they are no more under the supervision of any expert, which can conduct to a state of relaxation. This leads to a bad execution of the exercises, and in consequence to an extension of their rehabilitation process. For example, among other applications, there is one focused on a knee joint rehabilitation. It shows the patients a table with all the exercises, indicating the speed, repetitions, level and intensity of the exercises [9]. This application is really helpful for the patients because there is not any chance for them to forget how to perform the exercises or do them in a wrong way.

1.3.3 Technology

Sensors

A sensor is a device which catch physical magnitudes from the environment such as temperature, sound, light, speed etc. The sensors are used for a lot of equipments: microphones, speedometer, thermometer, accelerometers, cameras, GPS, etc.

At the health field, a lot of sensors are used to monitor the patients. All the information that the sensors pick up, are send to other devices to process the data and make it readable for doctors [10]. Some example of sensors that are used in the health field are the following:

- Medical electrodes: These types of sensors conduct electricity from a device to the patient (which is in a surgery or is receiving a medical treatment). But the electrodes can also catch the electrical signals from the muscles, organs, or other parts of the body, and display that signals in a screen. Electrodes help to the diagnosis [11].
- Optical fibres: These kind of sensors are really flexible and thin. They are introduced through little human cavities, or through little incisions in order to get to the sick area [12].
- IMUS: These sensors are used to measure the patients movements, such as in rehabilitation.

As it is explained, there are a lot of different types of sensors that are used in health field. For this project IMUs (Inertial Measurement Unit) sensors are going to be used. These are special types of sensors which measure angular rate, force and sometimes magnetic field, they have 3-axis accelerometer and 3-axis gyroscope and 3-axis magnetometer [13].

The sensors need to be connected to the mobile phone (where the application is running) in order to send the data. To do so, there are two ways: USB and Bluetooth. The latter (Bluetooth) is more expensive than the first one, but it is worth it because it is a wireless connection, so the wires do not disturb the patient while doing the exercise [14].

The latest version of Bluetooth is 5.0, and it is only compatible with devices that have the same version. It has a lot of improvements in comparison with the previous version, one of them reduces energy consumption of the wireless devices that are connected. The other one, for example, consists in two headphones that can be connected to the same device while listening to different songs.

Electronic Devices: mobile phones

Nowadays, there are different types of mobile phones with different types of operative systems. The two most well known are: Android and IOS (Apple operative system).

They have some differences such as: Android users have permissions to customize their phones, while IOS not. Android can have more problems because it is an operative system which is used for more manufacturers than just Apple in the case of IOS. So, as they have advantages and disadvantages, it is up to the users to choose which one is better for them.

In this project, the application is going to be developed with Android Studio platform. The latest version of android studio is the 4.1, released on October of 2020. However, they are working on the version 4.2. This platform is used in order to develop applications in Android [15].

Data Storage

When the connection via Bluetooth between the application and the sensors is established, the application starts receiving information from the sensors. All that information can be stored at a database. There are a lot of different programs that manage databases, some examples are: MySQL Database, SQL Server, Firebase...

In this project is going to be used Firebase. It is a Backend-as-a-Service — BaaS — which grew up into Google Cloud Platform.

The main positive differences, between Firebase and other programs, are that Firebase sends new data as soon as it is updated, while others wait until the user asks for the information. Other advantage is that the application is connected to Firebase through a WebSocket which is much faster than HTTP (what others programs do). Another advantage is its authentication, directly included in Firebase database (so it can be used to control the access to the data). One disadvantage is that there are limited queries because of its data stream model [16].

Chapter 2

Methods

2.1 Breast cancer rehabilitation exercises

The following stages and exercises are part of the rehabilitation program carry out by the Ramon y Cajal Hospital (the authors have given us permission to use the photos and videos of the exercises). These exercises has to be followed by the patients [17].

These exercises should be started on the day after surgery, with some limitations in the immediate postoperative period (7-10 days) so as not to increase the amount of surgical drainage and seroma formation. The exercises will therefore be carried out in three phases.

2.1.1 Stage 1

This stage should be perform during the first seven or ten days after the surgery.

Instructions: The movements of the shoulder should be restricted by avoiding raising the arm above 90°. Feeling any "discomfort" while performing them is considered to be natural. Exercise slowly, minimizing discomfort. If any of the exercises cause extreme pain, stop and start again in a couple of days. If the issue continues, check with the clinicians who are treating you. If you think it is important, you can also do the exercises sitting down. IMPORTANT: during the execution of all exercises.

- Hold your back straight all the way.
- The head is expected to be in line with the body, looking straight ahead.
- Do not move your neck or turn your head when exercising
- Keep the muscles of your abdominal and pelvic floor clenched during exercises.

Exercise 1: Shoulder lift

Starting position: standing, facing forward, the legs detach from each other and the arms along the body. The palms face each other. Hold your back straight all the way. Exercise: lift the shoulders upwards, hold on for 5 seconds and return to the starting point. Start with 3 repetitions and progress to 5 repetitions in the next few days. Exercise four times a day.

Figure 2.1: Stage1: Exercise 1

Exercise 2: Elbow bending

Starting position: palms facing forwards.
Exercise: Bend the elbows. Bring the hands to the shoulders on the same side. Don't move your neck around. Keep the spot for 5 seconds and go back to the starting point. Start with 3 repetitions and progress to 5 repetitions in the next few days.

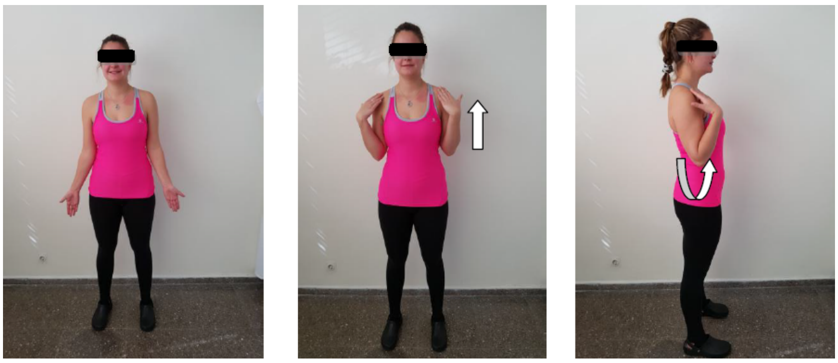


Figure 2.2: Stage1: Exercise 2

Exercise 3: Arm twist with elbows outstretched

Starting position: arms a little apart. Palms looking ahead.
Exercise: slowly turn your arms around so that the palms of your hands face backwards, without turning your body. Keep for 5 seconds and go back to the starting point. Start with 3 repetitions and progress to 5 repetitions in the next few days.

Figure 2.3: Stage1: Exercise 3

Exercise 4: Arms elevation to the horizontal with elbows bent

Starting position: elbows bent and attached to the body. The tips of the fingers touch the shoulders on the same side, the arms pointing backwards. Back straight.
Exercise: Slowly direct the elbows forward and upwards while touching the shoulders with the fingers. DO NOT raise your elbows above shoulder level. Do not lean your body to the side. Hold for 5 seconds and return to the starting position. Start with 3 repetitions and progress to 5 repetitions on the following days.

Figure 2.4: Stage1: Exercise 4

Exercise 5: Separation of arms up to the horizontal with the elbows bent. (This can only be done if the surgeon authorises it.)

Starting position: standing facing forward, elbow bent and fingertips touching the shoulders. Go back straight.
Exercise: slowly lift your elbows upwards, separating them from your sides as your fingertips touch your shoulders. You must not raise your elbows above shoulder level, nor must you tilt your body to the side. Keep this position for 5 seconds and go back to your starting position. Start with 3 repetitions and progress to 5 repetitions in the next few days.

Figure 2.5: Stage1: Exercise 5

Exercise 6: Shoulder extension

Starting position: standing, facing forward, the legs detach from each other and the arms along the body. The palms face each other. Hold the back straight all the way. Don't lift the shoulders.
Exercise: Gently move the arms backwards. Keep this position for five seconds and return to the starting position. Start with 3 repetitions and progress to 5 repetitions in the next few days.

Figure 2.6: Stage1: Exercise 6

2.1.2 Stage 2

After the first seven or ten days, this is the next stage. In this step, the patient will move forward, moving beyond the initial 90 degrees, using aids such as a table, a stick or a wall to make it easier to complete the movement. This process is going to last 10-15 days.

Exercise 1: Arm separation

Starting position: sitting on a chair with the back straight, lean the hand on a folded towel, on top of a table next to you.

a. Slide the towel forward on the table, separating your arm from your body. Hold for 5 seconds and return. Slide the towel to one side. Hold for 5 seconds and return. Slide the towel backwards. Hold for 5 seconds and return. Repeat each movement 5 times.

b. Make a combined movement by sliding the towel in a sweep: front-to-side-back and back-to-side-forward. Repeat 5 times.

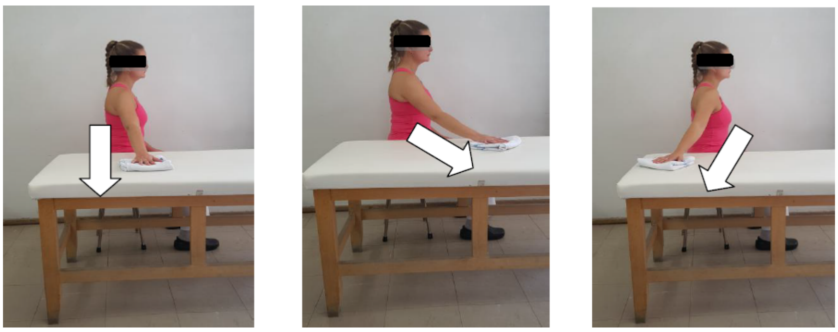


Figure 2.7: Stage2: Exercise 1

Exercise 2: Self-passive

Starting position: Lying face up with knees bent. Feet slightly apart. Holding a stick with both hands. Elbows bent with the stick close to the chest.

a. Stretch the arms and raise the stick up to the ceiling. Hold for 5 seconds and return. Repeat 5 times.

b. Arms stretched with the stick up. Bring the stick back, (towards the head) and then down (towards the knees). Hold for 5 seconds. Increase the direction of movement according to tolerance. Always keep your shoulders in contact with the table during the exercise. Repeat 5 times.

Figure 2.8: Stage2: Exercise 2

Exercise 3: Walk on the wall

Starting position: standing in front of a wall. Keep your back straight and your core active.

a. Walk with your fingers along the wall. Walk upwards until it is tolerable. Keep on for 5 seconds and walk down slowly. Repeat 5 times.

b. Carry out the exercise above but stand sideways on the wall to move your fingers up and down. Repeat 5 times.

Figure 2.9: Stage2: Exercise 3

2.1.3 Stage 3

Once the second stage has been completed, stage 3 is the next step. In this phase, the goal is to reach the complete movement of the shoulders.

Exercise 1: Complete arm lift

Starting position: standing facing forward. Arms forward and fingers interlaced.
Exercise: Raise your arms above your head. Keep the elbows straight. Do not arch the back. Keep on for 5 seconds and return to the starting spot. Start with 3 repetitions and progress to 5 repetitions in the next few days.

Figure 2.10: Stage3: Exercise 1

Exercise 2: Complete lateral arm lift

Starting position: standing facing forward. Arms apart and hands forward.
Exercise: Separate your hands and arms from your trunk. Bring your arms up to touch the edges of your hands. Do not bend the trunk or the elbows. Hold the position for 5 seconds and return to the starting position. Start with 3 repetitions and progress to 5 repetitions on the following days.

Figure 2.11: Stage3: Exercise 2

Exercise 3: Elbows separation with the hands on the head

Starting position: elbows bent and facing forward. Hands behind the neck.
Exercise: Bring the elbows out and back without raising the shoulders. Keep the palms of your hands behind your ears. Hold the position for 5 seconds and return to the starting position. Start with 3 repetitions and progress to 5 repetitions on the following days.

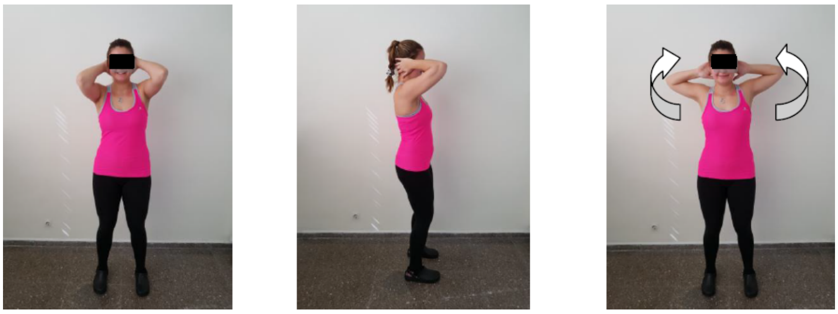


Figure 2.12: Stage3: Exercise 3

Exercise 4: Hands behind the back

Starting position: standing, with arms apart and palms facing backwards.
Exercise: Bring your hands behind your back until they touch. Bend your elbows as far as you can, trying to keep your hands together. Hold for 5 seconds and return to the starting position. Start with 3 repetitions and progress to 5 repetitions on the following days.

Figure 2.13: Stage3: Exercise 4

2.1.4 Tips and Clarifications

According to the Ramon y Cajal Hospital, these are the general tips after a breast removal [17]:

- Feelings like tingling, puncture or even an increase of the sensibility of the skin, are normal. These sensations tend to disappear over time.
- It is convenient to put some cushions or pillows under the armpit in order to keep the arm separated from the body, avoiding the shoulder stiffness. Moreover, this helps to the transport of the lymphatic liquid.
- Bands of tissue can appear in the armpit (they will disappear). They produce an irritating sensation of tautness when the rehabilitation exercises are done. These exercises can help to overcome the pain, and to recover the mobility of the arms.
- If three weeks after the surgery, there exists an intense pain or a limitation of the arms mobility, the doctor will refer to the rehabilitation's room.
- The exercises should be done everyday until the arm's mobility is similar than before.
- Do not drive during the first two weeks after the surgery.
- If six weeks after the surgery the scar is well healed, the patient can swim unless he/she is receiving chemo or radiotherapy treatment. Other kind of sport can be practised two months after the surgery.

2.2 Study Population

Due to the current situation, it has been impossible to perform any test in a hospital with real patients with breast cancer. However, the tests have been carried out by healthy people. These people are from my family, from the university, or simply me.

In the future, the participants to validate the application will be patients from the Ramon y Cajal Hospital (Madrid, Spain). These patients have been operated due to breast cancer, and their doctors have allowed them to do these rehabilitation exercises. To validate this application, there is no specific age or gender, because the only requirement is to have been operated recently.

For this study, the research team has applied for the Ethical Approval to both Guadalajara University Hospital and University of Alcalá Ethics Commitees.

Chapter 3

Materials

In this project, some materials are going to be used for developing the application and the rehabilitation correctly. Those materials are: sensors and a mobile phone.

3.1 Computer

In order to create the application, a personal computer is needed. The PC needs to have Windows or Mac as the operative system, and the Android Studio application installed (version 4.0.1).

3.2 Mobile Phone

As the application is developed in Android, the telephone must have Android as the operative system (version 5.0). The telephone must have Bluetooth connection, otherwise the patient will not be able to perform the exercises at home. This is necessary because if not the results of his/her exercises are not going to be saved, so the doctor would not know if the patient is doing right or not.

In addition the telephone should have WiFi (and it has to be activated), otherwise the data cannot be stored in the database.

3.3 Sensors

3.3.1 Theoretical Concept

The sensors that are going to be used are called IMUs (Inertial Measurement Unit). They are the measurement unit of the inertial systems. An inertial system is a coordinate system in which bodies move uniformly in a straight line, but there is no force acts on them. This is what is called inertia, when a body keeps moving, but there is no force acting on it. These inertial systems should be taken into considerations within a reference system. So depending on the reference system that is chosen, the bodies will be considered: in movement or motionless.

IMUs are used mostly in navigation systems, so the data that is picked up by the IMUs sensors, let the computer knows where is located the body. These types of sensors are very useful for knowing the exact bodies location every moment [18].

But, in the last few years, IMUs are more used in the health field. They are being used to monitor the different movements of the patients with different diseases, or for athletes in order to quantify their training results and their improvements.

Inertial sensors respond to motion of the sensor itself. As it is said in subsection 1.3.3, these sensors measure angular rate, force and sometimes magnetic field. They have 3-axis accelerometer and 3-axis gyroscope and 3-axis magnetometer.

The gyroscope sensor measures angular rate, which is expressed in degrees per second. This sensor helps to track changes in orientation. It is also known as angular velocity sensor.

The accelerometer sensor measures acceleration. There are two types of acceleration that are measured, one caused by device motion and other one due gravity. It is expressed in g's (G). They measure the static orientation of the device, which is done computing the angle of the device compared to gravitational force.

An accelerometer can measure gravity when the device is motionless, or with a gyroscope during motion cycles. For example, there are phone with gyroscope sensor which have more precise gravity measurement when the phones are in use, and a quicker response time to rapid orientation changes.

In addition, IMUs experiment changes in their measurement output. So, for that reason, a calibration is needed at the very beginning and periodically during the use of the sensor [19].

3.3.2 IMU BWT61

IMU BWT61 is the sensor that is going to be used in the project. It has an accelerometer and a gyroscope sensor, but no magnetic one. The Figure 3.1 shows the IMU BWT61.

The axis of the module are shown in the figure above. In order to know in which axis is the sensor rotating, the Law of the right hand is implemented. So, the direction of rotation around the axis is the four-finger bending direction. And the thumb points at the axis.

Moreover, the Law of the left hand it is also used in order to know where are the axis located. Being he thumb the Z-axis, the index finger is the Y-axis, and finally the middle finger is the X-axis.

The manufacturer provides an application which can be installed on the PC and on the phone, so the

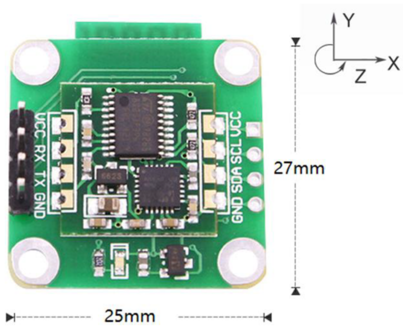


Figure 3.1: IMU BWT61 sensor, dimensions and axis [20].

sensor can be tested. First of all,the sensor has to be connected via Bluetooth with the PC or with the phone. A password (1234) is asked for matching with the sensor (which name is "HC-06"). The user knows that the sensor is connected to the phone or to the PC when its red light is not flashing.

Once this is done, the screen shows data that the sensor is sending to the application. That data are: acceleration, angular velocity, or the angle (all of them given in the three axis (X, Y and Z)).

In order to establish the coordinate system centering at (0,0,0), the X, Y and Z axis have to be calibrated. For doing this, the module needs to be static, and the calibration process has to follow an order, being X and Y axis the first ones, and Z axis the last one. The application also has a button to calibrate X, Y and Z axis.

When all these steps have been completed, a communication between the PC and the sensor starts. The first instruction that is needed to be sent from the PC to the module, is the calibration in every axis. After that, some additional settings such as horizontal or vertical installation of the module (the default position is horizontal) have to be done. In addition, the PC can send to the module an instruction to enter the standby state from the working state (Dormancy), or the other way around, from the standby state to the working state (Break dormancy), this is done when the user want to stop sending data to the PC or when the user want to restart receiving data. In Table 3.1 the sensor settings can be observed.

Instruction content	**Function**	**Remark**
0xFF 0XAA 0X52	Angle initialization	Z axis to 0
0XFF 0XAA 0X67	Accelerometer calibration	X, Y axis to 0
0XFF 0XAA 0X60	Dormancy/Break dormancy	Standby state/working state
0XFF 0XAA 0X65	Horizontal instalation	Horizontal placed
0XFF 0XAA 0X66	Vertical instalation	Vertical placed

Table 3.1: Instructions from PC to module [21].

The sensor sends 33 characters all the time to the PC. It starts when the device is connected via Bluetooth. The data have to be processed by the PC in order to understand the information.

Those 33 characters represent: Acceleration output, Angular velocity output, and Angle output (11 characters for each of them, creating three arrays). The array's positions are from 0 to 10, being 0 the head of the frame, which value is 0x55 in hexadecimal, and 85 in decimal value (is the same value for the three arrays). This is done for detecting the correct three frames which are been looking for. After that, in order to distinguish between the three of them, the character at the position 1 tells what frame it is. Being 0x51 (81 in decimal) for the acceleration output, 0x52 (82 in decimal) for the angular velocity output, and 0x53 (83 in decimal) for the angle output. The following values (show in Tables 3.2, 3.3 and 3.4), are the valid data that has to be processed.

Data number	Data content	Implication
0	0x55	Header of packet
1	0x51	Acceleration packet
2	AxL	X axis acceleration low byte
3	AxH	X axis acceleration high byte
4	AyL	Y axis acceleration low byte
5	AyH	Y axis acceleration high byte
6	AzL	Z axis acceleration low byte
7	AzH	Z axis acceleration high byte
8	TL	Temperature low byte
9	TH	Temperature high byte
10	Sum	Checksum

Table 3.2: Acceleration output [21].

Data number	Data content	Implication
0	0x55	Header of packet
1	0x52	Angular velocity packet
2	wxL	X axis angular velocity low byte
3	wxH	X axis angular velocity high byte
4	wyL	Y axis angular velocity low byte
5	wyH	Y axis angular velocity high byte
6	wzL	Z axis angular velocity low byte
7	wzH	Z axis angular velocity high byte
8	TL	Temperature low byte
9	TH	Temperature high byte
10	Sum	Checksum

Table 3.3: Angular velocity output [21].

Data number	Data content	Implication
0	0x55	Header of packet
1	0x53	Angle packet
2	RollL	X axis angle low byte
3	RollH	X axis angle high byte
4	PitchL	Y axis angle low byte
5	PitchH	Y axis angle high byte
6	YawL	Z axis angle low byte
7	YawH	Z axis angle high byte
8	TL	Temperature low byte
9	TH	Temperature high byte
10	Sum	Checksum

Table 3.4: Angle output [21].

Chapter 4

Programming

4.1 Android Based Application

4.1.1 Structure

The application is divided into different parts:

- Log in: is where the user enters the ID and the password. The password has been given by the doctor. So only the patients that have been registered previously by their doctors can use the application.
- Change the password (optional): Once the user has logged in, the password can be change. This option is in the upper right part of the screen (three dots). To change the password the user has to enter its ID and the new password twice. If the user is in the database, the password will be change.
- Select the stage: In this part, the patient chooses which stage does he/she wants to do. There are three stages, which should be done in order, starting at Stage 1. Each stage has a different color depending if the whole stage has been completed or not.
- Exercises: Inside each stage there are few exercises. In each exercise the patient has access to a timer, to an image explaining where the sensor should be place, and to a demo video (where it is explained how the exercises is done). Moreover, the user can navigate through the exercise menu to move from one exercise to another. In each exercise a Bluetooth connection should be establish between the sensor an the mobile phone.
- Feedback: when the exercise has been completed, a feedback is displayed. It could be positive or negative, depending on how the patient has done the exercise.

All these parts are developed in Android Studio. They have two files: one in java, where all the code is written, and other one in xml where it is designed the application.

4.2 Bluetooth and Sensor communications

As it is said in section 4.1, when a patient enters into an exercise, a Bluetooth connection has to be established between the sensor and the mobile phone.

4.2.1 Looking for Bluetooth

The first thing to do is to check whether the mobile phone has Bluetooth or not. If it does, then the application will have to check whether it is activated or not. If it is not activated, the patient will be asked if he/she wants to activate it, and once activated, the sensor (which had to be linked previously with the mobile phone, HC-06) will be searched in the list of linked devices of the mobile phone. Once it has been found, it will establish the Bluetooth connection, showing a message to the user whether the connection has been made or not. However, in the case that the Bluetooth had been activated, it would be necessary to deactivate it and then establish the connection as explained. The following code shows how to check the Bluetooth.

```
btAdapter = BluetoothAdapter.getDefaultAdapter();
if(btAdapter == null) {
    Toast.makeText(getActivity(), "El bluetooth no se encuentra en
        este dispositivo", Toast.LENGTH_SHORT).show();
}
else if(!btAdapter.isEnabled()){ //Bluetooth is not activated

    requestBluetooth();//asks to activate the Bluetooth

    setupConnectionBT();//establishing connection

}
else{ //it has Bluetooth and it is activated

    btAdapter.disable();//deactivating Bluetooth
    requestBluetooth();
    setupConnectionBT();
}
```

```
private void requestBluetooth(){
    Intent enableBtIntent = new Intent(BluetoothAdapter.
        ACTION_REQUEST_ENABLE);
    startActivityForResult(enableBtIntent, REQUEST_ENABLE_BT);
}
private void setupConnectionBT(){
 ConstantsBWT61.btManagerBWT61 = new BluetoothManagerBWT61(
     getActivity(), bluetoothIn);
}
```

Every time the requestBluetooth() function is running, another function called OnActivityResult() runs. Within this function, a pop-up message shows up, this message asks to the user to activate the Bluetooth, if the answer is OK then the searching through the linked devices will start.

Once the connection is made, the mobile's Bluetooth will be kept waiting to receive information sent by the sensor. This is done with a handler and with a switch case structure. The cases are the states of the Bluetooth: connected (which value is 3), connecting (which value is 2), or listen (which value is 1). When the state is listen, is because the connection could not be make.

4.2.2 Sensor Settings

In the connected state, the application will proceed to set the settings into the sensors. These settings are the calibration of the three axis (X, Y and Z) and, if necessary, set the sensor in vertical or in horizontal. For these, three methods have been developed: setXYAxis(), setZAxis(), and setVertical(). In order to have a really good performance of the exercise, the sensor has to be configured perfectly. So for that reason, these settings are going to be perform not only in the connected state, but also at the beginning of the exercise (when the user clicks start button). The following part of code is an example of how to do one of these settings.

```
public void setXYAxis(){
    new Thread(new Runnable() {
        @Override
        public void run() {
            ConstantsBWT61.btManagerBWT61.write(new byte[]{-1, -86,
                ConstantsBWT61.SET_XY_ANGLE_TO_0});
        }
    }).start();
}
```

Inside write() function of the code above, there are three numbers, -1, -86 and the last one which is defined by ConstantsBWT61.SET XY ANGLE TO 0. The first two numbers are always the same, but the last one is different depending on what is the setting that want to be performed. These numbers are defined in Table 3.1. Although the numbers are written in hexadecimal in Tables 3.2, 3.3, and 3.4, in the code they should be written in decimal.

As it can be seen, the function run() makes reference to ConstantsBWT61. ConstantsBWT61 is a java file where some static variables are defined, these variables are used along all the project. However, this is not the only file that is used, BluetoothManagerBWT61 is a library created for the Bluetooth connection between the mobile phone and the sensor.

At the end of the BluetoothManagerBWT61 file there is a a function called Cope-

SerialData(). This function, which is divided into different cases, stores the data sent by the sensor into a float array (fData array) of thirty three positions (eleven for acceleration, eleven for angular velocity, and eleven for angle; as explained in 3.3.2). After storing the data in the array, the array is sent by a bundle to the handler defined in the java file where the Bluetooth settings are done. Once the array has been received, the data can be manipulated to obtain the desired final result. In the following codes, an example of the storage in the array and the bundle can be seen.

```
case 81: //este es el 51, aceleracion
    this.fData[0] = (((float) ((((short) this.frameBuffer[1]) << 8) |
        (((short) this.frameBuffer[0]) & 255))) / 32768.0f) * 16.0f *
        GRAVITY;
    this.fData[1] = (((float) ((((short) this.frameBuffer[3]) << 8) |
        (((short) this.frameBuffer[2]) & 255))) / 32768.0f) * 16.0f *
        GRAVITY;
    this.fData[2] = (((float) ((((short) this.frameBuffer[5]) << 8) |
        (((short) this.frameBuffer[4]) & 255))) / 32768.0f) * 16.0f *
        GRAVITY;
    this.fData[16] = ((float) ((((short) this.frameBuffer[7]) << 8) |
        (((short) this.frameBuffer[6]) & 255))) / 10.0f; //la
        temperatura
```

In the above code, some operations within case 81 can be observed. These operations are extracted from the sensor manual [21]. In the fData array, the temperature is also stored but in the sixteenth position. And, as it can be seen, although the tables settings are written with hexadecimal code (Tables 3.2, 3.3 and 3.4), the case number is written in decimal number (81 and 00x51 in this case for the acceleration).

Moreover, it always follows the same order, that is, the first position in each case is for the X-axis, then for Y-axis, and the last one for Z-axis.

GRAVITY is a global variable with value 9.8.

```
int SPEED = 1;
long lTimeNow = System.currentTimeMillis();
if (lTimeNow - this.lLastTime > SPEED) {
    this.lLastTime = lTimeNow;
    Message msg = this.mHandler.obtainMessage(ConstantsBWT61.
        MESSAGE_READ);
    Bundle bundle = new Bundle();
    bundle.putFloatArray("Data", this.fData);//envia el fdata es el
        array de 33 posiciones(aceleracion velocidad y angulo)


    bundle.putString("Date", this.strDate);//te pasa la fecha
    bundle.putString("Time", this.strTime);//te pasa la hora
    msg.setData(bundle); //al bluetoothIn del fragmento le llega el
        fData de este bundle
         this.mHandler.sendMessage(msg);
}
```

In the previous fragment of code, the speed in which the sensor sends data is determined by the second line of the code, that is, $lTimeNow - this.lLastTime > SPEED$, where SPEED is initialized to value 1, which means that the sensor sends data each millisecond. This frequency can be reduced or increased by replacing the number 1 by other number (bigger or smaller), in case there is an interest to send data slowly or fast.

Once the fData array is sent by the bundle, the manipulation of the data starts. This manipulation is done with the handler (it is defined in the java file where the Bluetooth connection has been established, it is called bluetoothIn). As it is explained before in this section, there are different cases inside the bluetoothIn handler. One of them is when the Bluetooth connection is done, so the application's Bluetooth is waiting to receive information sent by the sensor. That information that is being waited is what the fData array has sent.

An important fact to consider is that the data that want to be collected from the fData array it has to be specified in the code (within the bluetoothIn handler). So, for example $Float.valueOf(fData[6])$ specifies position 6 of fData in case the X angle is needed.

Depending on the type of exercise that is going to be performed, the treatment of the data sent by fData will be different.

4.3 Exercises Example

4.3.1 Exercise 1

In this exercise, the patient has to bend her/his elbows bringing her/his hands to her/his shoulders on the same side, holding position five seconds, and then come back to the starting point. That is, exercise 2.1.1. The programming of this exercise follows the flowchart 4.1.

The only angle that should be taken in consideration in this exercise, is the X angle (after setting the vertical direction). It is only this angle because there is no other movement in other direction. So, for that reason, it is only needed the data that is stored in position six (this is extracted from the BluetoothManagerBWT61 library).

In every exercise there is a chronometer to time the exercise. So every time the user presses the start button, the manipulation with the data will start. And when the user presses the stop or pause button, the sensor stops sending data (this is done with the Dormancy, explained in Table 3.1).

The following code is where the Bluetooth's application starts receiving information from the sensor. That information is stored in fData. The fData array is used in order to pick up specific information within the array (in this case angleX). At the following lines the angleX is checked so it is positive always. And also the Boolean variable "pressed" is checked, which is true when the start button has been pressed, and false when the stop or pause button are pushed.

```
case ConstantsBWT61.MESSAGE_READ:
//Waiting to receive or to send messages
    float[] fData = msg.getData().getFloatArray("Data");

    //takes X angle
    angleX =Float.valueOf(fData[6]);
    if (angleX < 0){
        angleX = angleX * -1;
    }
    if (pressed) { //if start button has been pushed
        Data();
    }
```

Before the patient starts performing the exercise, he/she has to select how many repetitions (three or five) are going to be done. After the selection, and during the performing of the exercise, some conditions have to be accomplished in order to conclude that the exercise was done perfectly.

In this exercise, the angle X should be between 0 and 180 degrees. Being 0 degrees the starting position, and 180 degrees with the hands at the shoulders. If the patient exceeds 180 degrees, or if the user does not reach these degrees, the exercise will not be perfectly completed (a Boolean variable is set to true).

The patient has to go from 0 to 180 degrees as many times as he/she has previously selected. As the repetitions have to be counted in order to stop the sending of information from the sensor (done with Dormancy explained in Table 3.1), every time the patient goes to the starting position, between 0 and 15 degrees, the counter will add one (starting from zero).

In order to check that the patient goes to the shoulders, between 100 and 180 degrees, the counter is also checked. Therefore, depending on the value of the counter, a different Boolean variable ("up1", "up2", "up3", "up4" and "up5") is set to true. This is a good way to know if the patient has bent the elbow well, and if not, to know in which of all the repetitions he/she has not done it well.

The following code is how all the previous explanation is implemented with three repetitions:

```
if (angleX >= 0 && angleX <= 180)
{
    if(caso==1) {
        if (angleX >= 0 && angleX <= 15) { //counts the repetitions
            counter += 1;
            caso=2;
            if (counter == 4)
                setDormancy();
        }
    }
```

```
        if(caso==2) {
            if (angleX >= 100 && angleX <= 180) {
                if (counter == 1)
                    up1 = true;
                if (counter == 2)
                    up2 = true;
                if (counter == 3)
                    up3 = true;
                caso=1;
            }
        }
    }
    else {
        bad_angle = true;
    }
```

When the patient presses the stop button, that means that the exercise has been completed. After that, a pop-up message will show a success message or a failure one. This message is composed depending on the values of those Boolean variables:

- If "bad_angle" is true is because the patient has exceeded 180 degrees or he/she has not reached 0 degrees.
- If "start" is true is because the patient has not gone to the starting position as many times as he/she has selected.
- If some of these variables: "up1", "up2", or "up3" ("up4" and "up5" for five repetitions) are false is because the patient has not bend the elbow correctly.

Otherwise, if those variables have the opposite values (false or true), that means that the exercise was completed perfectly, so the pop-up message will be positive.

Figure 4.1 shows a flowchart of this exercise. In this flowchart, it is explained the code related with the selection of three repetitions.

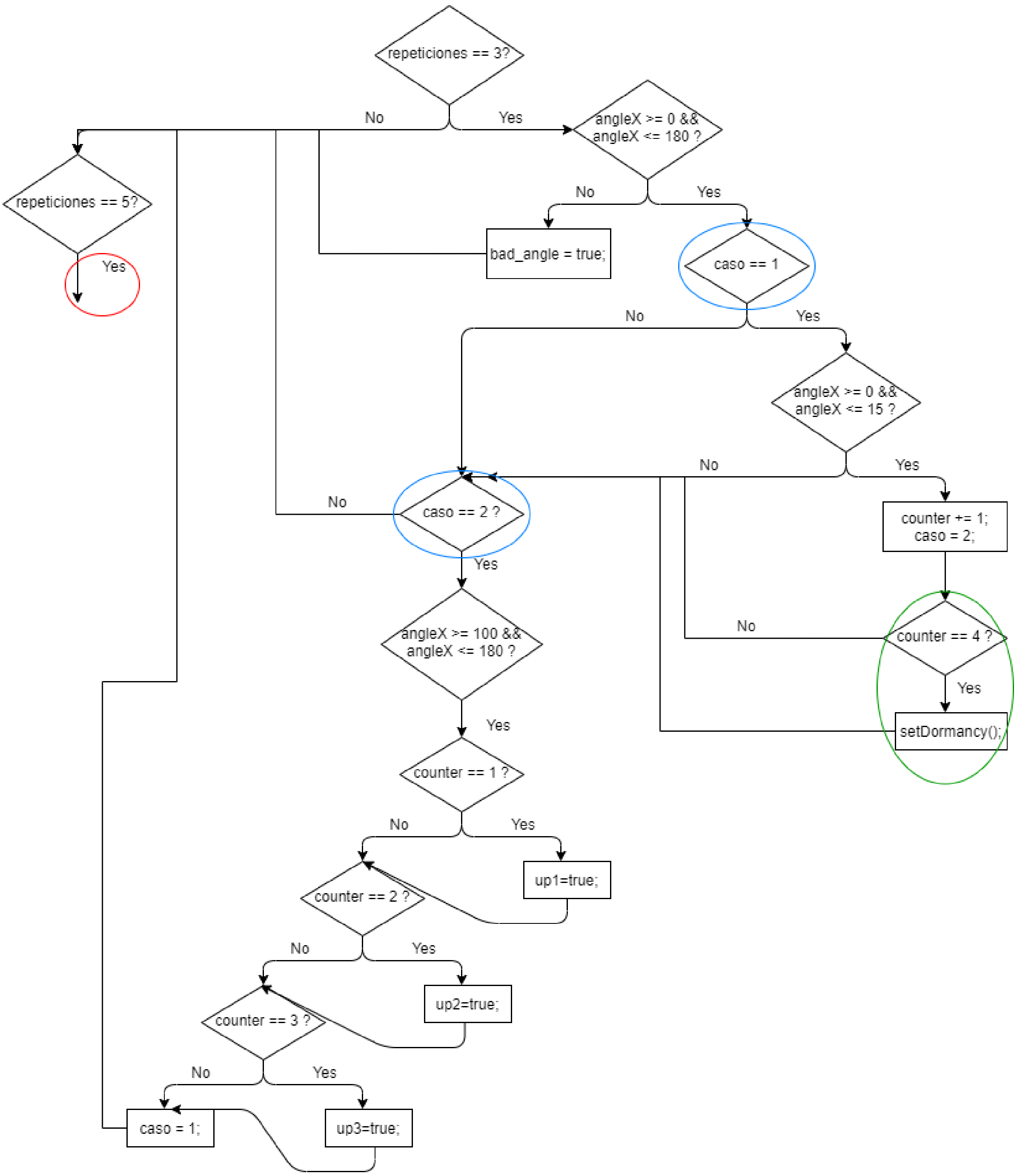


Figure 4.1: Exercise's flowchart.

Where the red circle is located in figure 4.1, the flowchart is uncompleted, this is because for five repetitions it is the same flowchart but adding two more variables, "up4" and "up5".

In the flowchart there is a new variable that has not been explained before: "caso" (with a blue circle in the flowchart). This variable is initialized to one. It is used for establishing the position where the patient should go next (starting position, or hands in the shoulders). If the patient is in the starting position, the variable changes its value to two (so next step are the shoulders). Once the patient has reached this second step, the variable changes its value to one again. This helps to count the repetitions, and to know if the patient has reached both positions correctly.

For instance, if the patient does not reach the shoulders position, the variable "caso" will not change its value to one, so even if the patient reaches the starting point correctly, it will not be valid because the exercise has not done well.

The last observation to be made in relation to the flowchart is the green circle. This condition is to check if the patient has reached the three repetitions. The patient starts the exercise at 0 degrees so, at that point, the counter has added one to its current value (which was zero), so the repetitions are counted from 1. If it was selected three repetitions, the counter reaches number four instead of three. However, if the number of repetitions was five, the counter reaches number six.

4.3.2 Exercise 2

In this exercise, the patient has to touch the shoulders with the fingers, and slowly raise the elbows upwards until the shoulders level. And then go down again. That is, exercise 2.1.1.

As it is done in the previous exercise, the only angle that should be taken in consideration is angle X, as there is no other movement in other direction.

The value from this angle is sent within position 6 from the fData array (take it from BluetoothManagerBWT61 library).

Until now, it is the same as the previous exercise. The difference it is that here, the X angle must be between 0 and 90 degrees, instead of between 0 and 180 degrees. So, related with the code it is exactly the same but changing the X angle range.

```
if (angleX >= 0 && angleX <= 90)
{
    if(caso==1) {
        if (angleX >= 0 && angleX <= 15) { //counts the repetitions
            //same as before
        }
    }
    if(caso==2) {
        if (angleX >= 70 && angleX <= 90) {
            //same as before
        }
    }
}
else {
    bad_angle = true;
}
```

4.3.3 Exercise 3

In this exercise, the patient has to touch the shoulders with the fingers. After that, he/she has to slowly lift the elbows upwards separating them from the body. It is important to not raising the elbows above the shoulders level. This is exercise 2.1.1.

This exercise has some things in common with the previous two exercises. It takes into account the X-angle, as it measures the angle of the arm's rises and falls. As in the previous exercise, this angle must not exceed 90 degrees, so it must be between 0 and 90 degrees.

In addition, it is also necessary the information obtained by the Z angle, since this measures the angle in which the arm moves forwards and backwards (taking as a reference that the elbows have to be aligned with the shoulders and back).

In the fData array, the X angle is in the sixth position, and the Z angle is in the eighth position, both of them are extracted in the same way.

```
angleZ = Float.valueOf(fData[8]);
```

Regarding the manipulation of the data, the X angle is treated in the same way as in the previous exercise, and Z angle has to go between 0 and 40 degrees. If this condition is not accomplished, a Boolean variable called "bad_angle2" will take true value, this means that the patient has not aligned correctly the elbows with the shoulders (then the exercise was not done correctly).

```
if (angleZ >= 0 && angleZ <=40) {
    if (angleX >= 0 && angleX <= 90) {
        if (caso == 1) {
            if (angleX >= 0 && angleX <= 15) { //counts the
                repetitions
            }
        }

        if (caso == 2) {
            if (angleX >= 70 && angleX <= 90) {
            }
        }

    }
    else {
        bad_angle = true;
    }
}
else{
    bad_angle2 = true; //bad Z angle
}
```

4.4 Database Management (Firebase)

4.4.1 Structure

The following image shows the structure of the database. It will be seen with more details in the following parts:

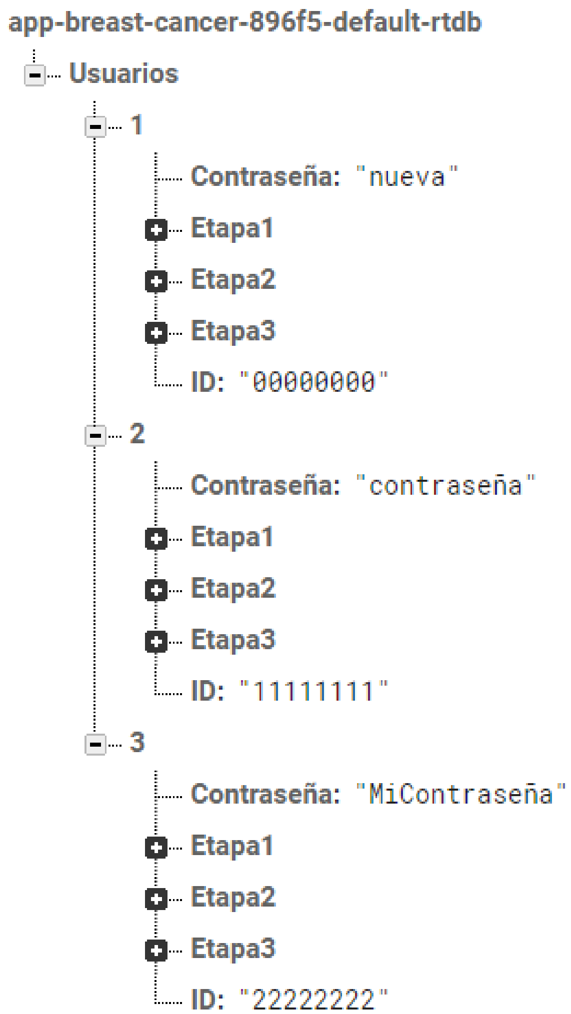


Figure 4.2: Structure of the database.

As it can be seen, the database is structured according to the number of users (previously registered by their doctors). Within each user, there are different fields: ID, password, and the three different stages.

This database is needed in order to store the data of the patients such as their personal data and their results of performing different exercises. So, there are going to be multiple queries to Firebase.

Log in

In this part of the mobile application, the patient has to be previously registered by his/her doctor. The user has to enter the ID and the password in the corresponding fields of the application. Once this is done, a query to the database is done. If the ID and the password are in the database, the patient can start the exercises. On the contrary, if the user or the password is not registered in the database, an error message will be displayed at the bottom of the screen.

To know if the user and the password are in the database, the data from the database must be extracted. To do so, first of all it has to be a connection between the database and the application code (java), this is done with a specific variable with a DatabaseReference type, the variable that is used in this case is called mDatabase.

```
private DatabaseReference mDatabase;
mDatabase = FirebaseDatabase.getInstance().getReference()
```

As the variable is now related with firebase, there is access to the data from the database. To extract the data, in this case the password and the ID, it has to go through out the entire database, storing the IDs and the passwords in two different arrays.

```
mDatabase.child("Usuarios").addValueEventListener(new
    ValueEventListener() {
    @Override
    public void onDataChange(@NonNull DataSnapshot snapshot) {
        if (snapshot.exists()){
            for (DataSnapshot ds: snapshot.getChildren()){
                //Go through the entire database
                //Store the passwords and IDs in two different arrays
            }
        }
        else{
            //If "Usuarios" does not exits in the database
        }
    }
```

Once the arrays have been full filled, a comparison will be made between what the patient has written in the ID and password fields and what is stored in the arrays. If they are the same, then the patient can start the exercises, if not, an error message will be displayed at the bottom of the screen. This message could be: "Wrong password" (in case that the IDs matches but the password do not), or "This user is not registered" (in case the ID written by the user is not in the database).

Change Password

Once the user has logged in, he/she can change the password. To do so, the user needs to enter the ID and the new password twice.

Considering the database and the explanations given before, the way the database is treated in terms of extracting the IDs, and storing them in an array, is done in the same way.

Once the array of the IDs is full filled, a comparison will be made between what the patient has written in the ID field and what is stored in the array. If they are the same, then the password from that ID will be updated with the new one the user has entered in the new password fields (both fields have to match).

To update the password, a Map structure is needed. Within this map, the ID and the new password is written, both of them written with string format. If the update was a success, a message will be displayed with the following sentence "The data have been updated". On the contrary, if occurs any problem with the database, this message will be shown: "There was an error during the update".

```
Map<String, Object> personaMap = new HashMap<>();
personaMap.put("ID", ID_text); //ID written in the ID field
personaMap.put("Contrasena", contrasena2_text); //new password

mDatabase.child("Usuarios").child(""+(i+1)).updateChildren(personaMap)
    .addOnSuccessListener(new OnSuccessListener<Void>() {
    @Override
    public void onSuccess(Void aVoid) {
        //Success message
    }
}).addOnFailureListener(new OnFailureListener() {
    @Override
    public void onFailure(@NonNull Exception e) {
        //Error message
    }
});
```

The password change is done when the patient clicks on the "OK" button. It automatically redirects to the home page.

Stages

In this part of the application, three buttons are displayed, one for each stage. Next to each button, there is a box with a background color. This color can be red, yellow or green, depending on the amount of properly finished exercises.

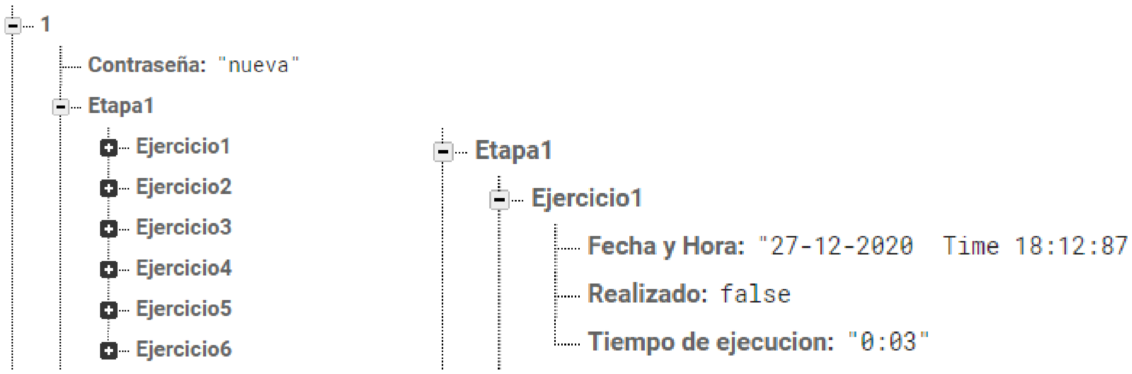
In order to determine the color, each exercise inside each stage has a Boolean variable (which is stored in the database). If the exercise was properly finished, that variable takes true value, if not false value.

- Red: No exercise is properly finished. The variable in every exercise is false.
- Yellow: At least one of the exercises is correctly finished. The variable is true in some exercises.
- Green: All the exercises are finished with good results. the variable is true in all the exercises.

It has to go through out the entire database of the actual user, looking for the Boolean variable (called "Realizado"). All the values of the variable are stored in three different arrays (first, second, and third stage). So, every time the user is in this screen, this three arrays are analyzed in order to set the correct color next to each stage depending on the exercises progress.

Exercises

The following images show how is the structure of an exercise in the database:



(a) Stages structure in the database

(b) Exercise structure in the database

Figure 4.3: Database

Every user entry in the database, has three stages. Although all of them have the same appearance as Image 4.3(a), the third stage has four exercises, and the second stage has six exercises.

As it can be seen in Image 4.3(b), when the user finishes the exercise, a few variables are going to be updated in the database:

- "Realizado" variable: As explained before, is a Boolean variable, which depending on how the exercise was performed, it takes true value (correctly performed), or false value (incorrectly performed).

- "Tiempo de ejecucion" variable: This variable stores the time in which the user has done the exercise. This is done with the help of a chronometer (every exercise has one).

- "Fecha y Hora" variable: This variable stores date and time when the exercise has been performed.

The update of the database is done in the same way as explained in the previous part 4.4.1. A new Map is needed, but this time with the values shown in Image 4.3(b).

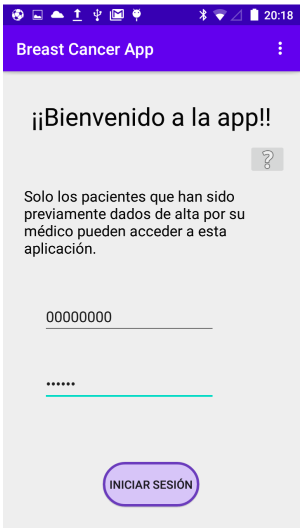
Chapter 5

Results

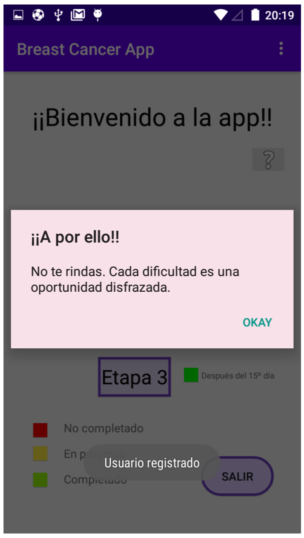
In this chapter, the results of the application and the results of some exercises are going to be shown.

5.1 Log in

These images show the log in screen. The patient needs to enter the username and the password in the corresponding fields: "Usuario (DNI)" and "Contrasena" respectively.



(a) Application



(b) A successful login

Figure 5.1: Logging in

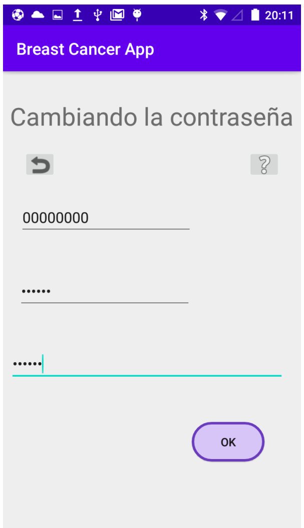
As it can be seen in Image 5.1(b), if the data introduced in the fields are correct, a success message will be displayed at the bottom of the screen. If not, the user will not move forward to the next screen until the data are correctly introduced. In addition, in this image, it appears a pop-up message, this message is to encourage the patients to do not give up.

As it is explained at the very beginning of the project, these particular patients need a lot of emotional and mental support, that is why this message is displayed. Every time the user is in this page, a new message with a new sentence will appear.

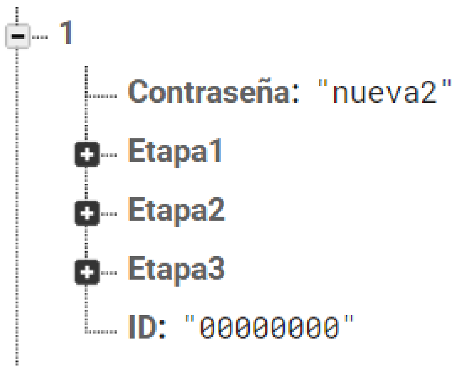
5.2 Change Password

If the user wants to change the password, he/she has to click at the three dots which are located at the top of the screen. A pop-up menu appears, and the change password option should be selected. Then, the user needs to enter the ID and the new password twice.

As it can be seen in Image 4.3(b), the password for the ID: "00000000" is the word "nueva". So, if the patient enter a new password like "nueva2", the database will update the password. The result of this action can be seen in the following images.



(a) Application



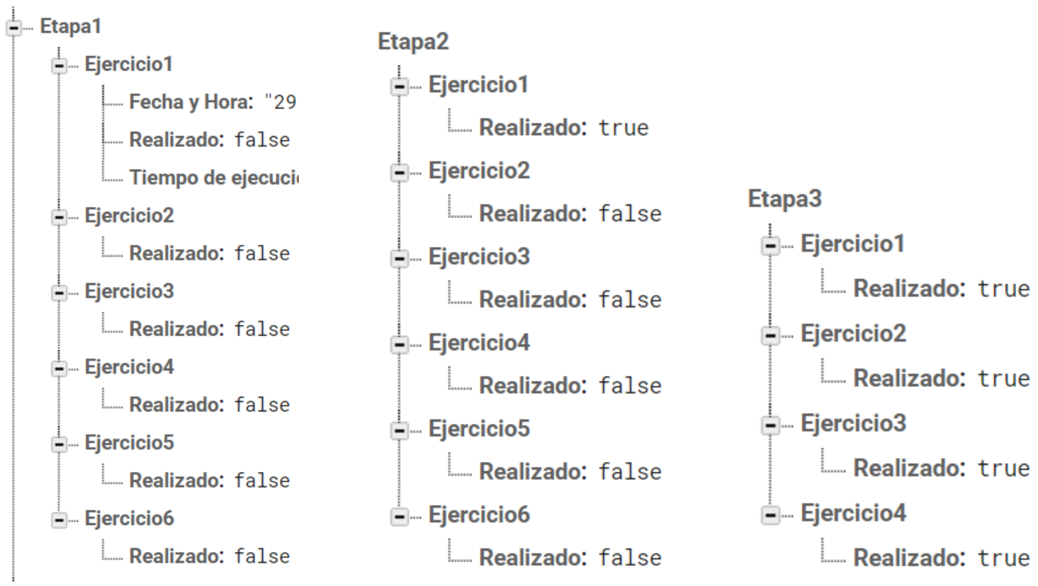
(b) Result in the database

Figure 5.2: Changing the Password

5.3 Stages

At this screen, the patient can see the progress in his/her rehabilitation exercises. As explained before, there are three different colors that could be assign to each stage (red, yellow and green).

Assuming the patient has performed one stage perfectly, other half finished, and other one not started yet (or any of the exercises not well done), the next images show the appearance of the database.



(a) Stage 1 (b) Stage 2 (c) Stage 3

Figure 5.3: Appearance of the database

As it can be observed, the variable "Realizado", has the values true or false. This values have been changed manually directly in the database in order to check the color algorithm.

As a reminder, the variable "Realizado" takes true value when the exercise was performed correctly, and false value when not. So, with this situation, the patient will see stage one with color red, stage two with color yellow, and stage three with color green.

This is an example. The correct order of performing the exercises is the other way around, that is, stage one, stage two and finally stage three. However, even if the patient has not finished a stage correctly, there is not any restriction to start the next one. This is done in order to give freedom to the patient so he/she can choose the exercise to perform according to his/her pains.

The following image shows what the patient will see in the application:

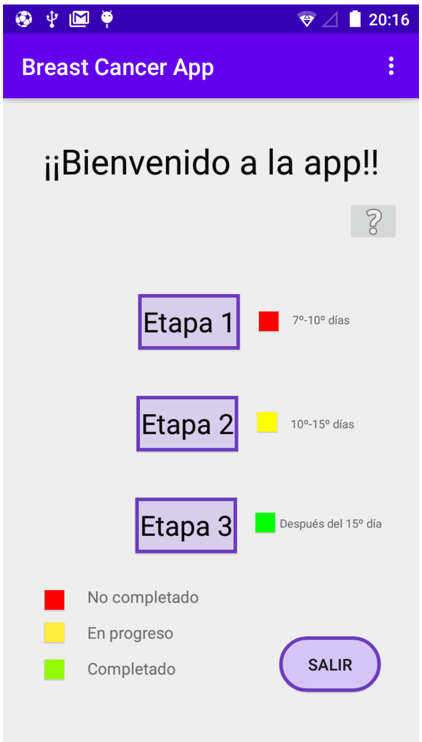


Figure 5.4: Progress in stages

5.4 Exercises

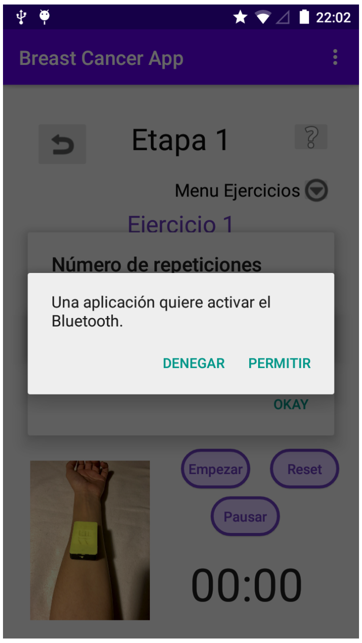
Once the patient selects the stage and the exercise to perform, the application asks if the mobile's Bluetooth can be used, if the answer is "allow", the Bluetooth will be activated. On the contrary, if the answer is "deny", the application will come back to the previous screen (5.4).

When the Bluetooth have been activated, the connection between the mobile and the sensor will start. At the same time, a list appears at the center of the screen, asking for the amount of repetitions.

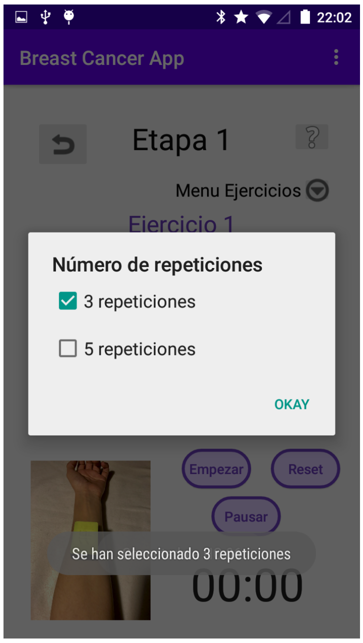
Once the repetitions have been selected, the patient can take a look to the video and to the sensor image. The video shows how should be the exercise done, and the image shows how should be placed the sensor in the patient's arms.

When the patient is ready to start the exercise, he/she has to press the start button and the chronometer will start. If there is any problem during the exercise, the patient can push the pause button (the chronometer will pause), and start again with the start button. When the patient finishes the exercise, he/she has to push the stop button. after this, a pop-up message will appear with the feedback of the exercise.

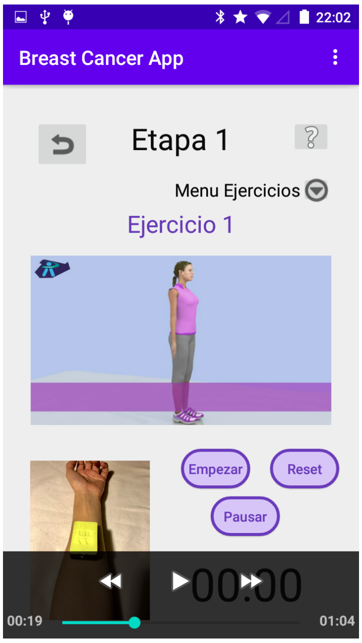
The following figures show the application and the feedback in case the exercise is not perfectly performed.



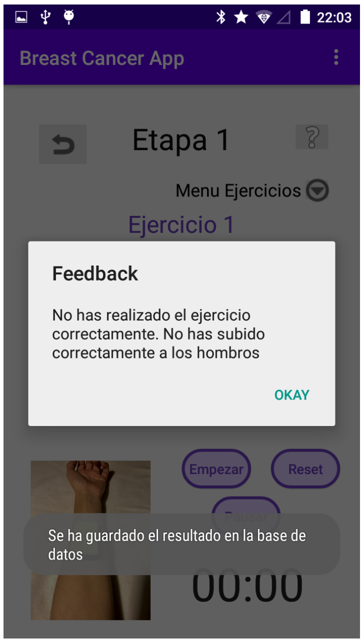
(a) Bluetooth



(b) Repetitions



(c) Video



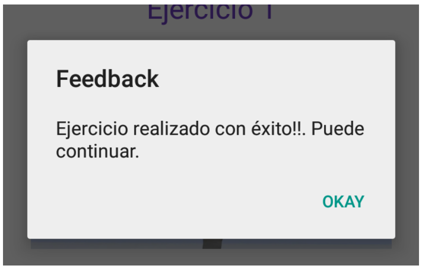
(d) Negative feedback

Figure 5.5: Exercise

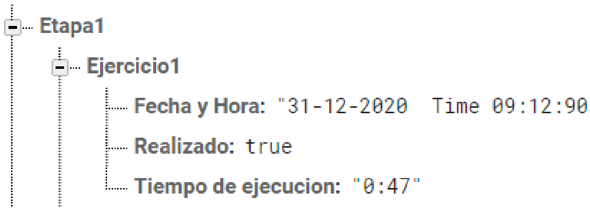
At the top right of image 5.5(b) it can be seen the Bluetooth logo, this means that it was activated correctly in the previous step 5.5(a).

The only differences between when the exercise is not correctly performed (Figure 5.5), and when it is correctly performed is the feedback result and the variable "Realizado" in the database.

If the patient performs again the same exercise, but this time well done, the application will show the following message:



(a) Positive feedback



(b) Result in the database

Figure 5.6: Exercise correctly performed.

As it can be seen in Figure 5.6(b), the "Realizado" variable has change its value to true since the exercise was successfully completed .

Once the feedback has been given, the application gives the patient the option to redo the exercise. In the next message the patient selects if he/she wants or if not.

- If the answer is yes: then the user has to select the amount of repetitions, and then he/she can start the exercise.
- If the answer is no: the user has to select at the exercise's menu another exercise.

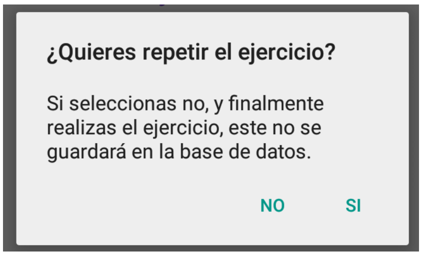


Figure 5.7: Retake the exercise

Chapter 6

Conclusions and Future work

6.1 Conclusions

The application created for patients diagnosed with breast cancer is a really helpful tool for them. This application with the help of the IMU BWT61 have achieved the main goal of this project. This combination give patients the enough help to monitor their rehabilitation exercises from home, and to know if they are performing the exercises well or not. This is a positive point considering that exits a communication between the doctor and the patients, since doctors can see the progress of their patients without the necessity of being in person.

It is true that the sensor has to be placed perfectly in the patient's arms in order to pick up the data provided by the sensor correctly. Otherwise, the expected results will not be obtained. For that reason, an image showing the location of the sensor in each exercise has been added. In addition, the application tries to guide the patient through the different screens, so he/she knows what to exactly do in each step. But, if even with this guidance the user does not know what to do, there are help buttons along the application in order to give more help.

In general, the data provided by the sensor are highly reliable as it sends information every millisecond. Considering the different movements changes during the performing of the exercises along the multiple tests, the sensor has given very accurate data.

6.2 Future work

As possible future work, it is proposed to carry out the rest of the exercises until completing the sixteen in the corresponding rehabilitation manual. To do so, it would be necessary to study which types of data are going to be needed from the sensor, such as the angles in which the movement is being performed. And later on, write the corresponding code for each of them.

In addition, as another possible future work, it is proposed to set colors red, yellow, and green within the exercise menu in each exercise. So the patients can see inside each stage which exercises have been completed correctly, and which ones have not.

It is also proposed to modify the code so when the patient reaches the selected amount of repetitions, the timer stops and the feedback appears immediately (no matter if the stop button is either pressed or not).

Moreover, a web application for doctors can be developed in order to follow the improvements of the patients.

Appendix A

Specifications

As it is explained in Chapter 3, the materials that are used in this project are a personal computer, an Android-base mobile phone, and a sensor (IMU BWT61).

The only requirements that the personal computer must have are:

- Windows operative system.
- Android Studio Application version 4.0.1.

The mobile phone must have the following:

- Bluetooth.
- Wifi connection.
- Android operative system (version 5.0).

The sensor (IMU BWT61) has these characteristics (they have been extracting from its manual[20]):

- Voltage: 3.3V-5V.
- Current: <40mA
- Size : 25mmx 27mm X 5mm
- Dimension: 2 Axis Angle(Roll Pitch) + 3 Axis Acceleration + 3 Axis Angular Velocity
- Range : Acceleration : ±16g + Angular Velocity : ±2000°/s + Angle: (X±180°,Y±90°)

- Stability: Acceleration : -0.01g Angular Velocity : -0.05°/s
- Attitude measurement stability: 0.05°
- Output content: Time,3D- Acceleration ,3D- Angular Velocity,2-D Angle (Roll Pitch)
- Output frequency: 0.1-100 Hz
- Date interface: Serial TTL level Bate rate–115200(default and cant be changed)
- Bluetooth transmission distance : >10m
- Support for Android and PC.

Appendix B

User Manual

In this appendix is explained in detail how to run the application and how to use it.

B.1 Run the application

To run the application, the user has to simply click on the logo application, and it will start to run.

Once the application is running, the next step is to turn on the sensor (it has a switch). The sensor is activated when it shows a red flashing light, this means that is not connected yet to any other device. When this occurs, the red light is permanent.

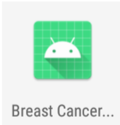


Figure B.1: Logo

B.2 Log in

Once the application is running, the first step to do is to log in (only the patients which have been previously registered by their doctors).

The Username (ID) and the password has to be enter into the corresponding fields. After, by clicking the "Log in" button, a message at the bottom of the screen will appear. This message depends on if both fields are correct or not. If they are, the user can start doing the exercises, but if not, the username and the password have to be enter again.

As it can be seen in Figure B.3, there is a help button at the top right. This button is useful for helping the user to understand better what is displayed in this screen, and what he/she should write in the fields.

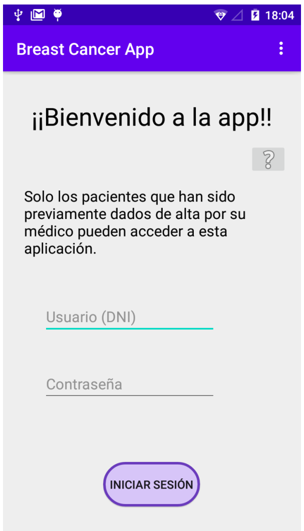


Figure B.2: Log in

B.3 Change the password

Once the log in have been a success, the user can change the password. This can be done by clicking in the three dots at the top right of any of the screens of the application.

Here, the user enters the Username (ID), and the new password twice. Once all the fields have been filled, by clicking in the "OK" button, a message will appear communicating if the password updating was done or not.

At the top left there is a back button which go back to the home page. And at the top right there is a help button, which explains the user what should be written in the different fields.

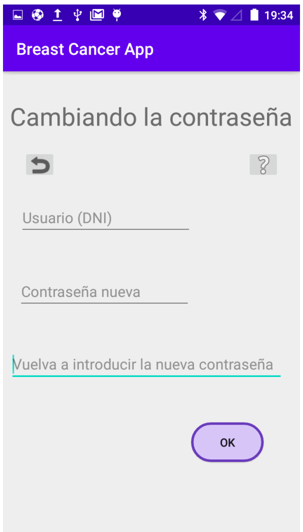


Figure B.3: Change the password

B.4 Stages

In this part of the application, there are three main buttons, one for each stage (this can be seen in Figure 5.4). Next to each stage there is the a box with a different color depending on the progress of the exercises. Depending on the exercise that want to be performed, a different stage button should be pushed. In addition, there is a help button at the top right. This button provides information about the current screen, to help the patient.

B.5 Exercises

As it is explained in Figure 5.5. When the user clicks on a stage, the first exercise appears. It asks for the Bluetooth permissions, and later on for the amount of repetitions that are going to be done.

Once the repetitions have been selected, it is highly recommended to wait until a message saying "Connected to HC-06" is displayed, at this same moment the red light from the sensor will be permanent. Otherwise, if the user starts the exercise, the data will not be valid, and it will not be stored in the database correctly.

Once the connected message has been displayed, the user can watch the video to know how to do the exercise, and also the image to know how to place the sensor. After, the patient can start the chronometer with the start button, pause it and stop it. When the stop button have been pressed, a pop-up message appears showing the feedback of the exercise.

After the feedback message, the user is asked if he/she want to retake the exercise. If the answer is "yes", a new message asks for the amount of repetitions that the patient wants to do. But, if the answer is no, the patient has to go to another exercise.

There is a help button, which helps the user, at the top right of the screen.

Moreover there is an exercise menu below the help button. This menu allows the user to navigate through the different exercises. It can be seen at the following figure:

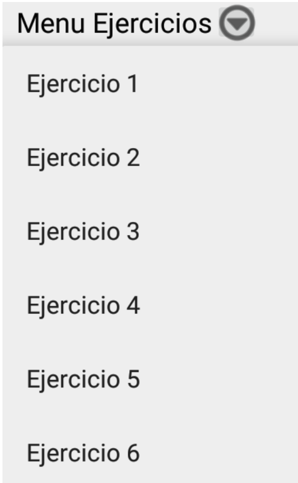


Figure B.4: Menu

Appendix C

Budget

The following tables show the budget estimation of the project. The first one is about the material costs, and the second one about the personnel costs.

Description		**Amount**	**Price per unit**	**Total Price**
Hardware	PC	1	900 euros	900 euros
	Mobile	1	350 euros	350 euros
	Sensor IMU BWT61	1	25 euros	25 euros
	USB wire	1	4 euros	4 euros
Software	Windows 10	1	- euros	- euros
	Android Studio	1	- euros	- euros
	Latex	1	- euros	- euros
TOTAL				1.279 euros

Table C.1: Material Budget

Description	**Total hours**	**Price per hour**	**Total Price**
Engineering	300	50 euros	15.000 euros
Writing	80	25 euros	2.000 euros
TOTAL			17.000 euros

Table C.2: Personnel Budget

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