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Recognizing Activities of Daily Living of People with Parkinson's

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To all the clinicians and patients at Parkinson's clinics.

Resumo Alargado

A doença de Parkinson é uma doença neurodegenerativa comum que afeta uma grande parte da população mundial. Esta doença implica bastante sintomas, contudo o mais predominante é a alteração nos movimentos do doente ou até mesmo a perda da funcionalidade do mesmo. Em casos mais avançados pode levar à queda do doente devido a este não se conseguir mexer de um momento para o outro e perder controlo da sua postura, levando à queda. A cura é inexistente, apenas existem tratamentos que aliviam os sintomas do paciente. O tratamento mais comum é a ingestão de medicamentos e os pacientes precisam ser avaliados várias vezes para saber se o tratamento está a ter efeito. O paciente ao tomar a medicação, os sintomas vão ser atenuados, contudo ao longo do dia, os sintomas vão ficando cada vez mais severos, fazendo com que, uma avaliação ou testes de manhã não se vai obter ter os mesmos resultados que uma avaliação ou testes realizados à tarde, não havendo uma real perspetiva na evolução da doença. Com este problema surgiu a necessidade de avaliar o paciente ao longo do dia para avaliar as suas flutuações motoras, sendo uma avaliação continua e não pontual. Estudos que foram realizados nesta área, maioritariamente avaliam atividades motoras comuns como caminhar, sentar, levantar, subir ou descer um lanço de escadas, contudo atividades mais subtis e complexas como escovar os dentes, lavar a louça, preparar comida, trazem um maior valor para a avaliação da doença, permitindo a visualização e monitorização de movimentos mais ligeiros que estão suscetíveis às flutuações provocadas pela doença de Parkinson e podem não ser detetadas nas atividades mais comuns.

No início da tese foi feita uma revisão sobre estudos já realizados nesta área. Com a revisão realizada foi possível verificar que a área de reconhecimento de atividades do dia-a-dia em pacientes com Parkinson ainda é muito limitada e com muito potencial e muito para explorar, com isto em mente decidimos começar o projeto desenvolvendo várias ideias para um protótipo de monitorização.

Destacamos alguns artigos [1][2] com estudos realizados com pacientes com Parkinson onde foram usados acelerómetros e foi possível detetar atividades diárias dos pacientes em suas casas, como andar, sentar, levantar. São estudos bastantes importantes que dão a base para esta tese. Contudo temos a ambição de classificar não só, atividades comuns, mas também atividades mais complexas e mais finas do nosso dia-a-dia.

Destacamos alguns artigos que mesmo não realizando o estudo com pacientes com Parkinson, conseguem realizar a classificação de atividades da vida diária mais finas [3][4][5]. Para além dos acelerómetros existem outras tecnologias que podem ser utilizadas para a deteção de atividades do dia-a-dia como é explorado nestes artigos.

A nossa ideia principal, foi começar com o desenvolvimento de um sistema de recolha de dados, que conseguisse de alguma forma, legendar cada intervalo de tempo em que o paciente está a realizar uma atividade diária durante *free living*. Isto é possível de variadíssimas maneiras, a ideia mais simples que foi abordada foi a utilização de uma câmara ao peito do paciente e depois da recolha de dados, legendar tudo à mão, contudo iria ser uma tarefa mais trabalhosa na fase da legendagem.

Outra abordagem, sendo a mais apropriada seria a criação de uma aplicação de smartphone que funcione como um mecanismo de anotação de atividades. Onde o paciente iria inserir a atividade e a duração ou ser uma terceira pessoa que vigia e anota as atividades do paciente. Enquanto isto é anotado o paciente seria monitorizado por acelerómetros e os padrões dos valores deste seriam associados à atividade, permitindo uma melhor classificação. Posteriormente há ajustes manuais. Isto permitindo ter um *dataset* com o dia do paciente e por cada atividade realizada, vai estar associado um padrão sensorial, esta abordagem viria a tornar-se o nosso foco.

Ainda outra opção, poderia ser a identificação dos objetos ou áreas com algum marcador. Foi verificado o uso de alguns marcadores em outros trabalhos, sendo um desses marcadores o identificador por radio (RFID) [3] onde os objetos contem o RFID *tagger* que quando perto do recetor, que neste caso seria uma pulseira do paciente, vai haver uma ativação significando que o objeto identificado está a ser usado, isto depois pode ser processado por algum tipo de raciocínio que irá ajudar a prever que atividade ao certo estava a ser executada naquela altura com aquele objeto. Noutro caso [5], em conjunto com RFID, usam-se sensores de movimento, infravermelhos e de uso de eletricidade, que iram garantir a localização do objeto e do paciente dentro da casa em estudo, isto em conjunto com uma "*behavior tree"* que consoante o trajeto do paciente e os objetos que estão a ser transportados, irá poder ser compilada uma atividade complexa, como por exemplo, o paciente agarrar numa taça e depois nos cereais e ir para a mesa, irá ser concluído que o paciente comeu cereais naquela altura. Outra maneira de identificar objetos e áreas, é com o uso de sensores elétricos e de vibração [4]. Neste estudo foram usados esses sensores numa bancada da cozinha, pois consoante o objeto que é usado, irá reproduzir uma vibração que será captada pelo sensor e, com facilidade poderá ser especificado que objeto foi usado. No caso de serem usados objetos que não são móveis como o fogão, o micro-ondas ou a chaleira, é usado o sensor de uso elétrico que quando algum desses eletrodomésticos é usado, irá ser contada uma interação com esse objeto.

Com as ideias discutidas e revistas foi concluído que a aplicação móvel seria um sistema de anotação das atividades para servir como um tipo de diário era a melhor opção, sendo barata de implementar, mais facilidade e rapidez para realizar estudos com pacientes, pois só tem necessidade de instalar uma aplicação no telemóvel e usar uma pulseira com acelerómetro, para além de ser mais intuitivo de se usar, e mais facilidade de implementar futuras iterações e funções que sejam sugeridas à aplicação móvel.

Com isto, deu-se ao início da criação da aplicação móvel de raiz, utilizando a linguagem de programação Kotlin, como era uma linguagem nova, foi um desafio e durante as primeiras semanas, realizaram-se tutoriais entre outras ferramentas de aprendizagem para se ter um à-vontade com a linguagem. Como um dos objetivos principais era a análise dos dados recolhidos, era obrigatório uma base de dados onde se podia guardar os dados para futura análise, a base de dados da Google, a Firebase foi a escolhida, devido á sua fácil implementação em android e flexibilidade.

A aplicação foi desenvolvida com uma ligação à base de dados com um sistema de login para cada paciente e clínico, onde cada clínico tem a opção de pedir acesso a certo paciente utilizando um identificador, ao ser aceite esse pedido, o clínico fica com acesso à conta do paciente onde pode realizar todas as funções que o paciente pode na sua aplicação. Na primeira iteração da aplicação foi possível realizar o registo da atividade que estava a ser realizada no momento, que posteriormente era guardado na base de dados o tempo em que foi iniciado e acabada a atividade, o nome da atividade e se tinha sido guardada por um paciente ou um clínico. Para além disto, foi implementada uma função para alterar registos anteriores, tanto a atividade em sim, se a pessoa se enganou e registou “andar”, mas na realidade tinha era lavado os dentes, com esta função, a pessoa podia simplesmente mudar a atividade anterior para “lavar dentes” isto facilitando em casos onde a pessoa cometia erros.

Depois desta primeira versão, foi sugerido a implementação de um tipo de lista de atividades onde o clínico podia programar uma hora e dia para o paciente realizar. Esta função foi sugerida com a intuição de criar um tipo de controlo onde o clínico pode querer analisar certas sequências de atividades motoras para analisar futuramente, ou simplesmente fazer o paciente exercitar em casa sem ter de ir à clínica.

Com a última iteração do sistema de monitorizações recolha de dados já implementada com a lista de atividades, deu-se ao início do estudo para validar o sistema e para recolher dados para a criação de um *dataset.*

Devido à pandemia não foi possível realizar o estudo com pessoas com a doença de Parkinson, contudo foi realizado o estudo com 10 pessoas saudáveis onde cada voluntário participou durante 3 dias, realizando no mínimo 5 atividades por dia e 1 lista de atividades por dia. No fim dos 3 dias, o voluntário participou num questionário e numa entrevista para se poder retirar informações úteis para futuras iterações e problemas que pudessem ter decorrido durante o estudo.

No fim do estudo analisaram-se os dados recolhidos pela aplicação e pelo acelerómetro. Combinando os dados é possível escolher uma atividade num dia específico e ver a sua atividade e se tem possíveis perturbações.

Palavras-chave: Parkinson, Monitorização, Aplicação móvel, Atividades do dia-a-dia, Sensor

Abstract

Parkinson's disease is a common neurodegenerative disease that affects a large part of the world's population. This disease involves a lot of symptoms, however the most prevalent is the change in the patient's movements or even the loss of functionality. There is no treatment, however it exists medication that relieves and reduces the symptoms for a period. A Parkinson’s patient needs to be watched by clinicians to understand if the medication is working correctly and to analyse the disease progression. The current way of doing this evaluation is at clinics where the patient needs to go to the clinic or to live there. With this into consideration it was requested a monitoring system of activities of daily living for Parkinson’s patient.

The monitoring system consists in a mobile application in an Android smartphone serving as a diary for the patient of clinician to record the activities done at that moment. With this application, the patient needs to wear an accelerometer in the wrist to gather the acceleration in the 3-axis. The application besides the monitoring function, it gives the ability to the clinician to schedule lists of activities for the patient to do during the day, allowing the clinician to have some control.

We carried out a study with 10 healthy participants which used the monitorization system for 3 days each. The patient would worn the accelerometer and record the activities that they would do throughout the day, was asked a minimum of 5 activities per day. Alongside this recording it was schedule 1 list of activities to be carried out each day, this list only had motor activities such as walk, sit down, and stand up. At the end of each participant study, it was made a questionnaire with standard usability questions and an interview that helped us understand if the system was reliable or not.

Keywords: Parkinson, monitoring, mobile application, accelerometer, diary.

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Acronyms

PD – Parkinson's disease

H&Y - Hoehn and Yahr

UPDRS - Unified Parkinson's Disease Rating Scale

ADL - activities of daily living

RFID - Radio frequency identification

WISP -Wireless Identification and Sensing Platforms

DNN - dynamic neural network

SVM - Signal Vector Magnitude

UID - unique identifier

SUS - System Usability Scale

Chapter 1 - Introduction

Parkinson disease is the most common neurodegenerative movement disorder, its more prevalent symptoms are tremor, rigidity, bradykinesia/akinesia and postural instability. This disease affects the daily lives activities of the patients, making each activity harder or difficult to perform, in some cases forbidding them to do certain activities. In more severe cases the patient may even fall, causing other problems such as wounds, head trauma, broken bones, etc.

There is no cure for Parkinson's disease, however there are treatments that are designed to alleviate the symptoms, mainly drugs that are taken in a certain time of the day and the effect wears off throughout the time. For this treatment it is needed an evaluation of the Parkinson's disease progression and the effect of the medication on the patient since everyone reacts to the disease and medication in a different way and at different speeds. One of the evaluations is the monitoring of motor symptoms and gait impairments which are one of the bigger issues in the patient quality of life.

Wearable sensors are a great tool for this type of evaluation, providing spatial-temporal parameters that are useful to evaluate the progression of the gait problems in a patient with PD, without the need for expensive equipment to make the movement analysis of the patient.

The accelerometers are one of the most used sensors in this type of evaluation since it can measure the acceleration in three axes of the body part, allowing the capture of seizures and contrast between evaluations giving the perception on the speed of the symptom's progression.

Another sensor that is commonly used is the gyroscope which measures angular velocities for three orthogonal axes (yaw, pitch, and roll). It is used with the same purpose as the accelerometers.

With these sensors in clinics, it is tested the alterations in the gait velocity, cadence, stride time, and length of a walking patient, further evaluated with rating scales such as

Hoehn and Yahr (H&Y), the Unified Parkinson's Disease Rating Scale (UPDRS) staging and the Schwab and England rating of activities of daily living [6].

With the typical clinical evaluation of the patient not reflecting the appropriate actual status of a patient during daily life. An at-home evaluation is a more reliable solution to characterize the alterations of the patients during their daily activities.

For this type of evaluation there are already a good amount of evaluations and techniques, some papers use only accelerometers for a more limited evaluation that only will detect common daily activity like walking, standing up, sitting, laying down, using the cellphone imbued accelerometer [1] or dedicated accelerometers [2], in some cases there is other component besides the gathering and evaluation of the data collected, some papers use the real time data collection to enable clinicians to examine and evaluate what the patient is doing and if some disturbance is detected in the movement. Even giving the ability to the clinician contact the patient for a video call and see the live activity feed with the opportunity to ask the patient to carry out some sort of activity to evaluate [7].

Besides the use of only accelerometers, even if not tested with PD patients, there are some studies where certain objects or areas are marked with some sort of marker that allows the detection of the proximity of the patient to certain objects or areas, helping the classification of activities granting a wider and more specific list of activity detection like brushing teeth, drinking, eating, dishwashing, between others [3][4][5]. There are systems that use cameras instead of sensors to determine the activity without being reliant in data collection. Instead, it is evaluated frame by frame of the transmitted video to dictate the activity [8].

With all the existent studies in thought we wanted to provide another example of evaluation. In this study we had the idea to combine some sort of diary with a sensorial aspect and the possibility of a staged activity session at home equivalent to those done in a clinic. Contributing to a more specified monitorization of the activities of daily living at home.

In a study with healthy people, we were able to assess a wide range of activities, the usability of the application, and user's perceptions regarding its future use.

1.1 Objectives and Contributions

The main goal of this thesis was to create a dataset from that has valuable information about the daily life of Parkinson's patient at home. This dataset was created using a data collection system designed by us, with the purpose of having a fully detailed and categorized dataset with the corresponded specific daily activities performed at home or at a center.

We created a data collection system not evasive and comfortable to the patient, so the system does not interfere with the patient daily activities and health.

The contributions of this thesis are:

- System that allows real-time annotation of activities by patients, as well as the execution of activities previously prescribed by a therapist.
- Preliminary assessment of usability and perceptions of usefulness with healthy users
- Database sample with an acceptable number of activities recorded for further use in machine learning in the subject.

With this we initiate with the reviewing of the works already done in the field. And the proper approach to our data collection.

1.2 Document Structure

This thesis is organized as follows:

- Chapter 2 – In this chapter it is described some main aspects about the Parkinson’s disease, the daily living activity monitorization. This chapter ends with a literature review about the monitorization of daily living.
- Chapter 3 – This chapter explains how the process was for the creation of the application, the context, requirements, and a system overview.
- Chapter 4 – In this chapter it is explained how it was performed the study, the data analysis, and it is discussed the results taken from the study.
- Chapter 5 – This chapter is the conclusion of the thesis in which is represented our final thought about the project, future possible iterations several limitations that occurred during the project.

Chapter 2 – Background and Related Work

2.1 Background

As explained in the introduction, the PD is a neurodegenerative disorder which reduces the production of dopamine since the cells that produce it die with the disease. PD has no cure but has treatment, the typical therapy is the replacement of dopamine with levodopa, however there are several dopaminergic drugs to dull the symptoms that have been introduced. Nevertheless, the patients need to be continued evaluated to see the evolution of the disease and to understand if the medication is taking effect, the use of wearable sensing has become more common and of easy access, with this, it was developed DataPark [9], a web platform that is capable of giving valuable information to the clinicians about the patients. The data is collected with an accelerometer (AX3), and at the end of each session it is created a personalized report according to the needs of each patient. This reporting system has been implemented in a clinic, where the patients wear the accelerometer and at the end of the study, which is a free-living context, the patient does the normal days activities at the clinic and at the end it is produced the report that gives an overview of the whole study. It was from this project suggestions that surged this thesis, the development of a monitoring system of activities of daily living (ADL) that could give the possibility to be done at home.

2.2 Monitoring PD with Accelerometers

The most common and viable approach is the use of sensors, typically accelerometer from the patient's smartphone or bracelets worn by them, to analyze the patient movement and alterations during a short set of common activities of the daily living, for example, walking, sitting, getting up [6][1][2]. However, it will only recognize activities that are simple, a patient can be standing but, drinking something, or brushing their teeth, the standing activities for itself can give some information, however, the ability to distinguish finer activities like brushing the hair or eating breakfast can give a more characterized monitorization of the patient health condition.

As explained in the background section, the DataPark [9] is also an example of monitoring PD with accelerometers where the patient wears the accelerometer all the time and it gives a report as a review of the time he wear it.

2.3 Recognizing ADL

The PD is difficult to control due to its variations during its evolution and even during the day. The clinicals only evaluate the patients from time to time, creating a challenge to understand the evolution of the disease, the response to interventions, and the fluctuations that happened throughout the day of the patient. One possible solution is to ask the patients questions about their daily activities using some type of questionnaire [10]; however, this is very unreliable, since the questions probably will not give much information and can be not so accurate. Other way to approach this challenge would be the implementation of a diary [11][12], still, it would create a problem of compliance, since the patients would forget to point all their activities and probably not correctly describe the patient’s situation.

The following examples are not tested with PD patients, however, it gives a great idea what can be a good ADL recognition system.

The use of radio frequency identification (RFID) sensors enables the identification of objects and when they are interacting with the volunteer in the study, it allows to connect certain activities to certain objects, for example, if the volunteer is near an identified bowl, it is easy to assume that the user will eat something out of it. This is the simplest way of connecting objects to activities, in some studies they only use one interaction, for example if the patient is grabbing the bowl the output will be vague, not being able to achieve a perfect categorization, since the patient can grab the bowl just to place it somewhere or even clean it or store in the cabinet. In a study [3] it was used RFID tags and Wireless Identification and Sensing Platforms (WISPs) to understand if there is a better way to identify the objects, since the use of RFID tags rely on the use of a bracelet by the user to identify close contact with the objects and sometimes it can be uncomfortable and unreliable if the patient forgets to wear the bracelet. The WISPs can communicate with the standard RFID readers not needing close range readers, it has a built-in accelerometer that is used to detect the movement of the identified object, basically working like the RFID taggers. It was implemented in 25 objects, WISPs, and RFID taggers to compare the results. The WISPs achieved 90% precision which tells the times that the system identified the right object in use and had 91% recall which classifies the time in which the sensor was detecting the object being used during the activity. The RFID had a much bigger precision, at 95%, however due to the short distance communication between the tags and the object, the recall was only 60%, certain objects have different ways to grab, making the distance between the tag and the bracelet vary and in some instances of time when the activity was being performed the RFID reader didn't detect the tagger. These results showing that the use of WISPs is better when it is needed a more consistent detection and when there is the probability of the patient to forget the bracelet, however it is still expensive, being the RFID readers of long range very pricy. The use of RFID taggers is a simpler way and much cheaper, that can probably be used in a lower stage of development.

The characterization of a more complex activity can be achieved using other technology. In this paper [5], it is used motion sensors, infrared sensors and electric usage sensors that provide the location of the user with or without an object. In this case it is used a behavior tree that allows to declare certain path of activities that will conclude in a complex activity, for example, if the user is in the kitchen and grabs a bowl, the user can go grab the spoon meaning he will eat something, or he can go to the dishwasher, meaning he will wash the bowl, depending on the position of the user and the object, the path on the tree will predict a final complex activity.

Other study [4] goes in a different approach, instead of having objects identified or the user wearing something, it is used vibration and electrical sensing for a non-invasive recognition. The use of vibration is possible due to the different frequencies that are produced when using different objects, in this study it was placed two vibration sensors, one on the floor and other on the countertop of the kitchen to try to predict which object is being used depending on the frequency obtained in these sensors. The electrical sensors will precisely measure the usage time and duration of the electrical objects that are being "measured", the microwave, fridge, stove, kettle, and microwave. These two sensors complete each other, due to the difference between appliance usage and human motion, which are two significant aspects of human activities. To classify the events, the system conducts feature extraction on the detected event signal, which after they are used to train a classifier using support vector machine. This system was tested with different persons, resulting in a 90% average precision on the ADL recognition.

2.4 Datasets

To able the characterization of an activity it is needed to collect data from the sensors that are being used, these data is stored in a dataset. The dataset will only store the collected data, only after that, there will be the recognition in which will dictate the activity made, automatically or even manually. The next sub sections are divided as result of the accelerometry being the most predominant technology on the PD treatment and deserve a sub section for its own.

2.4.1 Datasets of accelerometry with PD patients

There already some datasets focused on people with PD that categorize some activities of daily living. In this study [2], there was recruited PD patients from a clinic, that did not had any fall experience, difficulty walking or some sort of device that is needed to walk. For comparison it was recruited a healthy age matched control group that had no medical conditions. The participants wore the Mobi8 ambulatory monitoring system, which is a data logger connected to a 3D accelerometer sensor worn on the lower back, approximately at the body’s center of mass. The data was sampled at 256 Hz and were acquired via flash memory and downloaded to the personal computer for further processing in MATLAB.

The PD participants did a 1-minute straight-line walk before and after the medication to compare with the group control. For the ADL simulation, participants did 500 meters walk through the hospital, they walked down a flight of stairs and turned back through another entrance, also including sitting for those who had difficulty performing these tasks all at once, all this after the medication. The values were compared between the before and after the medication to determine if the activities were affected in a positive way by the medication.

In this paper [13] it is presented a system called MercuryLive that provides an integrated platform to enable access to data gathering using wearable devices via a web application. It runs in 3 tiers, central sever, patient’s hosts which uses a body sensor network developed by them, consisting in multiple accelerometers and a base station, typically a laptop with an 802.15.4 transceiver, and clinical’s hosts. The clinicians can adjust remotely different parameters of the sensor nodes (e.g., number of recorded sensor channels, sampling rate, and data features estimated on the node).

As sensor data are being collected, a data uploading daemon runs in the background to connect to the central server and upload sensor data opportunistically.

The clinicians can ask the patients to perform some activities that can be scored depending on the severity of the tremor using accelerometers. Besides the referred papers there are more that are similar, regarding other symptoms, bradykinesia, hypokinesia, dyskinesia and motor fluctuations.

In this study [14], it is used the 9x2 inertial measurement unit which consists in a triaxial accelerometer, a Bluetooth communication module, memory storage and a battery. The signals were captured at 200Hz and saved in a microSD card. A portable video camera was used to record patients while they performed the experimental procedure, which were at the patient home, since the PD symptoms may vary depending on the environment. The activities were scripted but execution free. For example, walking around their home, carrying a glass of water, between each activity, the patient sat several times in a chair, so many postural transitions were included in the recording. During the activities other random activities took place, such as answering a phone call or other unexpected situation, each test had a duration of 10 to 30 minutes and were executed before and after the medication. It was tested with 12 patients. After the collection, it was used to analyze the bradykinesia severity in both states.

Another example is the following study [15], it was used 8 piezo resistive uni-axial accelerometers attached in pairs, on the leg, trunk, arm in the most affected side of the body. It was asked to realize some tasks for less than a minute with during a videotaping session for further analysis by clinicians. The tasks were sitting on a chair, counting forward and spelling a predefined set of words backwards to evaluate the influence of talking and stress, drinking from a cup, putting on a coat, buttoning, and walking. These tasks were performed by 23 PD patients.

In this study [16], it is used seven piezoresistive uniaxial accelerometer, two on the sternum (sensitive axis in the sagittal and coronal plane), 3 on the writ and 2 on the upper leg. Each accelerometer signal was digitally filtered to obtain 3 signals with a frequency range of 0-1 Hz (The DC component), 1-3,5 Hz, and 3.5-8.0 Hz (AC component). The DC component represents the position of the sensor with respect to the gravitational field, it is used to determine the body position. The AC component represent movement in a general sense. For 24 hours, 15 PD patients besides the data recording, they evaluated their state, sleep, and medication.

In the university of Genoa [17], it was created a multi-sensory dataset for the activities of daily living. It was collected using inertial measurement units (IMUs), two for each arm, one on the back and one on the right thigh. The 10 patients performed 186 ADL common activities (walking, getting up and sitting down) and other more specific (drinking water, eating with knife and fork and teeth brushing). The labelling of the activities was performed with the help of recorded videos by a RGB camera. The environment was controlled, in a room with pre-determined sequences of activities. The video was synchronized with the data using the SyncPlay that places together the video and the data with the corresponding timestamp.

The last study in this category [18] used a system that is composed by a triaxial accelerometer, Bluetooth radio that allows the streaming of sensor data at high rates. The sensors were the 12 participants performed tasks for example quiet sitting, finger tapping, walking, alternating hand movements and heel tapping, before and after the medication, 30 seconds each activity.

2.4.2 Datasets using other sensors beside accelerometer

Even if the accelerometers are the most common sensor used in studies related to PD patients [19], gyroscopes are used in some cases [20], in this study, the participants used one bracelet in each forearm, which contained 3 miniature uni-axial gyroscopes measuring the angular velocity of the forearms movements in roll, yaw, and pitch direction. To record the data the patient needed to carry a light-portable data-logger and 12-bit resolution of A/D. This in the first study, in the second study it was used two gyroscopes, data-logger, battery and flash memory in a single small box for more comfort and to extend the battery duration. The study was performed by 10 PD patients and 10 healthy control participants. For the first study the groups performed a protocol of 17 tasks that included, sitting, standing, holding hands in certain angles, climbing stairs and some more common activities, being recorded meanwhile. In the second study the participants were free to perform any daily activity during several hours. The resulted dataset was further analyzed to identify tremors during the two studies.

Combining tri-axial accelerometers and gyroscopes into inertial measurement units (IMUs) is another common type of instrumentation, which exploits information in both linear and angular motion, and in both velocity and acceleration. For example in a study [21] it is used the IMUs on the wrists, thighs and ankles in fifteen PD patients during scripted ADL tasks, such as drinking, dressing, combing hair, buttoning a coat and cutting food. These tasks were performed two time, one before and on after the medication to get the difference in the performance in the worst and in the best state of the patient.

A less common, but still relevant combination, is the combination of accelerometers with surface electromyography, in this study [22] it is used a hybrid sensor constituted by a surface electromyography sensor (SEMG) and a triaxial accelerometer, attached near the origin of the wrist extensor muscle of the dominant arm to detect tremor. The data were recorded for 4 hours during unscripted and unconstrained simulated daily activities, such as washing dishes, setting the table, and making the bed. Using a dynamic neural network (DNN) it was able to detect tremor vs no tremor compared to an annotate video, and it was further used to detect dyskinesia.

2.5 Discussion

Following the literature review we noticed some limitations, the first one is that there is no free-living monitoring at home for PD patients, or it is performed at a clinic or at home but scripted, not having the free-living aspect. Even if not with PD patients the ones that could be carried out at home need some sort of preparation or equipment that are invasive. Most of the monitoring systems don’t give the option to record ADL more complex such as toothbrushing. In cases of questionnaires and diaries the patient would forget to annotate in the book for not being easy and fast to perform.

Chapter 3 – Remote monitoring of ADL for PD

3.1 Context and requirements

In the Datapark project [9] that is already implemented in clinics and is currently working with them helping the clinicians every day giving the clinicians the tools to assess more concrete data of their patients at the clinics, it is given feedback from the clinicians which improves the system incrementally. In one of the feedback sessions it was proposed the creation of a system that would had a method to collect data at home in real time allowing the registration of activities that were made throughout the day, receive train plans by the clinician, grant access to the activities giving the possibility to observe the patient activity at their home and all this being accessible and easy to use. With this proposition of an iteration to the Datapark it appeared this project that led to this thesis.

3.2 Research Goals

The main goal of this thesis is the validation of an approach for recording activities of daily living in uncontrolled environments. Alongside this, the goal to create a sample of a dataset to help in future projects relating monitoring ADL with accelerometers.

3.3 Requirements

As seen in the related work there are some limitations to the current monitoring of ADL at home for Parkinson's patients, one of them is the lack of the free-living component which consists of the patient to do their daily lives without any type of scripts or control from clinicians, for this this projects needs to have a registration system however, the patient will perform the activities at their will when they want and what they want, simulating their normal day. The other case is the lack of ADL registration at home so for this we implemented various activities that could be recorded such as dish washing and dressing up.

3.4 User Scenarios

It was created two different user scenarios to give different perspectives of use for the system, the first one is a PD patient that can live at home and do he's own life as much as possible so he can record the activities himself. The second case is a more severe case of PD and the patient lives at the clinic where the registration task falls over the clinician that follows the patient while he takes care of her.

The first user scenario is about Alexandre João with 56 years old and who is a Parkinson's patient at a clinic however he lives at home, only going to the clinic 3 times a week, he performs some exercises at the clinic for 1 hour and goes back to home. Alexandre takes the medication at the mid of the day, around 2 hours before going to the clinic, as it is known the effects of the medication decay throughout the day, and which degrade the movements with it. The clinicians proposed the patient to use the system so he can be evaluated at home during different times of the day to see the decay speed of the medications and to analyze the degradation of the movements throughout the day at different times of medication levels. Alexandre goes home with the accelerometer bracelet on the arm and the application in his smartphone. The next day he starts to use the application to record him brushing his teeth, the time is recorded on the database. The clinician that is watching over Alexandre schedule a list of activities to him later on the day, so he is sure that the patient is performing some exercises. Later that day after registering all the activities available to record, Alexandre receives a notification on the smartphone asking him to realize the scheduled list of activities. After several days of use, Alexandre goes to the clinic and presents the accelerometer which is downloaded the data from for further analysis.

The second user scenario regards Cristina Afonso that is a Parkinson's patient with 70 years and is currently living in a clinic in which is taken care of and perform exercises and is analyzed in a fixed hour of the day at the lab. On the lab it is performed motor activities that are indeed a good way to evaluate the state of the disease however it is studied that ADL can be proven to give furthermore information about the progression so Cristina volunteered to use the system, nevertheless she doesn't know how to use a smartphone so in this case a responsible clinician will be monitoring and registering Cristina throughout the day in his smartphone. The patient wakes up and goes to the main room area where she eats the first meal while the clinician activated the recording until she ended the activity. Cristina goes to the bathroom to brush her hair and the clinician goes with her, after she finished, the recording is finished as well. During the day it is like the other activities and later in the day she is asked to perform the scheduled list with the clinician present. At the end of the day the accelerometer is collected and downloaded the data to be analyzed. In these two scenarios the data collected allows the clinicians to see the different performed activities with the respective accelerometer values, allowing the visualization of possible disturbance in the movements. With this granting the ability to study the patient's movements at home and/or throughout the day without being in a lab and performing a big variety of activities.

3.5 System overview

In this section it is discussed the different options that were taken into consideration for the monitoring system and the further structure of the chosen method.

3.5.1 Options for the monitoring system

Our main goal was to develop a system capable of monitoring activities of daily living in a non-controlled environment. With this objective in mind and reviewing related work, reviewing the possibility to implement RFID sensors in objects and associate that object to certain activities, however this method would need a lot of preparation for each patient being monitored, which is not optimal regarding the time and the price of each patient case. There were other approaches that were taken into consideration for example the use of a video recording device or the preparation of some electronic devices to detect the usage of them, however these cases are only viable in a controlled space, not the patient home which is our target as an environment. As seen in the related work there was a study that used a type of diary [11][12], taking the compliance problem related to this method into consideration, we incorporated this feature of a diary with the use of an accelerometer like in other studies [1][2][6].

With this monitorization system in mind we started to establish the workflow and the first objective was to determine the method that would be used as the diary component. We concluded that a mobile application would provide the better solution as a diary owing to the fact that it is easier to gather the information in one place quicker, effortless to use in different places and has more room for improvement and implementation of other features.

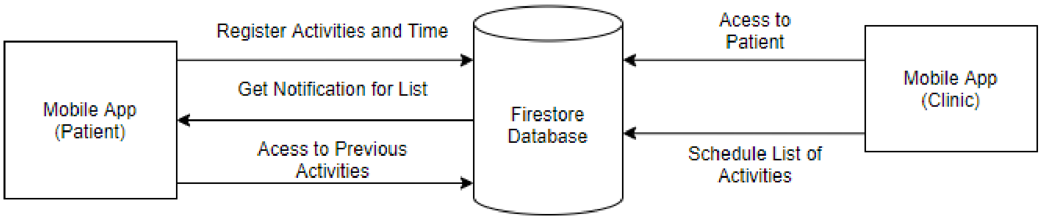


Figure 1- Software structure

3.5.2 System's structure

The structure is built around the database, which is the Firestore Database, Firebase from Google, it was free to use, it has a great accessibility to the Android Studio and an overall good capability in terms of service. In the figure 1 it is represented the structure of our application.

Having in mind that the patient has an internet connection, firstly they create an account that will be their own with their information and data. In this section it is available the basic information asked in the moment of registration, the list of possible activities that the patient can perform (having in mind that each patient have the possibility to create their own activity). When an activity is performed, the starting and stopping time of the recording is saved into the database. The patient can access the last ten activities they realized, allowing them to change the starting or stopping time if it was a mistake or even change the activity itself in case of human mistake (clicking in the wrong activity and recording it the whole time), or delete the activity.

When it is created the list of activities, from the clinician side and the patient side, the database will store a value that will allow the scheduling for the notification in the patient phone.

In the clinician side, when the account is created, they will have an empty list where they can add the patient code to it and after the patient confirmation they will have the access to the patient account, being able to add, change or delete activities and list of activities.

3.6 Mobile Application

The application has two main features, the first one it the diary feature in which the patient is able to select and record the activity that it is being performed at the moment. If the patient makes a mistake and register toothbrushing instead of hair brushing, it is possible to change the last 5 activities, the activity itself or the time that it was started and at what time it ended. Each patient or clinician can create unique activities for them, to provide a wider range of activities that can be recorded and analyzed. When the clinician account is created, they will have a blank list where it can be added patients by their identifier, followed by the patient confirmation in their account, after that pairing the clinician can access the patient account and do the same thing as them, however when an activity is registered, it will have a property identifying if it was the clinician or the patient.

The second feature is a supplemental aspect for the clinicians to have the ability to propose a set of activities to the patient at a certain time of the day. This last feature is compelling due to the fact that the patient will be doing their activities with no supervision and this set of activities will give a bit of control in some parts of the day for evaluation or even just to make the patient due some activities in specific, this scheduling will notify the patient at that specific time of the day.

3.6.1 Registering activities

The main feature is the activity recording which consists in the patient or the clinician overseeing the patient to interact with a list of activities (represented in figure 2a) and select the current activity they are performing at the moment. Interacting with the activity will start a timer that will guide the current user letting them know that it is being recorded denominated activity (represented in figure 2b). To finish the recording the user presses the "*parar*" button or any activity. With this in the clock button it is possible to access to previous recorded activities and edit or delete them.

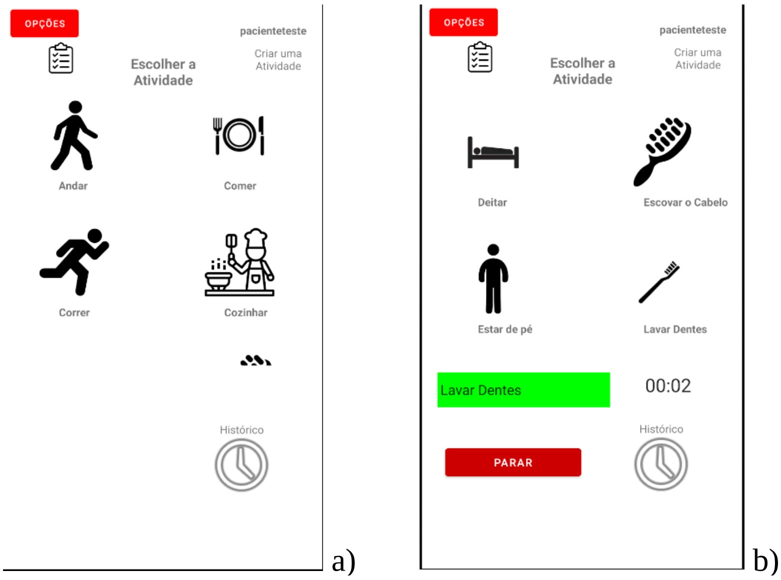


Figure 2- Recording an Activity Layout a) Main screen with the list of available activities b) Activity "*lavar dentes*" selected and being recorded.

3.6.2 List of activities

The other feature is the scheduling of a predetermined set of activities to be performed at a certain time in a certain day. This feature helps the clinicians in a way that they can interact with the patient at home, making the patient do some exercise at home or to have a more controlled activity recording since the activity recording there is being done by the software itself. It is possible to have multiple lists schedule (figure 3a) allowing a bigger diversification in the exercises. Inside each list will be all the activities with the corresponding time (figure 3b). The patient clicks on the Start button and the list starts the countdown, passing from activity to activity automatically, at the end of the list the user will receive a visual pop-up warning them that the list was completed.

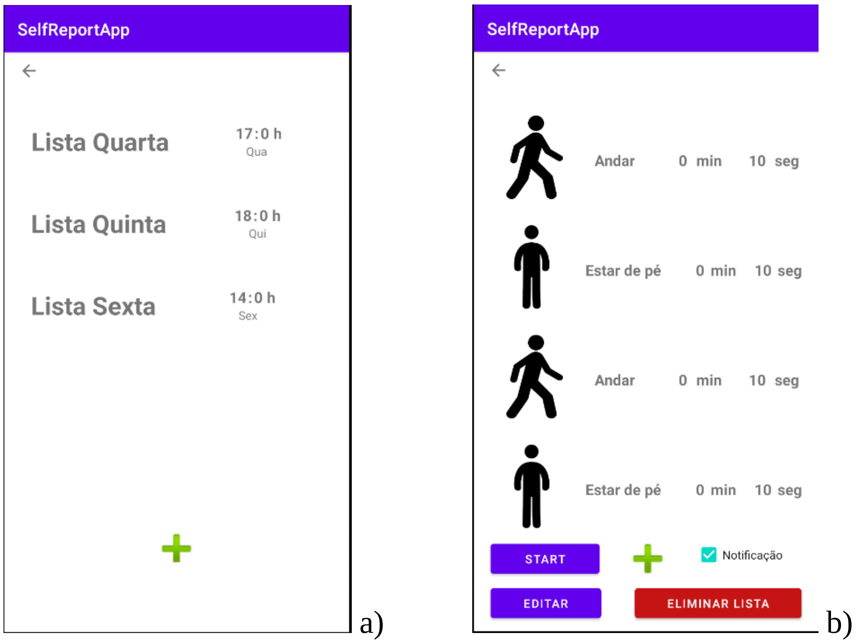


Figure 3- List of Activities Layout a) List of schedule lists b) Inside a list with the activities and their time

3.7 Sensors and data collection

In this section it is explored the collection system functions and how they word, as well a brief explanation about the sensor used alongside the application.

3.7.1 Collection system

It is installed on the participant’s smartphone the application and created an account, with this, it is created a folder on the database with the information given. The participant uses the system throughout the days of the trial, in combination with the accelerometer on a form of a bracelet on their predominant hand, it is advised to use as much as possible however it is only mandatory when the activities are being recorded.

The application uses the internet connection to save the starting time and the end time of the activities recording on the database so it can be used in further analysis and can be followed by the clinicians at real time to see which activities the participants are doing.

The accelerometer will capture the x,y and z acceleration on the dominant arm and save it in the accelerometer own memory card that will be downloaded at the end of the study.

3.7.2 Sensor used

The sensor used for this study was the AX3 accelerometer by Axivity [23]. It is a data logger with a 3-axis Accelerometer, an on-board memory, a temperature sensor, and a time quartz clock that is used to set up the device in each study.

The device detects and store movement, vibrations, and orientation changes in all the 3-axis with a very good precision.

To set-up the device for the studies and to collect the resulting data we used the software OmGui [24], the raw data collected through this software is the 3 axis in a temporal graphic. In the end it is downloaded a CWA file that has the x,y and z acceleration on the arm and for further use in Python it is possible to resample the data for a CSV comma separated file.

Chapter 4 – User study

4.1 Participants

We performed a first study with a colleague from the lab to give us some feedback if the system was working correctly and if it needed some changes before starting the study.

After the given feedback we fixed some bugs, in particularly related to the notification system, the notification would not be triggered at the time that was needed. The connection between clinician and patient was restructured, before it was not needed the confirmation from the patient which would create some bugs and in real cases every clinician would have access to any patient they want, which is not optimal, since each clinician has determinate patients, and it is not correct to access other clinician patient without some sort of control.

After some minor iterations and fixes, we started with the study with 10 participants, with the age ranging from 19 to 50 with most of the participants between 40 and 50, all of them are healthy in terms of motor movements, only one of them used the accelerometer on the left hand (dominant hand) which is demonstrated in table 1.

Table 1 - Participant's information, age and dominant hand

Identifier	Age	Hand
P2	50	Right
P3	24	Right
P4	41	Right
P5	46	Right
P6	29	Right
P7	48	Right

P8	41	Right
P9	48	Left
P10	46	Right
P11	19	Right

4.2 Procedure

It was put together a study to evaluate the application and the accelerometer as a monitorization method for activities of daily living. The study was realized with the help of 10 volunteers that performed the paper of the patient. The role of a clinician was performed by us, scheduling the list of exercises and to oversee the activity of the patients during the day. (The study guide is found on the appendix, in Portuguese)

It was asked to the volunteer to register at least 5 activities during the day and realize 1 list that was purpose by the us once per day, for 3 days.

There was a first meeting that consisted in the explanation of the project, the objectives, how the system worked, giving details, examples of what the volunteer need to do, installation of the application in the participant's smartphone and the filling of a questionnaires to give basic information, email, name, age, and dominant hand. Following with their account creation and association of the patient account to the us, the clinicians. During the following 3 days the volunteers would perform their normal routine and register some daily activities from our list of already predefined activities or even add one activity of their own such as cleaning the floor.

At the end of the 3rd day, it was asked to stop using the bracelet and in the 4th day it was scheduled the interview and questionnaire alongside with the bracelet devolution.

During the interview the participant filled a Google Questionnaire answering to simple questions that are furthered explored, in the interview the participant was asked some questions while the conversation was recorded by a smartphone for further analysis. We decided to do a questionnaire to ask straightforward questions like the System Usability Scale and use a freer method like the interview to explore some questions more openly giving more room for answers.

4.3 Data analysis

The data collected was very helpful to create a small dataset that can be used for a future activity recognition of activities of daily living.

Alongside this, we used the data collected specially from the questionaries and interviews done at the end of each participant to give us feedback about the system to give us the validation of an approach to recording activities of daily living in uncontrolled environments which is the main focus of the thesis.

It was developed a python script to adjust the graphic to a certain activity using the timestamps collected during each participant showing us the axis acceleration during that period of time corresponding to the activity.

For more results it was performed an analysis with the Signal Vector Magnitude (SVM), which allows us to see the differences between participants in each activity and get a classification in the activities about their efforts. This was done using a Python script created by us that uses the activities logs and search on the accelerometer data and does the following equation $\sum\left(\sqrt{x^2 + y^2 + z^2}\right) - 1$, making the sum of all the instances of time from the beginning of the activity until the end.

4.4 Results

For the 10 participants it was collected in total 205 instances of daily activities, which 192 are default activities and 13 were created by the participants as it was told that they could create to give more possibilities of activities to record. The study was performed smoothly with 9 of the participants however with the participant p6 it happened a problem with the participant's internet, and they could not submit the activities on the second and third day. The participant participation was counted in the study since this problem can happen at any time and it is an event that needs to be accounted for, this part will be more clarified on the discussion.

The database is possible to be downloaded as a JSON file and used at free will accessing the different accounts through their unique identifier (UID) which was resumed into a CSV file that has the list of activities for each individual, and the data collected from the accelerometer is available in CWA file. The SVM and its average for all the activities is in the CSV file which facilitates possible future work with the database.

In table 2 it is shown the number of default activities that were collected throughout the study. With some activities having a high record count such as eat, toothbrushing, hair brushing, and some of the activities were less used, run, wash dishes.

The created activities are represented in the table 3, being the sweeping the floor created three times in different participants and driving in two participants.

Table 2- Total number of activities recorded

Name of Activity	Number of Times Performed
Dish Washing	3
Run	4
Lay Down	9
Dress	11
Walk	13
Stand Up	15
Cook	17
Sit Down	20
Hair Brushing	26
Toothbrushing	29
Eat	45

Table 3 – Total number of created activities performed

Name of Created Activity	Number of Times Performed
Write	1
Clean Stairs	2
Drive	2
Sweep Floor	8

With the data that was assembled during our study it gave us the chance to correlate the acceleration in the "patient's" arm in the 3 axes with the activity that they were performing at that specific moment.

Each person does the activities in their own manner, however there are some similarities in certain activities for example the toothbrushing is a common activity that everyone does, brushing their teeth with the toothbrush in certain movements, top to bottom, left to right, circular movements etc.

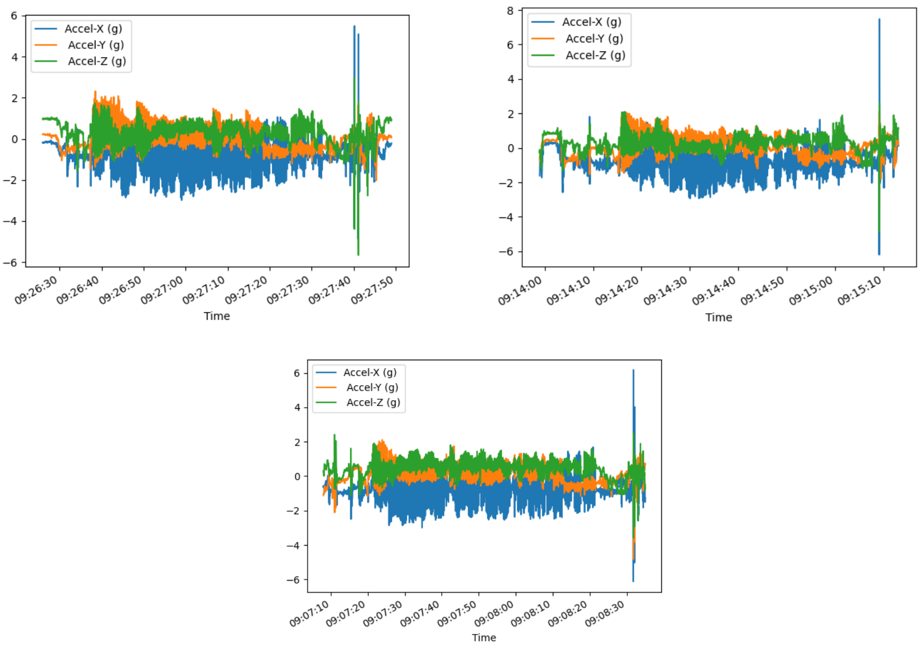


Figure 4- Graphs of the same person (p8) doing the toothbrushing activity

In figure 4 it is possible to detect similarities between them in the pattern that it is represented, showing that this participant performed the activity "toothbrushing" in similar ways in 3 different times, representing that in some cases it is possible to detect patterns of some sort in some individuals, however this is not always true, in figure 5 it is represented 3 instances of the same activity of toothbrushing of other participant, and it is possible to detect a sizeable difference between each instance, confirming that an individual can perform the same activity in different ways each day.

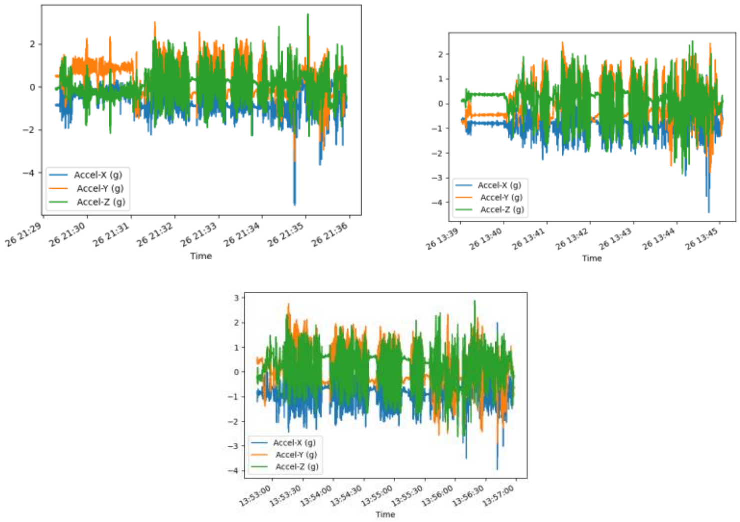
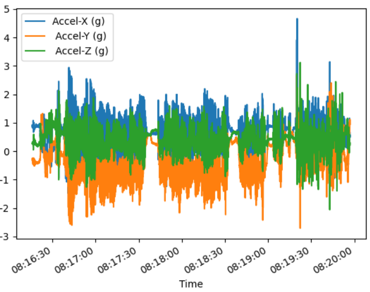
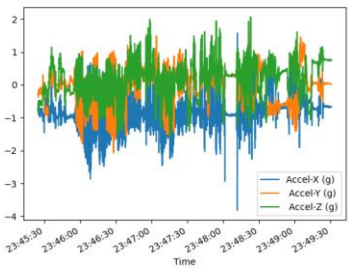


Figure 5 - Graphs of the same person (p10) performing the toothbrushing activity

However, when comparing the same activity from two different persons, the pattern will not be so clear, in the following figure 6 it is possible to see that in the first graphic figure 6a), the values vary much more on the z and y axis, probably the patient does the movement faster than the participant p8, in addiction to that, this participant had some spaces where the acceleration dropped to almost 0, meaning that they stopped brushing in comparison to the non-stop brushing of the first participant p8. The figure 6b)



a)



b)

Figure 6 - Graphs different person same activity a) p10 participant b) p9 participant

participant 9 was much more random, having a different pattern meaning that the toothbrushing movement was not so linear.

With these examples we can identify that each activity can be done in a variety of ways, changing from person to person. And this was in a more restricted activity such as toothbrushing, if we took into consideration the broader activities such as brushing the hair, there will be no similarity at all even with the same person it can be difficult to detect a pattern.

In the figure 7 the two graphics are from the same participant (p4) and there is no visible pattern between the two different instances confirming the affirmation that each person is different.

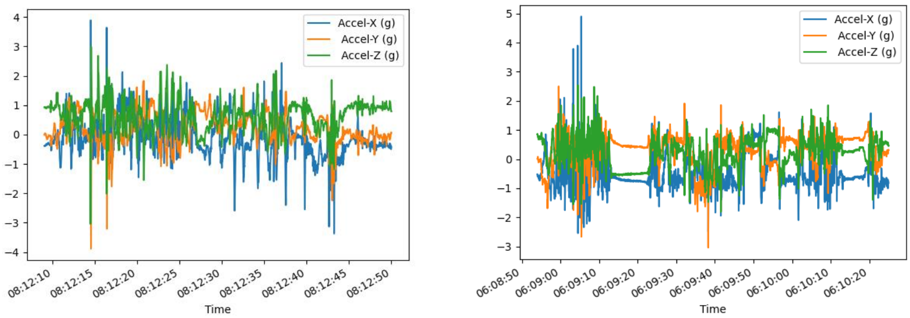


Figure 7 - Graphics participant p4 brushing hair

The list of activities realization was recorded in the database, and we gathered the times that each participant realized the activities, giving us some interesting results that gave us a better perspective on this feature.

In table 4 we can see that 40% of the participants did not carry out the requested standard of one list per day, receiving the notification but forgetting to do the list, or they erased the notification by mistake or would erase thinking they would remember to do when they had time but forgetting along the way, even though one of the 2 participants that did only 2 times, was the case that the participant did not perform anything in the second and third day.

In two cases the participants did more than the requested for a reason, in the interview phase they clarified that they didn't know if the first list they did was saved, so they did it again just for safety. This happened because there is no confirmation of the list realization besides the pop-up that appears at the end of each session.

Table 4 - Number of performed list of activities

Number of Times Concluded	Number of Participants
<2	2
2	2
3	4
4	1
>4	1

4.4.1 Usability

Our method to validate and evaluate our system was to have a questionnaire consisting in a usability questionnaire with predefined questions from the System Usability Scale (SUS) which is essential to determine if the system is favorable in terms of usability (Questions in appendix). Besides these questions, there were more specific questions towards the study.

These questions were given to the participants several options to answer, totally disagree, disagree, don´t disagree or agree, agree, totally agree, and at the end it was asked the confidence that each patient have in their activity recording, and the final question were if the patient were to do a week monitorization how much activities they would feel comfortable to do at minimum during the day. The questionnaire answer results (presented on the appendix) shown us some results:

- The system needs some changes so it can be used without a technician's help and with much ease (4^{th} question two participants said they needed help from a technician to use the system, 10^{th} question two participants said they would need to learn a lot before using the system)
- The functions need to be refined and more stable (5^{th} question one participant answered that the functions were not very well implemented)

In the 6^{th} question one person said there was inconsistency in the system, however the person in question contacted me and was a problem where the back button on the phone would ruin the application, the issue was resolved since it was the first participant.

4.4.2 Users' perceptions

In the phase of the interview, it was asked to the participants a few questions predetermined, giving them a more open way to speak and give their opinions while maintaining a structure in all the interviews. The questions can be found in the appendix on the questionnaire. In this phase there are some points that we found interesting to analyze and discuss them.

No one created their own list

At the beginning of each participant study, it was said to them that they could create their own list instead of doing the predefined one by us. Even with this message, in the end there was not even one list created by the participants. This suggesting that it does not benefit the user at all, since they are being evaluated and are not so sure what they can do, meaning that if they created a list, probably they would fear of doing something wrong, preferring to do the predetermined list.

Receiving the notification was not enough

When it was performed the interview, it was asked if it was easy to perform the list of activities suggested by us. It was stated by the participant who didn't perform the list, that they received the notification however they would erase it and forget to do it later, or even erase the notification by mistake and forget to see the daily list.

No confirmation of completion of the daily list of activities

Two participant that completed the daily lists more than it was asked (1 per day), in the interview they expressed their mistake. They would do the list one time, not seeing the pop-up that appeared at the end of the list and they didn't know if the list was completed, making them perform the same list again. This happened because there is no sort of confirmation besides the pop-up, creating the need for a sign in the list overview if it was completed or not in that day.

Locking screen would stop the recording

In one participant, it was mentioned that when recording an activity and having the smartphone lock the screen it would stop the recording of the activity, it only happened to one patient, even though it is an improvement that should be taken into consideration.

Application not compatible with smaller phones

One participant's phone was a lot smaller, the application was not adapted to that kind of display, which made the registration more difficult, the participant would not have access to the stop button, only allowing to stop the activity by pressing other activity which created some confusion at the beginning.

Smartwatch as a registration method

One of the questions was if the possibility to use a smartwatch that would have the same task as the smartphone would be better than the current system, the smartwatch would allow the patient to record the activity without the need to reach for the smartphone, this iteration would not be so suitable to Parkinson's patients however they would have some benefits such as:

- Easier access to the registration of an activity
- Faster reach for the registration
- Some users would prefer another method besides the constant use of the smartphone giving more flexibility
- It would possibly allow the use of the embedded accelerometer in some of the smartwatches, removing the need to use a bracelet only for the accelerometer.

However, it would come with some disadvantages as well:

- More battery use from the smartphone and the addition of other battery device.
- For Parkinson's patient it would be impossible to use taking into consideration the small screen that are available in the smartwatches, so, it would only be used for persons with a healthy motor system.
- They are not so communally used, some users could have a difficult time using it, since smartwatches are not so common as smartphones and a lot of people don't know how to use them.

Audio log as a registration method

Alongside the smartwatch question it was asked to the participants regarding an audio recording system, in this case, the recording would be performed via audio, which means that when a user would start an activity they would speak to the smartphone and say for example "running", and when finished the user would press stop. However only 2 participants said that it would be easier to record the activities. The others said that speaking to the phone would be weird or not so practical since they were comfortable to use the smartwatch. We don't know if it is truly related however the only 2 participants in favor of the audio system were the older participants, making a point that older people would tend to prefer the audio system since it has less contact with the technology that they are not so familiar. This leading to a point that the audio system for the PD patient probably would be more reasonable since it is not needed a finer movement as such for the smartwatch, and it is easier to understand for people that are not so familiar with the smartphone technology.

4.4.3 Signal Vector Magnitude (SVM) in different activities

The SVM gives the average energy expenditure for the activity in question. It was calculated for each participant the average for the activities, with a quick analysis it is possible to see the different levels of energy expenditure varies from person to person, table 5 represents the SVM for an activity that vary in the movements a lot, a person eating will do a great variety of movements and it is not linear what movements each person will perform during each recording. With this it is possible to see a great variety in the intensity. Even if the activity is more linear for example, walking the deviation will be higher as well, showing that even if the activity is simpler, each individual will have higher or lower energy expenditure activity than others, in the case of walking, the rhythm or speed of each step is different from participant to participant.

Table 5 - SVM of eating and walking in different participants, average and deviation. Ex: 0.03+-0.01

Participant	Eat	Walk
P2	0.01134	0.04306
P3	0.023033	0.077287
P4	0.014577	0.048999
P5	0.023267736	0
P6	0.012725764	0.133083414
P7	0.008383	0.049827
P8	0.009046	0.068846
P9	0.009511681	0.040813222
P10	0.013900695	0.105685508
P11	0.005556489	0.065046457

Average	0.013134157	0.070295245
Deviation	0.005626424	0.029356647

This evaluation served to us to see the different levels of energy expenditure in all the activities recorded during the study, in figure 8 it is represented the average SVM of all the participants with the corresponding standard deviation to give a better view on how the values can change from participant to participant, taking into consideration that write and clean stairs have only one participant doing the activity so there is no standard deviation. Figure 8 serves to categorize the activities into different levels of energy expenditure it is possible to distinguish that some activities have much higher SVM than others, higher the value, higher the energy expenditure meaning that the movement of the wrist is much faster on those activities (this taking into consideration that the accelerometer is worn on the wrist).

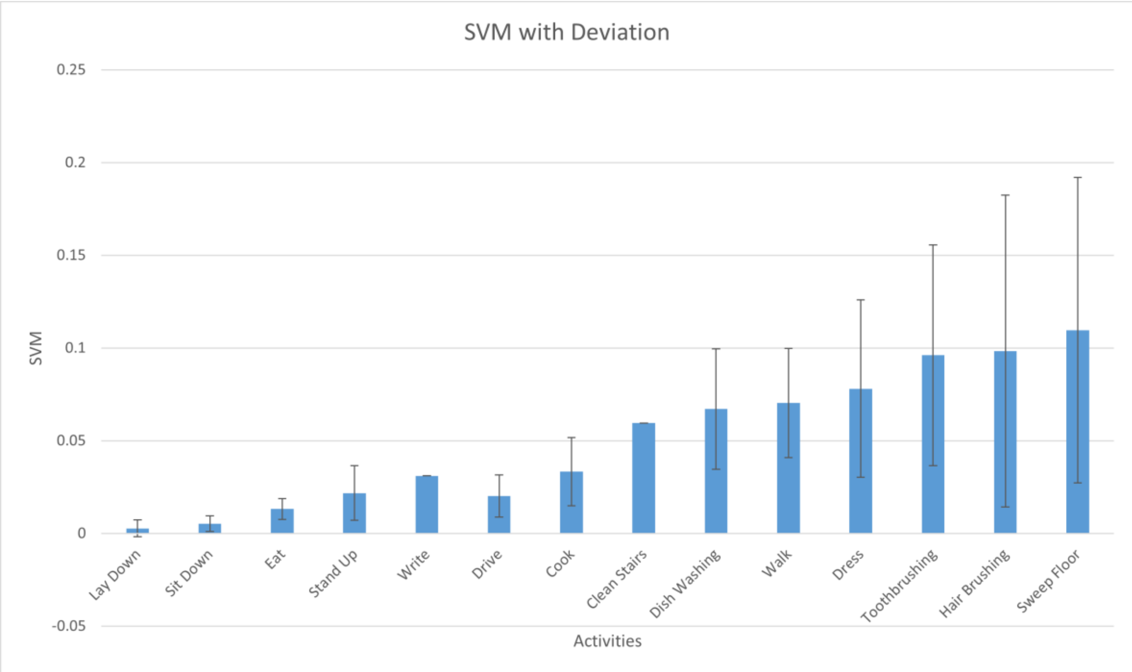


Figure 8 - Average SVM of all the participants in all activities.

4.5 Discussion

With the results defined in the previous subsection it is possible for use to draw some conclusions and discuss about such. The discussion is divided into two sections since we had the objective to create a dataset that can help further investigation and the other objective is the validation of the system as a collection method for activities of daily living in Parkinson's patients.

4.5.1 Database sample

With this database it is possible to use it as a source of learning for a machine learning tool since it has a comprehensive number of samples. This database achieves several purposes:

- Gives 10 samples of different people performing various ADL in different times of the day.
- These samples have information for the 3 axes at the current time.
- SVM for each activity in each person.
- SVM for the entirety of the population for all the activities.

4.5.2 Validation of system

There were some relevant problems that affected the monitoring during the study.

For simplification it will be shown the problems that appeared during the study and respective possible solution:

Participant can't record without internet:

One way to solve this, is the implementation of a local save that happened within the smartphone and it is deleted if the connection with the database is established, if it is not established the connection, it will save the recordings until the connection is initiated successfully.

Participants didn't realize the list of activities even with the notification:

A simple way to mitigate this issue is the addition of a visual notification on the main screen like a red symbol on the list button that would represent unfinished tasks on that day and when the list was completed the red symbol would disappear until the next day of a schedule list.

Nocturnal mode is not compatible with the application

Only after the beginning of the study and the detection of this error it was searched a way to enable the use of the application with the nocturnal mode on the smartphone turned on without messing with the display of the application. A straightforward solution would be to implement a setting that disables the change in the application display with the nocturnal mode switched on. In most of the cases during the study it was requested to the participant to turn the setting off which is kind of an inconvenient to the users, however one participant didn't want to change and used anyway with minor difficulties.

Not possible to see the list of activities history

As referred in the interview section, two participants performed the list of activities more than once since they didn't know if the list have been recorded successfully. One way to solve this problem would be the implementation of a history button inside each list to see each day it was completed, showing the date and if it was completed or cancelled.

These were the predominant problems that were collected from the interviews and data collection, however there are improvements that we took into consideration since it would improve the quality of the application and give a more ease of use.

Figure 9 -Edit history screen on application

In the history page, changing the time can be quite confusing

In figure 9 it is represented an example of a screen when editing an activity history, and the date is kind of hard to manage even for people without the Parkinson's disease, taking in consideration the disease it cannot be sensitive to typical convulsions. A solution would be to implement kind of an incremental and decremental buttons for the time, that would go up and down each second, since it would be unlikely to change the day, this function should be used to adjust little mistakes in time.

Chapter 5 – Conclusions

In this thesis we developed and assessed an approach to the monitorization of daily activities at home with the objective to give a more stable way to evaluate Parkinson's disease degradation throughout the day, enable the monitorization beyond the clinic and allow the evaluation of ADL.

The results indicate that the system is working properly, with some few improvements and more studies the monitorization system should be a great way to monitor Parkinson's patients at home helping a lot of clinics.

5.1 Limitations

The Covid-19 pandemic changed our plans of doing the study with Parkinson's patients which unfortunately removed the feedback for the accessibility from our target population. However, we did get feedback from healthy volunteers which is not what we intended initially but it was useful feedback anyways.

Another obstacle that appeared was the limitation in the number of available accelerometers for the study, which was 1 bracelet for the whole study, if it was possible to acquire more, we could have had a much bigger dataset and more reliable material. Nevertheless, we did our best and studied 10 volunteers which is an acceptable number for population.

Limitations that occurred because of the application were the need for internet to use the application, if the participant didn't have an internet connection the recording would not work, making the application unusable. Other limitation in this section is that the nocturnal mode is not compatible with the application, making it almost unreadable.

5.2 Possible future iterations

Over the course of the project, some possible iterations to the system emerged and they are relevant enough to be presented in the section with possible implementations.

Offline save

The most important iteration is the implementation of a method to store the recording in the device when there is no internet connection and when the internet is available it would be erased from the device and saved in the database.

Widget for recording

Another iteration would be the addition of a widget to the smartphone application in which the user would not need to open the application each time they wanted to record an activity, removing some time of the process, and giving a higher flexibility to the use of the application.

Accelerometer connection and real time save in the database

Other good iteration would be the implementation of a connection from the accelerometer to the application, allowing the saving of the data in real time to the database, having some advantages:

- Real time visualization of the accelerometer activity on the database.
- Simplify the end of the study, instead of downloading the data from the accelerometer, the data would be on the database without the need of extra steps.

With this it would come with some drawbacks:

- Bigger internet usage, since it is transferring real time data to the database with a big sample-rate.
- More battery use on the accelerometer and smartphone.

Accessibility adjustments

A necessary iteration would be an accessibility change, making the application easier to use for older people and Parkinson’s patients taking into consideration their reduced movements capabilities. This could be done, simplifying the history panel with the ability to change dates with incremental values in the seconds, more 5 seconds, less 5 seconds, etc. All this with big buttons in a different panel with visible text. In the registration panel, it would be better to have delimiters for each activity and much more explicit icons.

Video session with clinician while doing the list of activities

In the list of activities, it would be interesting to add the possibility of a video session with the clinician to allow the clinician to overview the list of exercises and gather some notes with the help of the smartphone camera, giving an even more connection between patient and clinician.

Study with patients with Parkinson's Disease

A future study with Parkinson's patient would be mandatory, since it is the population focus it would supply feedback for the accessibility which we know is not the best, even more for patients with Parkinson's.

Bibliography

[1] W. Y. Cheng *et al.*, “Human Activity Recognition from Sensor-Based Large-Scale Continuous Monitoring of Parkinson’s Disease Patients,” *Proc. - 2017 IEEE 2nd Int. Conf. Connect. Heal. Appl. Syst. Eng. Technol. CHASE 2017*, pp. 249–250, 2017, doi: 10.1109/CHASE.2017.87.

[2] A. Weiss, S. Sharifi, M. Plotnik, J. P. P. Van Vugt, N. Giladi, and J. M. Hausdorff, “Toward automated, at-home assessment of mobility among patients with Parkinson disease, using a body-worn accelerometer,” *Neurorehabil. Neural Repair*, vol. 25, no. 9, pp. 810–818, 2011, doi: 10.1177/1545968311424869.

[3] M. Buettner, R. Prasad, M. Philipose, and D. Wetherall, “Recognizing daily activities with RFID-based sensors,” *ACM Int. Conf. Proceeding Ser.*, pp. 51–60, 2009, doi: 10.1145/1620545.1620553.

[4] S. Pan, M. Berges, J. Rodakowski, P. Zhang, and H. Y. Noh, “Fine-grained recognition of activities of daily living through structural vibration and electrical sensing,” *BuildSys 2019 - Proc. 6th ACM Int. Conf. Syst. Energy-Efficient Build. Cities, Transp.*, pp. 149–158, 2019, doi: 10.1145/3360322.3360851.

[5] F. Bergeron, S. Giroux, K. Bouchard, and S. Gaboury, “RFID based activities of daily living recognition,” *2017 IEEE SmartWorld Ubiquitous Intell. Comput. Adv. Trust. Comput. Scalable Comput. Commun. Cloud Big Data Comput. Internet People Smart City Innov. SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI 2017 -* , pp. 1–5, 2018, doi: 10.1109/UIC-ATC.2017.8397548.

[6] L. Brognara, P. Palumbo, B. Grimm, and L. Palmerini, “Assessing Gait in Parkinson’s Disease Using Wearable Motion Sensors: A Systematic Review,” *Diseases*, vol. 7, no. 1, p. 18, 2019, doi: 10.3390/diseases7010018.

[7] C. Link *et al.*, “A Web-Based System for Home Monitoring of Patients With Parkinson’s Disease Using Wearable Sensors,” vol. 58, no. 3, pp. 831–836, 2016.

[8] C. Zhang and Y. Tian, “RGB-D Camera-based Daily Living Activity Recognition,” *J. Comput. Vis. Image Process.*, vol. 2, p. 12, 2012, [Online]. Available: http://media-lab.ccny.cuny.edu/wordpress/Publications/NWPJ-201209-15-CameraReady.pdf.

[9] D. Branco, J. Ferreira, R. Bouça, and T. Guerreiro, “Designing free-living reports for Parkinson’s disease,” *Conf. Hum. Factors Comput. Syst. - Proc.*, no. May, 2019, doi: 10.1145/3290607.3313032.

[10] A. G. E. M. De Boer, W. Wijker, J. D. Speelman, and J. C. J. M. De Haes, “Quality of life in patients with Parkinson’s disease: Development of a questionnaire,” *J. Neurol. Neurosurg. Psychiatry*, vol. 61, no. 1, pp. 70–74, 1996, doi: 10.1136/jnnp.61.1.70.

[11] R. A. Hauser *et al.*, “A home diary to assess functional status in patients with Parkinson’s disease with motor fluctuations and dyskinesia,” *Clin.*

Neuropharmacol., vol. 23, no. 2, pp. 75–81, 2000, doi: 10.1097/00002826-200003000-00003.

[12] R. A. Hauser, H. Russ, D. A. Haeger, M. Bruguiere-Fontenille, T. Müller, and G. K. Wenning, "Patient evaluation of a home diary to assess duration and severity of dyskinesia in parkinson disease," *Clin. Neuropharmacol.*, vol. 29, no. 6, pp. 322–330, 2006, doi: 10.1097/01.WNF.0000229546.81245.7F.

[13] R. Balestrino and A. H. V. Schapira, "Parkinson disease," *Eur. J. Neurol.*, vol. 27, no. 1, pp. 27–42, 2020, doi: 10.1111/ene.14108.

[14] A. Samà *et al.*, "Estimating bradykinesia severity in Parkinson's disease by analysing gait through a waist-worn sensor," *Comput. Biol. Med.*, vol. 84, no. January, pp. 114–123, 2017, doi: 10.1016/j.compbiomed.2017.03.020.

[15] J. I. Hoff, A. A. Plas, E. A. H. Wagemans, and J. J. van Hilten, "Accelerometric assessment of levodopa-induced dyskinesias in Parkinson's disease," *Mov. Disord.*, vol. 16, no. 1, pp. 58–61, 2001, doi: 10.1002/1531-8257(200101)16:1<58::AID-MDS1018>3.0.CO;2-9.

[16] J. I. Hoff, V. Van Der Meer, and J. J. Van Hilten, "Accuracy of Objective Ambulatory Accelerometry in Detecting Motor Complications in Patients with Parkinson Disease," *Clin. Neuropharmacol.*, vol. 27, no. 2, pp. 53–57, 2004, doi: 10.1097/00002826-200403000-00002.

[17] M. Ruzzon, A. Carfì, T. Ishikawa, F. Mastrogiovanni, and T. Murakami, "A multi-sensory dataset for the activities of daily living," *Data Br.*, vol. 32, p. 106122, 2020, doi: 10.1016/j.dib.2020.106122.

[18] S. Patel *et al.*, "Analysis of feature space for monitoring persons with parkinson's disease with application to a wireless wearable sensor system," *Annu. Int. Conf. IEEE Eng. Med. Biol. - Proc.*, pp. 6290–6293, 2007, doi: 10.1109/IEMBS.2007.4353793.

[19] J. E. Thorp, P. G. Adamczyk, H. L. Ploeg, and K. A. Pickett, "Monitoring Motor Symptoms During Activities of Daily Living in Individuals With Parkinson's Disease," *Front. Neurol.*, vol. 9, no. December, 2018, doi: 10.3389/fneur.2018.01036.

[20] A. Salarian, H. Russmann, C. Wider, P. R. Burkhard, F. J. G. Vingerhoets, and K. Aminian, "Quantification of tremor and bradykinesia in Parkinson's disease using a novel ambulatory monitoring system," *IEEE Trans. Biomed. Eng.*, vol. 54, no. 2, pp. 313–322, 2007, doi: 10.1109/TBME.2006.886670.

[21] C. L. Pulliam, M. A. Burack, D. A. Heldman, J. P. Giuffrida, and T. O. Mera, "Motion sensor dyskinesia assessment during activities of daily living," *J. Parkinsons. Dis.*, vol. 4, no. 4, pp. 609–615, 2014, doi: 10.3233/JPD-140348.

[22] B. T. Cole, S. H. Roy, C. J. De Luca, and S. H. Nawab, "Dynamic neural network detection of tremor and dyskinesia from wearable sensor data," *2010 Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBC'10*, pp. 6062–6065, 2010, doi: 10.1109/IEMBS.2010.5627618.

[23] "Axivitty AX3 Accelerometer." https://axivity.com/product/ax3.

[24] "OmGui software for AX3." https://github.com/digitalinteraction/openmovement/blob/master/Docs/omgui/index.md.

Appendix

4.2 Procedure

Guide used for the study

Guião de Estudo

Duração das sessões: 3 dias

Links para questionários

Participação no estudo: https://docs.google.com/forms/d/1QBIZQH3PDbp2c44hd14uZqW9r7fwSdeoJS2WlnxXHEk/edit

Questionário pessoal:

https://docs.google.com/forms/d/11qOAW0TLIRRIxsrR1nFt5IKHwLwZ-JgWg5I5Dy5tUr0/edit

Questionário Final:

https://docs.google.com/forms/d/1BnzGGfPcEGHWwJ3ehvAiRzScjEc6wS6Wjcz6g5e1ccQ/edit

Mensagem de divulgação

Olá! Estamos a convidar utilizadores de Android para participar num estudo sobre monitorização de atividades do dia-a-dia, que tem como objetivo validar o método de monitorização e a usabilidade da aplicação. Se tiver interesse em participar preencha este formulário

https://forms.gle/KxBof7xfCB4H6Ptb6

Obrigado!

- Introdução e contexto

Bom dia, o meu nome é Pedro Russo, estou a realizar a minha tese de mestrado em informática pela faculdade de ciências da universidade de lisboa.

A minha dissertação centra-se na criação de um dataset para a monitorização em casa de pessoas com Parkinson. Para esse efeito, foi desenvolvida uma aplicação móvel que permite o registo manual das atividades e em conjunto com acelerômetros AX3, permite coletar valores dos sensores associando a respectiva atividade realizada no momento. Para além da colecção de dados, também fornece a oportunidade de pedir ao paciente para realizar certas atividades a certas horas para facilitar a conexão entre paciente e clínico.

Neste estudo pedimos a utilização da aplicação móvel durante o dia-a-dia e que tentem realizar as tarefas propostas, isto enquanto estão a utilizar a pulseira. A duração deste estudo será de 3 dias.

O estudo tem como objetivo aferir a usabilidade da aplicação e testar a metodologia que pretendemos. Os dados recolhidos irão permitir obter uma base de dados que servirá de ponto de partida para futuras investigações nesta área.

PROCEDIMENTO DO ESTUDO

Preenchimento do questionário de participação:

https://forms.gle/iBH6mAzJvuJ2oCn17

(Presencial)

Introdução e contexto

-Preencher questionário de informação

https://forms.gle/JBBDtuC94rnZpo3G6

Instalar a aplicação

-Demonstração da pulseira - Demonstração de como funciona e se deve colocar a pulseira.

A utilização da pulseira vai feita na sua mão predominante.

-Experimentar a app – Pedimos que realize as seguintes tarefas

-Criar a sua conta como paciente

- Criar uma lista clinico e agenda notificação para 10 min depois

- Ande durante 10 segundos e registe na aplicação

- Criar uma atividade nova

-Editar uma atividade já feita

-Aceite o pedido do clínico

-Realize a lista de atividades proposta pelo clínico

- Criar uma lista de atividades

- Criar a lista e preparar agendamento para as tarefas em casa

Falar da parte das notificações e preparar o agendamento

(Em casa)

Durante os 3 dias de estudo irá ser-lhe pedido:

-Realizar as listas de atividades pedidas pelo clínico – O "clinico" irá ter acesso á sua conta e irá sugerir uma lista de atividades a certas horas (dentro do que respondeu no questionário, máx. 5 min, 1 vez ao dia). (Andar, correr, estar de pé, sentado) Com os possíveis seguintes nomes:

Lista Estudo 1, Lista Estudo 2, Lista Estudo 3

-Registar pelo menos 5 atividades durante o dia que realizou enquanto utiliza a pulseira – Dentro das suas possibilidades, registe alguma das atividades predefinidas ou crie uma atividade, se quiser registar mais de 5 atividades ainda melhor. Pode utilizar a criação de listas para gravar as atividades realizadas, e/ou criar uma atividade que não está presente.

No final dos 3 dias irá ser contactado para uma entrevista final e irá receber um relatório com um resumo da sua atividade física durante esses dias. O sensor será devolvido.

(Entrevista presencial)

https://forms.gle/FY2skyTWVqY2itdKA

Questões

- Quanto tempo utilizou a aplicação por dia?
- registo de atividades foi de fácil utilização, teve algum problema?
- Relativamente à lista de atividades foi fácil a realização da lista proposta?
- Chegou a criar alguma lista sua? Foi fácil? teve algum problema?
- Como foi a experiência de anotar atividades ao longo do dia?
- Se o método não foi o melhor, explorar alternativas, smartwatch, voz, outras.
- Sobre os dois métodos que lhe pedimos para registo de atividades, usando uma lista pré-definida com horário para realizar as atividades,

ou ir registando as atividades ao longo dia, existiu diferença no que diz respeito ao esforço para reportar estas atividades?

- Tem alguma sugestão para adicionar à aplicação original?

– Questionário

No mail inicial vai-lhe ser enviado um link para no fim do estudo preencher, com um questionário de usabilidade e umas perguntas de resposta aberta.

4.4.1 Usability

The SUS questionnaire is composed by the following questions:

- I think that I would like to use this system frequently.
- I found the system unnecessarily complex.
- I thought the system was easy to use.
- I think that I would need the support of a technical person to be able to use this system.
- I found the various functions in this system were well integrated.
- I thought there was too much inconsistency in this system.
- I would imagine that most people would learn to use this system very quickly.
- I found the system very cumbersome to use.
- I felt very confident using the system.
- I needed to learn a lot of things before I could get going with this system.

4.4.2 Questionaries and Interview

Questionaries answer results

Subtitle translation (the questionnaire was performed in Portuguese):

Blue – Totally disagree

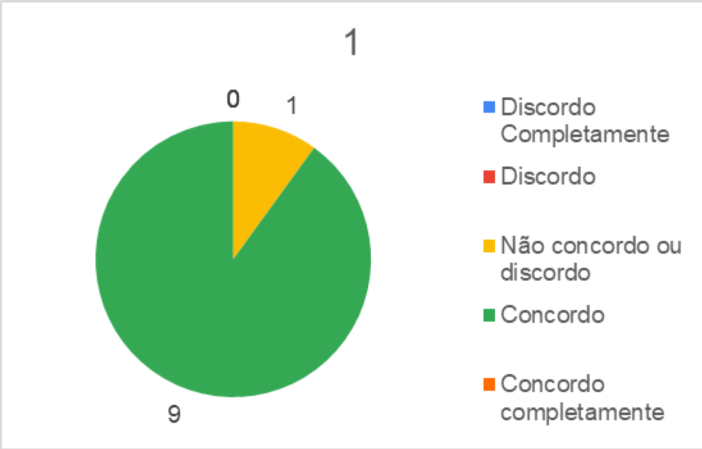
Red – Disagree

Yellow – I don’t agree or disagree

Green – Agree

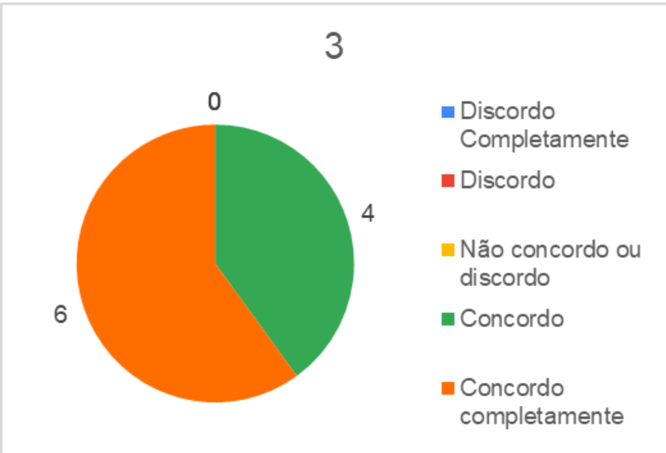
Orange – Totally agree

1- I think that I would like to use this system frequently.

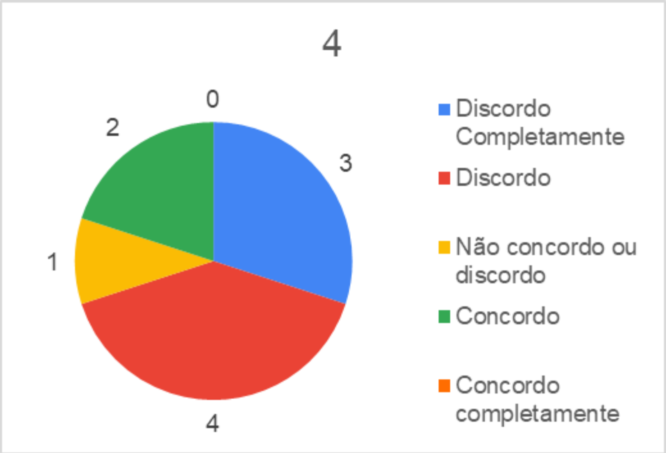


2- I found the system unnecessarily complex.

3- I thought the system was easy to use.



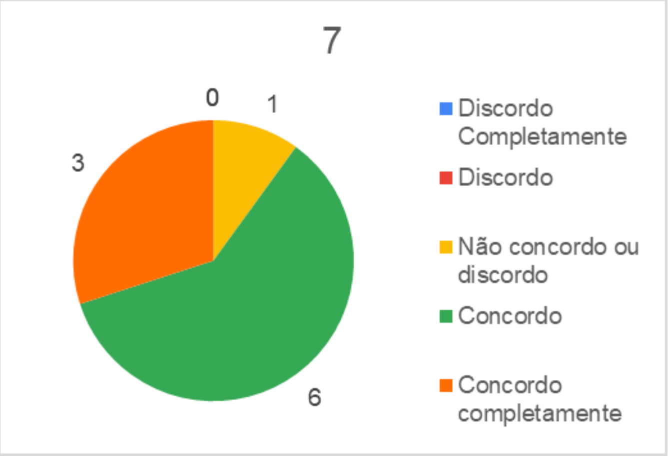
4- I think that I would need the support of a technical person to be able to use this system.



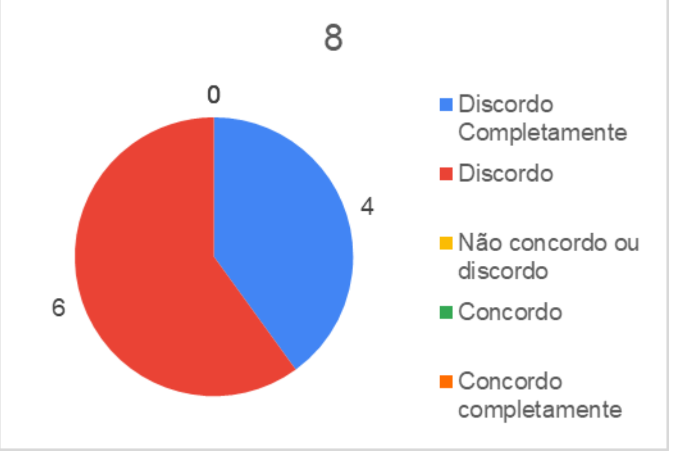
5- I found the various functions in this system were well integrated.

6- I thought there was too much inconsistency in this system.

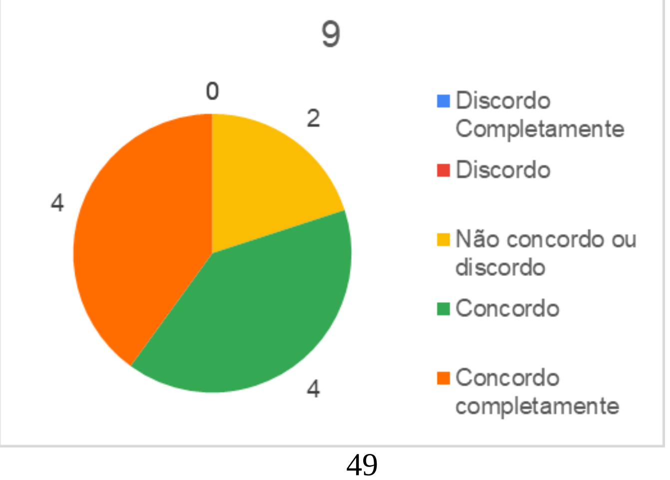
7- I would imagine that most people would learn to use this system very quickly.



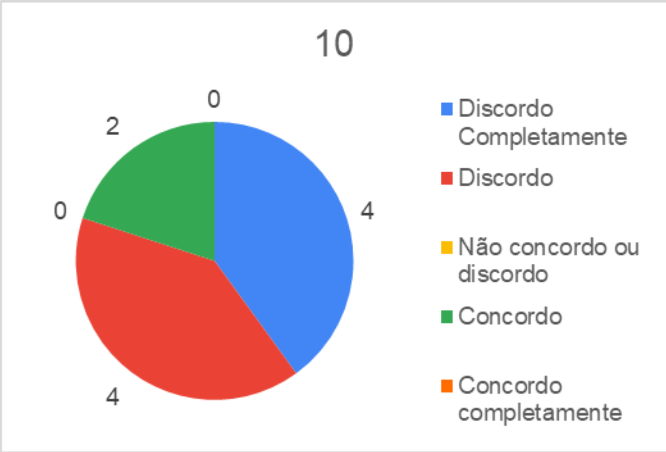
8- I found the system very cumbersome to use.



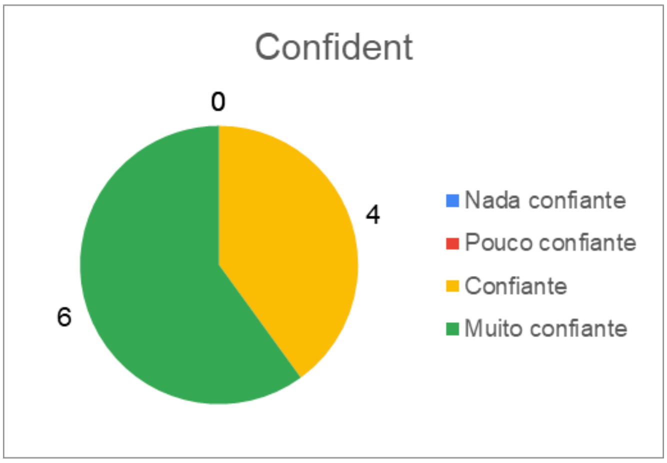
9- I felt very confident using the system.



10- I needed to learn a lot of things before I could get going with this system.



How confident are you that the period you wrote down was correct?



How many activities would you think it reasonable to ask to register if you had to do the study for 1 week?