STOP: A smartphone-based game for Parkinson's disease medication adherence

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Abstract

Parkinson’s disease (PD) is a second most common neurological disorder that affects up to 10 million people worldwide. However, in spite of this vast number of patients, there is still no universal and applicable for everyone type of treatment. The current way of PD handling is followed by semiannual clinical visits with observations on the place and the corresponding medication prescription. However, the problem is that PD has an evolving nature and its symptoms may vary several times per day. Thus, the current way of observation does not provide a full picture of the disease and makes the personal treatment plan customization impossible. This study aims at the development of a new way of patient observation via mobile devices that can increase the patients’ medication adherence. The outcome of the study is the mobile application that leverages smartphone’s inbuilt sensors in order to keep track of subject’s state of health during the day. In order to encourage patients to regularly follow health sampling, the application uses gamification approach: the sampling sessions are implemented as a short-term accelerometer-based game that asks patients to play it several times per day. Along with it, with the use of smartphones notifications, the application reminds patients to take medications on time and record the timestamps to the application medication journal. The designed application will be used as a tool for continuous observation on the PD patients. The combination of datasets collected with the application can be used in the future studies in order to estimate the correlation between the medication effect and the severity of PD during the day.

Keywords
Parkinson's disease, smartphone, gamification, design science research

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Foreword

I would like to thank my supervisors Dr. Dorina Rajanen and Dr. Denzil Ferreira for the great amount of help that they provided me during this thesis study. Also, I want to thank the members of the Project STOP for the opportunity to conduct the study as a part of the project and for their help. Finally, I want to thank all the volunteers who have participated in the artifact evaluation study and provided me the valuable feedback for this thesis.

Valerii Kan

Oulu, May 26, 2018

Abbreviations

DSR	Design Science Research
IoT	Internet of Things
IS	Information System
PD	Parkinson's disease
STOP	Sentient Tracking of Parkinson’s
UI	User interface
VCS	Version Control System

Contents

1. Introduction

Parkinson's disease (PD) is a progressive neurological disorder that influences human movement functionalities and complicates patients' daily life. PD has an effect on both the patient's physical and mental health status – along with tremor, slowing down and obstruction of body movements, it also becomes a reason for psychological and behavioral changes that break the subjects' routine (Vega, Jay, Vigo, & Harper, 2017). According to Vega (2016a), the amount of people affected by PD in the world varies from seven to ten million. Moreover, Dorsey et al. (2007) state that the number of patients tends to increase: the study projects that the number of patients living in five Western Europe's and ten world's most populous countries will double during the period from 2005 to 2030. However, despite the fact that the number of Parkinson's patients is high, there is still no universal and effective treatment method for the diseased.

Traditional treatment of PD is followed by clinical measurements and corresponding medicine prescriptions that are performed only twice per year (Vega et al., 2017). The problem with this approach is that PD evolves and its symptoms may vary several times per day. Semiannual clinical probes take into consideration only time-bounded patient condition markers but cannot provide the overall picture of the state of health and as the result, it is impossible to adapt the treatment program according to the personal needs (Sharma et al., 2014).

In order to make the treatment process of PD more customizable and increase the effectiveness of therapy, The University of Oulu, Carnegie Mellon University, The University of Manchester, Haltian Oy and Head Instruments Oy collaborate in the Project STOP (Sentient Tracking Of Parkinson's), funded by the Academy of Finland. The purpose of the project is to develop the analyzing infrastructure consisting of smartphones, wearable devices, and Internet of Things (IoT) components that would be applicable for PD symptoms tracking in an unobtrusive manner and do not affect the patient's daily life. The project starts with the instrumentation development stage, which is followed by data collection, its analysis and estimation and medication dosing adaptation (Center for Ubiquitous Computing, 2018). The Project STOP has started in January 2018 with instrumentation design stage and would be conducted in two years. The project timeline is represented in Figure 1.

This Master Thesis is conducted as the first working package of the Project STOP and is focused on instrumentation tools design that would be used for patients' symptom tracking and data collection. The purpose of the study is to design the application for Android smartphones that will increase the medication schedule adherence for PD patients. The study is focused on the opportunity of using gamification approach and Android devices inbuilt components in order to develop the application that will bond the use of smartphones and regular health status tracking. By collecting device's sensors data, medication taking timestamps and health status feedback from users it will be possible to estimate the effectiveness level of medication treatment flow. The gamification component of the application will be implemented as an accelerometer-based game with customizable parameters. The need of definition and validation of default parameters of the game will be covered with the lab evaluation conducted in the Center for Ubiquitous Computing. The study results will be defined as a standard and will be used in the game by default. Moreover, the application will utilize smartphones' notification component in order to remind patients to use the application on a regular basis and take the medications on time.

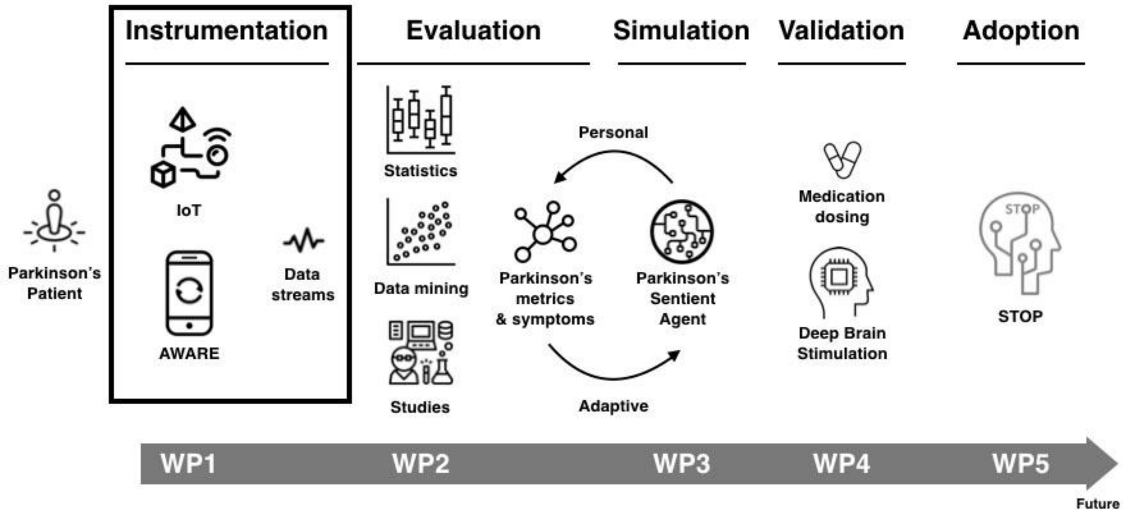

Figure 1. Project STOP timeline (Center for Ubiquitous Computing, 2018)

The thesis is structured in the following way. Section 2 represents the research problem with three research questions and research methodologies employed to answer these questions. Section 3 introduces the general perspective to PD and background study of the use of smartphones and gamification in its treatment. The implementation experience is described in Section 4. The following estimation of application parameters and the lab evaluation are explained in Section 5. Section 6 covers the study contributions and limitations and refers to the possibilities of future use of the study. Finally, Section 7 concludes the description of the study process.

2. Research methodology

This Master Thesis study is conducted as the first working package of the Project STOP and is focused on data collection tools design. For this purpose, Design Science approach is used as the primary research methodology. Along with it, the Quantitative method will be applied to collected data evaluation and analysis. This chapter describes the research problem and explains how every research method is applied to the study.

2.1 Research problem

The currently used way of patient health monitoring allows tracking the subject state only two times per year (Vega, 2016a). However, the manner how the disease affects the patient is highly volatile, so there is a need to develop a different way of patient observation that will allow collecting health probes in a more frequent way. The Project STOP is aimed to design a digital infrastructure that will be used as an assistant tool for PD patients: by unostentatious symptom tracking the system should provide a subject with a personally adapted medication plan (Center for Ubiquitous Computing, 2018). This thesis study narrows down the scope of the problem to the use of smartphones in PD treatment and focuses on the development of a mobile application that uses gamification as a method of health status estimation.

Hence, three research questions were defined that should be answered during the study:

RQ1: How can smartphone capabilities and gamification be leveraged to track Parkinson's disease symptoms?

RQ2: How Parkinson's disease can be measured using smartphone capabilities and gamification?

RQ3: What user-device interaction strategies can be used to maximize Parkinson's disease medication adherence?

The first research question focuses on the method of gamification application to PD tracking process with the use of smartphones. Mobile devices have become an inherent part of humans' life and there is a possibility to adapt its use for increasing the quality of PD patients' lives (Vega et al., 2017). At the same time, gamification is an emerging approach employed to increase user experience and engagement of individuals with a system (Deterding, Dixon, Khaled, & Nacke, 2011). Gamification can be used as a way of continual patient observation via regular short-term game-based health samples taking (Mühlhaus, Frieg, Bilda, & Ritterfeld, 2017). However, the opportunity of the use of smartphones and gamification in PD observation has not been widely studied yet and there is a chance to contribute to both scientific and practitioners' communities. The study aims at the development of an application that will engage users to play a short movement-based game several times throughout a day. Subsequently, the game-provided data can be analyzed and estimated from the perspective of PD severity.

The second research question concentrates on the means offered by smartphones and gamification capabilities that can be applied to PD patient's health state tracking. Nowadays smartphones have a wide variety of inbuilt components that can be utilized to keep an eye on a user. The designed artifact will focus on motion tracking observation and use device's sensors that are available for it. Along with accelerometer that will be used as the basis of the game, the application will collect gyroscope, linear accelerometer, and device rotation data. The provided dataset will allow to understand the levels of user's tremor during the day.

The third research question refers to artifact usability optimization in terms of PD patients' disabilities. In order to maximize the effectiveness of the application usage it is necessary to design it in a simple and convenient way for users, but at the same time it should collect and provide a sufficiently informative amount of data for practitioners. For this purpose, there is a need to develop several different user-device interaction methods, such as a combination of manual and voice data inputs, design a medication journal where a user will record medication session times and implement reminder system that will inform a user when to use the application.

2.2 Design science research

Design science research (DSR) approach is the primary methodology that is used in this thesis project. This chapter explains how the DSR is applied to the project according to the framework and guidelines provided by Hevner, March, Salvatore, Park, & Ram (2004).

2.2.1 Design science research guidelines

Hevner et al. (2004) describe DSR as a problem-solving process that has to follow seven guidelines listed in Table 1 below. Each guideline is considered and explained below in terms of the current study.

Design as an artifact: The artifact of this thesis is the mobile application for Android devices named "STOP". The application is created as a tool for data collection from PD patients. Relying on the two built-in components, accelerometer-based game, and medication journal, the application collects the data for receiving a picture of patient's health at the specific moment in time. The built-in game uses four different smartphone's sensors: gyroscope, accelerometer, linear accelerometer and rotation. The dataset provided by these sensors reflects the tremor effect of the user and is used for defining the correlation between medication effect and subject's health status.

Problem relevance: The current PD treatment approach based on semiannual clinical visits can provide neither patients nor doctors with sufficient amount of data for personal adaptation of medication plan (Vega, 2016a). The study aims to develop an artifact that can be used as a more effective way of patient observation. The application uses Android device's integrated notification component for regular reminding a user to use the artifact. During a day every user receives five notifications: four times the application requests the play a game to estimate the tremor effect and once per day user is asked about the net effect of PD on the previous day. The regular use of "STOP" allows collecting the rich picture of patient's health state. Furthermore, the artifact provides an opportunity to observe a patient remotely instead of face-to-face sessions that can be problematic for patients with body movements complications.

Design evaluation: The application's game component has a set of customizable settings which have to be verified before the actual use among PD patients. After the test release of the application, the artifact will be used in the lab evaluation study with a volunteers group who do not have any PD progression. The study will provide results for non-PD participants that can be considered as a standard for a healthy user. Based on the results, the received parameters will be defined as default settings for the game component. Moreover, the application usability characteristics will be evaluated with the use of questionnaire that considers artifact's ease of use, user engagement and playfulness, and perceived usefulness for PD. Finally, such approaches as performance optimization, battery life orientation, code readability, and reusability are taken into consideration during the development process.

Table 1. Design-Science Research Guidelines (Hevner et al., 2004)

Guideline	Description
Guideline 1: Design as an artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a search process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Research contributions: The research provides a contribution with the designed artifact itself, that can be used as a tool for PD severity level tracking and medication schedule adherence with the use of smartphones. Regular use of the artifact increases the frequency of PD sampling that gradually enriches the picture of patients' state of health. Also, the application allows to observe the patient distantly and allows clinicians to analyze patient's health changes without clinical visits. Besides, the developed application will be used in the following study flow of the STOP project as a data collection tool. The outcome dataset will be analyzed and used to develop a new way of PD handling and medication dose prescription.

Research rigor: The rigor of the research is based on the studying of existing related work on the topic and on the desired manner of interaction between a patient and the application. By studying the previous researches on the topics of mobile devices use in Parkinson's treatment and gamification use in PD evaluation, figuring out the missing points and analyzing the existing opportunities the research rigor is defined. Along with it, the study takes into account rigor in terms of development which is comprehended via game component parameters verification at the lab evaluation and the orientation towards application usability.

Design as a search process: The project is conducted with the use of continuous development approach (Beck et al., 2001). After the test release and the following evaluation of the artifact, the application will be updated according to the study of the test results. There is a need to define the default parameters for the game component which will be considered as a standard. Moreover, there is a need to develop a metric for daily health evaluation from users. Finally, the way of estimating the correlation between the results from the game component and medication journal has to be defined.

Communication of Research: The designing stage of the project is applicable both in technological and managerial terms of use. The technological value of the project is an artifact that is used in a desired continuous way and does not break patients' routine. From the managerial perspective, the use of the application provides a dataset, whose whole analysis may help to develop a new way of handling PD treatments. The subsequent working packages of the Project STOP will reuse the artifact as a way of collecting data and receiving the subjects' health state markers.

2.2.2 Design science research framework

Hevner et al. (2004) define the set of components of DSR in a framework of information systems (IS) research. The schema of the framework is represented in Figure 2 below. This subchapter describes how the framework is applied to the study and represents the components in details.

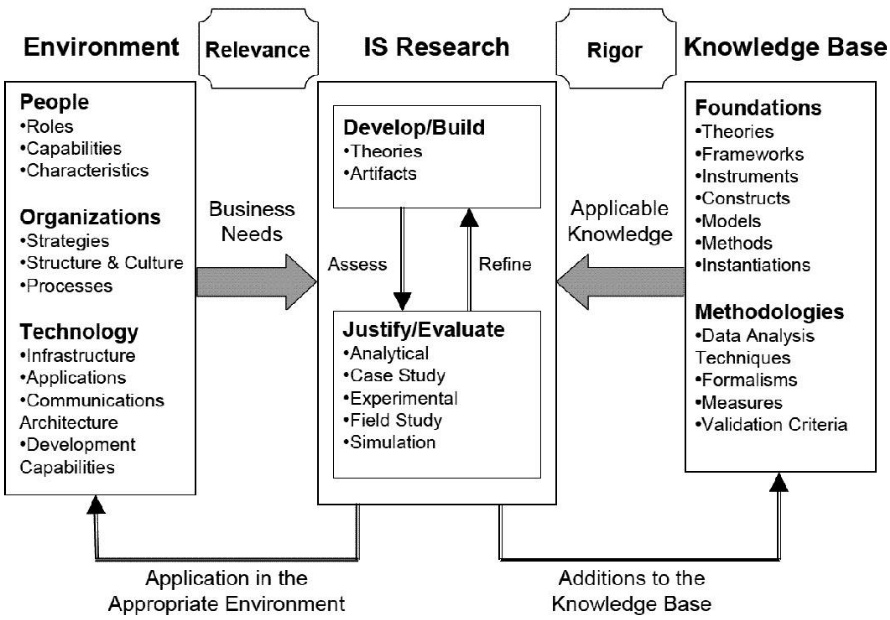

Figure 2. Information Systems Research Framework (Hevner et al., 2004)

According to Hevner et al. (2004), DSR in IS is applied in and influenced by an **environment** which is defined as a domain consisting of people, organizations, and technologies that are connected with the development of an artifact. The environment implies goals, tasks, problems, and opportunities that are covered with an artifact creation.

People: The application “STOP” will be designed as a tool for the regular observation of health state of PD patients. Thus, any person who has PD can be a user of the artifact. On the latest working packages of the Project STOP, the application will be uploaded to Google Play so the artifact will be available for any Android user whose device has Android 4.4 KitKat version or newer. In that case, the artifact will be available not only for PD patients but for also for those who do not have PD effect on their health. That increase of artifact users will be useful for observing the difference between healthy and diseased.

Organizations: The development of the artifact and its lab evaluation are conducted at the University of Oulu. However, the collaborative nature of the Project STOP involves the subsequent use of the artifact by Carnegie Mellon University, The University of Manchester, Haltian Oy and Head Instruments Oy (Center for Ubiquitous Computing, 2018).

Technology: The artifact of the study is the mobile application for Android devices. “STOP” will be implemented using Android Studio as the integrated development environment and GitHub as the version control system (VCS). For the data collection and storing, the application will use the AWARE framework (AWARE, 2018).

IS Research: The DSR in IS involves two phases: the actual development of an artifact and its validation. The development phase starts based on the Project STOP specifications. The application will be implemented based on the need of a tool for regular data collection and by taking into consideration limited abilities of PD patients. After the development of the artifact, it will be necessary to validate its game component. The customization of the game requires the lab evaluation among volunteers that will be conducted at the University of Oulu. After the data collection process, the received data will be analyzed with the use of quantitative research methods and results will be considered as a standard setting for the game. Furthermore, the validation phase will take into consideration the evaluation of the developed application from the users’ perspective in terms of the artifact’s ease of use, users’ engagement and playfulness, and perceived usefulness for PD.

Knowledge base: The knowledge base for the study is the existing literature on the topics of using smartphones and using gamification for PD treatment, as well as the data collection and analysis methodologies described further in sections 2.3 and 2.4.

2.3 Quantitative research

Along with DSR, quantitative methodologies will be used in the thesis project. With the use of quantitative approach, it will be possible to estimate, evaluate and provide an analysis of the data that will be collected during the lab evaluation period. The developed artifact will provide an ability to collect various sets of numerical data that can be applied to the answering on the second research question. The experimental study will be done on the focus group of non-PD volunteers. The collected data will represent the movement abilities of healthy users who do not have any tremor effect. The data analysis will provide an understanding of the standard health samples and how to differentiate PD patients' samples from it. In order to evaluate the collected data, box plots visualizations will be used, along with the calculations of mean, median, mode, minimum, maximum and standard deviation values for the collected sets of data representing the application-based results and artifact usability characteristics.

Besides the health samplings data, the artifact will provide an ability to collect datasets about users' medication timestamps, users' health self-assessment, application reminder statistical data and feedback about the artifact. Thus, the wider scope of the collected data will be available for use for the following working packages of the Project STOP (Center for Ubiquitous Computing, 2018).

2.4 Lab evaluation

In order to validate the gamification component of the artifact that has a set of customizable parameters, there will be a need to conduct a lab evaluation to verify the default settings for the inbuilt game. The study will be performed at the University of Oulu with the help of volunteer participants who do not have any PD effect on their health. This experimentation will provide a standard picture of a healthy user and will help to understand what kind of derivation should be observed with PD patients. The volunteers will take part in gamified component evaluation by playing the game for a defined amount of times with all possible setting combination. The purpose of the study is to collect as much experimental data as possible, so the evaluation results will allow to access a baseline of PD symptoms from the general population.

Moreover, along with the estimation of the playful component of the artifact, the volunteers will be asked to evaluate the application usability in general. At the end of each evaluation session, a participant will be asked a short questionnaire in order to rank the artifact in a *1 (low) - 5 (high)* scale with regards the following heuristics: ease of use, playfulness and user engagement, and perceived usefulness for PD. The ease of use and perceived usefulness are the factors in user acceptance model defined by Davis (1989). At the same time, the importance of sufficient level of playfulness is a key point to the increase of the user engagement (Deterding et al., 2011). In general, the questionnaire results will be useful for understanding how successful and applicable the received artifact will be.

3. Related work

This chapter explains the nature of Parkinson's disease and describes the existing studies on the topic of the use of smartphones and gamification method in disease progression tracking. The chapter provides an overview of the already conducted research projects on the subject. Definition of the scope of the work that had been done already and figuring out the missing points in the studies allows to comprehend the subject and determine available opportunities that can be applied in the current research project.

3.1 Parkinson's disease (PD)

Parkinson's disease (PD) is the second most prevalent neurogenerative disorder that is outstripped only by Alzheimer's disease. Dorsey et al. (2007) have investigated that the total amount of PD patients living in five Western Europe's and ten world's most populous countries in 2005 was about 4 million and this number have a tendency to increase twice by 2030. Moreover, PD has an effect not only on the subjects but on the groups who deal with the patients in everyday life. Family members and caregivers are faced with burden in daily interaction with PD patients (Dowding, Shenton, & Salek, 2006).

Age is the main and only factor that has notable correlation on the progression of PD. According to Weintraub, Comella, & Horn (2008), the general ratio of PD affected citizens in the US is 0.3%. Along with the increase of age, the proportion of patients increases as well. Thus, the group of people in the age of 65 and older is faced with 1-2% probability of having PD, while people in the age of 85 and older have a ratio of 4-5%. Though, younger groups also have a risk of PD: 10% of total subjects in the US are people in the age of 45 and younger. Together with the chance of the affecting PD on the aged groups, it can emerge due to neuropathological conditions or medication taking. However, these cases have mostly sporadic nature and it does not provide a strong reliable correlation. (Weintraub et al., 2008)

The reason for PD progression is the degeneration of dopaminergic neurons, organic chemicals that convey movement nervous signals (Wu & Hallett, 2013). The lack of dopamine results in movement dysfunctionalities such as resting tremor, bradykinesia, muscle rigidity and postural instability. Weintraub et al. (2008) represent the effect of PD on motor functionalities in Table 2. These problems are normally treated with taking medications that replace dopamine and decrease PD effect with the following motor abilities recovery (Lloyd, Davidson, & Hornykiewicz, 1975).

However, despite the fact that medication taking for the dopamine replacement is the common treatment way nowadays, it has notable disadvantages. The Michael J. Fox Foundation (Kuhl, 2014) has conducted a study based on PD patients survey that has examined medication effectiveness. The participants were asked about their health status over the day from the perspective of "on" and "off" medication effect. The results have shown that the efficiency of medication is lowered in the long-term use, resulting in lack of medication favor – "off" state. 90% of long-term patients reflected that they had experienced "off" state at least once per day, while 20% encounter "off" states for more than four hours daily. The significance of the problem is the fact that during "off" periods the severity of PD symptoms increases twice according to "on" states, arising movement disabilities and breaking patients' routine (Kuhl, 2014). Furthermore, the "off" states problem cannot be resolved with extra medication session planning. The medicine overdosing can have side effects such as severe dyskinesia that make subject's life even harder (Giovannoni, O'Sullivan, Turner, Manson, & Lees, 2000). In that case, there is a need to customize the medication plan according to patient's need, what is hard to do for the doctors and hard to follow for patients (Vega, 2016a).

Table 2. Motor Features of PD (Weintraub et al., 2008)

Feature	Characteristics
Resting tremor	70%-90% of patients More commonly distal, involving the hands May be observed as patients rest hands in lap; often "pill-rolling" in nature May have postural component Slow vertical jaw or tongue tremor may be evident, or leg tremor at rest
Bradykinesia	80%-90% of patients Slowness in movement Most disabling symptom of PD May have difficulty turning over in bed or arising from a chair Extreme manifestation is akinesia
Rigidity	>90% of patients Resistance to the passive movement occurring in both flexor and extensor muscles throughout entire range of motion May be "cogwheel" (resistance fluctuates in intensity while limb is passively moved) or "lead-pipe" (continuously rigid) Must distinguish from spasticity, which only has increased flexor tone
Postural instability	Last symptom to appear and reflects progression to advanced stages of PD Predisposes to falls and injuries Early onset is atypical for PD and suggests other cause of parkinsonism Poor or no response to dopaminergic therapy

3.2 Use of smartphones in PD observation

The idea of the use of mobile devices in PD treatment process has been taken into consideration in various research projects already. The general motivation for these projects was the fact that the current way of patient observation does not provide the full picture of subject's shape. During the short clinical visits doctors are able only to analyze the variations of health since the previous observing session. However, since PD itself is unstable and symptoms are impermanent, there is a gap in treatment effectiveness. On the opposite side, smartphones that are used by patients throughout the day can monitor owner's health via inbuilt sensors in a 24/7 manner. Moreover, the mobility approach can exclude the necessity of clinical visits by providing doctors the collected data on distance. This kind of result can be useful and convenient for the persons with the high level of movement complexities. (Vega, 2016a; Vega et al., 2017)

The framework SPARK developed by Sharma et al. (2014) was one of these attempts to shift the patient observation methodology to the mobile devices usage strategy. Authors took a focus on United States scope where PD treatment consumes 23$ billion costs per year. In spite of the vast budgets, the therapy effectiveness remains on the low level due to the inability of regular patient observation and the resulting inability of personalization of treatment plan according to every patients' state. The challenging way of PD treatment spurred authors to develop a system that allows observing PD patients in a non-clinical environment on a regular basis. (Sharma et al., 2014)

SPARK is a framework that is used both on smartphones and wearables and tracks various patient's symptoms: tremors, speech dysfunctionalities, limb dyskinesia, and gait abnormalities. The framework was applied for use in two different modes: active and passive. The active mode was focusing on specific activities that patients were suggested to act, while passive mode only collected health data in the background without interfering with a subject's routine in a daily manner. The use of SPARK followed the patient personalization idea: the use of wearables was adjusted according to every patient's needs: the number of devices, places to its attach were adapted to subject's convenience. The framework is designed as a three-layer system: data collection layer that fetches the information from smartphones and wearables, data analyzation layer that evaluates the received datasets both from active and passive modes and personalization layer that defines whether the treatment was useful for the patient or not. SPARK was applied into use in a pilot study and was followed with the results evaluation of its usefulness for patients, clinicians, caregivers, and families. The project was only focused on motor activities movements and has not taken into consideration medication perspective. (Sharma et al., 2014)

Arora et al. (2015) have performed a monthly study oriented to the patient health observation with the help of smartphones. Authors have developed the mobile application and provided ten PD patients and ten healthy participants with Android devices with the pre-installed tool that allowed tracking voice changes, posture, gait, finger tapping, and response time. The participants were asked to use the application on a daily basis by performing sample-taking four times per day with five-tasks exercise set. Along with it, each patient has participated once a week in a remote telemedicine session with the doctor via video conferencing. The study aimed to define the distinction in measurements, develop a differentiation between PD and non-PD participants and predict possible motor alteration based on received datasets. The pilot study participants have performed 68.9% adherence to the artifact use by carrying out in average 2.7 tests per day. The following analysis of collected data has allowed to detect the difference in sampling results between PD and non-PD patients. On the whole, the study has shown a potential of mobile devices using in PD observation and evaluation. (Arora et al., 2015)

Bot et al. (2016) have conducted a PD observational study called mPower that was performed only with the use of iPhone devices. By utilizing Apple's ResearchKit library, authors have designed mPower application for the users of iPhone 4S or newer living in the US. The application is available in the Apple App Store for all the iPhone owners, so the users' scope is not limited only to PD subjects. At the initial application run the users are asked to identify own PD status, either professionally diagnosed PD or none, and are offered to join the study and give the permission to share the collected data. Based on the participant's permission the data can be shared narrowly for the mPower study team only, for the whole research community worldwide or not shared at all. The users are suggested to take part in four different PD evaluation activities: memory activity that evaluates short-term spatial memory, tapping activity that measures dexterity and tapping speed, voice activity that collects microphone recordings and walking activity that focuses on gait and balance. The application itself is still available in the App Store and the collected data for worldwide share is available through Synapse. (Bot et al., 2016)

Generally, the studies conducted with the use of mobile devices in PD observation and treatment focus on the one main problem: the current clinical method of disease monitoring does not match its fluctuating nature, therefore there is a need to develop a new manner of following the patients' symptoms in a more frequent way. The wide variety of available inbuilt components from movement sensors to cameras and microphones can help to gather the vast amount of data that can be used for patients' observation and medication plan customization. However, it is significant to design tools that will be applicable for long-term use, will not break patients' daily routine, and will be supported via multiple sources (Vega, 2016b). There is a need to develop an ecosystem that can combine smartphones, wearables and IoT components together and not only collect the disease progression data, but also analyze it and transform to personalized treatment plans for patients (Center for Ubiquitous Computing, 2018).

3.3 Use of gamification method in PD observation

Gamification is a design methodology that applies gamified playful elements to the non-game contexts. The advantage of gamification is the fact that game-like design of a product engages users involvement and increases interest to a product. (Deterding et al., 2011). Moreover, integrating the usability perspective into gamification ensures that users are engaged with the application and the target objectives of using the application are reached (Rajanen & Rajanen, 2017). In terms of PD, gamification can be used in order to motivate the patients to use the measurement artifacts on a regular basis. The existing studies reflects how gamified health state sampling sessions can replace the tedious routine exercise that are performed for the patient observation.

For example, van der Meulen et al. (2016) describe the experience of an augmented reality game application to movement observation of PD patients. The authors have designed a virtual reality game that has demonstrated moving targets to users and provided players with haptic game controllers that should be used to interact with the targets. The game designed with the Unity3D engine was developed with the purpose of increasing the patients' engagement in health state monitoring process. Moreover, the authors have conducted a study of game usability and user experience that has reflected success in increasing the interest to the artifact. The results of the study have shown that the game can be used for quantitative measurement collection. However, the study has also shown the disadvantages of the approach resulted in a learning curve and user annoyance. (van der Meulen et al., 2016)

Gamification can notably increase the interest of the participant in the use of the artifact. Doerr et al. (2017) report PD patients feedback about the use of mPower mobile application. One of the participants has shown high interest in gamification as the way to increase the motivation and user engagement:

Make everything a game. Make it interactive and fun. Even though kids are the ones supposed to be playing games to learn, it makes it easier for adults too. It also makes it fun and makes me want to come back to finish the task every day...even the smallest rewards are still rewards and humans thrive to be rewarded. (Respondent 59f9, Doer et al., 2017)

Tous et al. (2014) describe the adjustment of Play for Health (P4H) platform functionalities for the use among PD patients. P4H is a platform that is used for patient rehabilitation via video games with the help of the off-shelf devices such as Kinect, WiiMote, and dance mats. The platform engages patients to perform trainings and follow therapy programs. The authors have created three new games for the platform for PD patients in order to train balance, sit-stand transition, gait, and arm swing amplitude. (Tous et al. 2014.)

Furthermore, gamification can be applied not only to movement functionalities assessment of PD. Mühlhaus et al. (2017) report the experience of using gamification in speech rehabilitation for PD subjects. Along with movement complications, PD can have an effect on speech abilities of the patient. As a result, it affects patients' routine, complicates regular communications and leads to social isolation. The training suggests to follow repeating and boring exercises that often resulted in lack of motivation to follow. At this point, gamification can be applied as a way of increasing interest to the practical tools. Hence, authors have developed ISi-Speech, a speech therapy application with the use of gamification that is both useful and interesting-to-use for the patients. Isi-Speech allows patients to be independent of others but still keep trainings in an acceptable and effective way. (Mühlhaus et al., 2017)

4. Implementation

The first working package of the Project STOP (Center for Ubiquitous Computing, 2018) focuses on the design of measurement instruments that will be applied for PD observation. In particular, the purpose of this thesis is to develop an application for Android smartphones that will be used by PD patients in order to observe their health state throughout a day. The study aims to the development of the artifact that will combine the accessibility of smartphones and gamification as the user engagement approach. This chapter reflects the implementation process of the application, which is based on the defined research questions. The architecture of the application is designed in a way to support the claim of smartphone use in PD observation with the help of gamification method (RQ1). The developed application is designed in a patient-friendly way (RQ3) and leverages smartphones' inbuilt sensors for measuring patient's movement capabilities during the day (RQ2). Moreover, the application design follows a number of functional requirements that improve the general user experience and provides opportunities for the further use of the artifact. The application is implemented in Java programming language with Android Studio integrated development environment. The artifact design process has followed continuous development approach (Beck et al., 2001) with the help of GitHub VCS.

4.1 Architecture

The designed artifact for the thesis study is the application for Android devices named "STOP". The application is compatible with devices having Android 4.4 KitKat version or newer, that is 90.1% of all Android devices according to Android Studio, the official integrated development environment (Android Studio, 2018). In order to follow the objectives defined in the first research question, the application is designed as a combination of two components: accelerometer-based ball game and medication journal. The PD effect measurement process is implemented as a game in order to enhance users' interest in the application and increase patients' engagement. Medication journal is used for medication timestamp collection, that can be used for analyzing the correlation between medication effect and PD severity level collected via games, this further analysis is not a part of this thesis and will be conducted during the following working packages of the Project STOP (Center for Ubiquitous Computing, 2018). Furthermore, the application has a set of features that support the consistency of the application and provide a user a flexibility in use: reminder notifications, health survey, and game settings.

4.1.1 Accelerometer-based ball game

The study of the related work described in Section 3 has shown that there is an opportunity to use gamification in PD observation. Thus, the main purpose of the artifact development was to design a game that can be used in tracking of PD effects. The gamified component of "STOP" is a simple accelerometer-based game that leverages smartphone's sensors and represents user's hand movements as the ball's movement on a device screen. When a user tilts own device forward, backward, left or right, the ball on the screen behaves correspondingly. Thus, the game makes possible to observe the level of tremor of a patient via short-term game sessions during the day.

The game interface, that is shown in Figure 3 below, consists of the ball, two auxiliary circles, and the timer that shows the stage status of the game. For example, Figure 3 represents the ongoing game that lasts for three seconds. The purpose of the game is to keep the ball as close as possible to the center of the circles for the defined time interval. The circles are centered relative to the screen and are used as auxiliary user interface (UI) elements, thus the center of the inner circle coincides with the center of the screen. The game is designed in a way to be used as a short-term gamified session that collects hands movement samples of the patient and transcribes it to the scoring system. If the player is successful and keeps the ball close enough to the center of the screen, the score is close to 100. On the other hand, if the player's tremor does not allow to keep the ball still, the score goes to 0. Thus, the game allows estimating how severe is the effect of tremor based only on the collected accelerometer data.

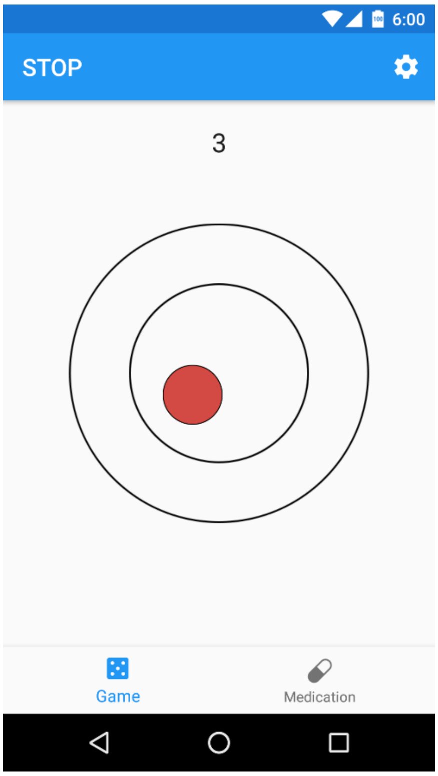

Figure 3. Interface of the accelerometer-based game

The game session continues for a defined number of seconds and collects a set of numerical sensors data. The detailed explanation of the dataset collected via sensors is described in section 4.2.1. The flow of the game is represented in Figure 4. The game screen starts with a control button, by pressing on which the user starts the game. The timer component reflects two different stages of the game session: preparation and sampling. When the game is started, a user has three seconds to prepare, calibrate the smartphone and put the ball to the center of the screen. During the preparatory stage, the device sensors are activated, but no any hand movement related data is collected. When the preparation stage is completed and the timer shows "Start" message, the application starts data collection and records samples from device's sensors. After the specified number of seconds, the game completes and shows to a user the score result. The detailed description of applied sensors and score system is explained in Section 4.2. In order to increase the adherence to the game samplings, the application uses Android's notification system that reminds patient to play a game at least four times per day. The description of reminder strategy is reflected in Section 4.3.1.

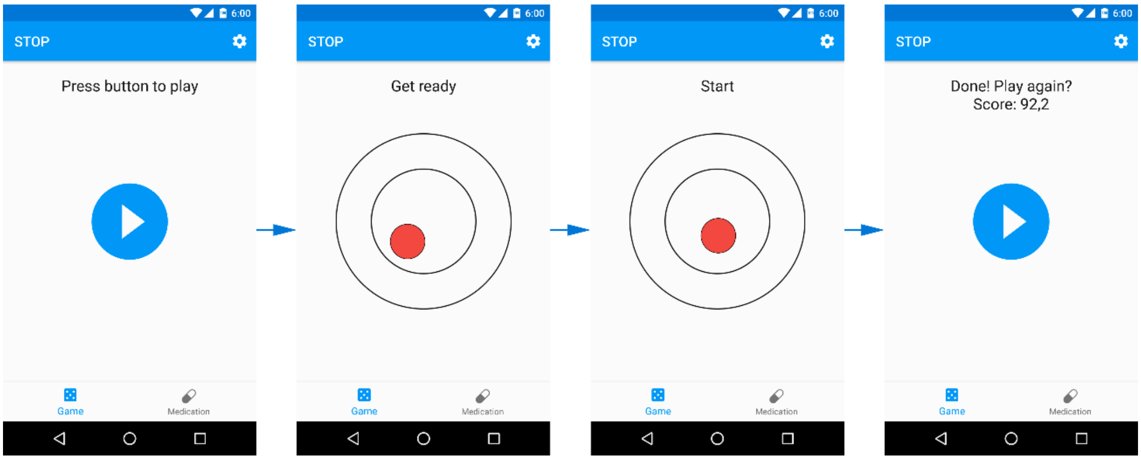

Figure 4. Gameplay flow of the accelerometer-based game

The game has a set of customizable parameters that can be adapted to each patient individually. The size of the gaming ball and auxiliary circles, the speed of the ball and the length of the game can be modified at the settings screen that is shown in Figure 5. The size of the circles and the ball customizes the UI of the game making the gameplay different based on the components' size. The sensitivity parameter affects how fast the playing ball moves on the screen either slowing it down or speeding it up. The game time settings define the length of the exercise while the users have to keep the ball still.

The provided flexibility in the use of the game allows estimating the severity of patients' tremor in various conditions. However, there is a need to conduct a test study in order to evaluate what parameters should be used as the default for the game. The evaluation study is conducted at the University of Oulu with the help of non-PD volunteers. The conducted test game experience will provide a picture how the game acts among the healthy players. The defined result will be set as a standard for the game, so the following use of the game among PD patients can be considered from the perspective of a healthy user. The detailed description of the evaluation study and its results are represented in Section 5.

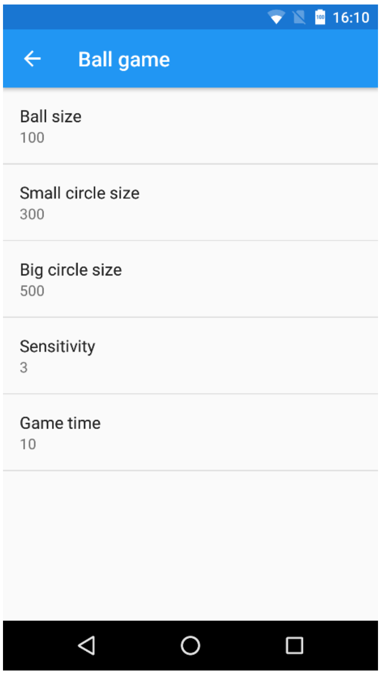

Figure 5. Customizable settings of the accelerometer-based game

4.1.2 Medication journal

In order to receive the meaningful result from the dataset collected via application's game component, there is a need to keep an eye on patient's treatment process during the day. Hence, the second application component, medication journal, has been developed with the purpose to trace patient's medicine taking timestamp. The journal requires a user to record every moment of time when the remedy has been taken. This information will be used in the following working packages of the Project STOP for the analysis of the correlation between the level of tremor and medication effect during the day (Center for Ubiquitous Computing, 2018). The interface of the journal is shown in Figure 6. It has a list of previously recorded medications and three buttons that are used for timestamp input. The detailed description of the control buttons and the motivation for its use are reflected in Section 4.3.2.

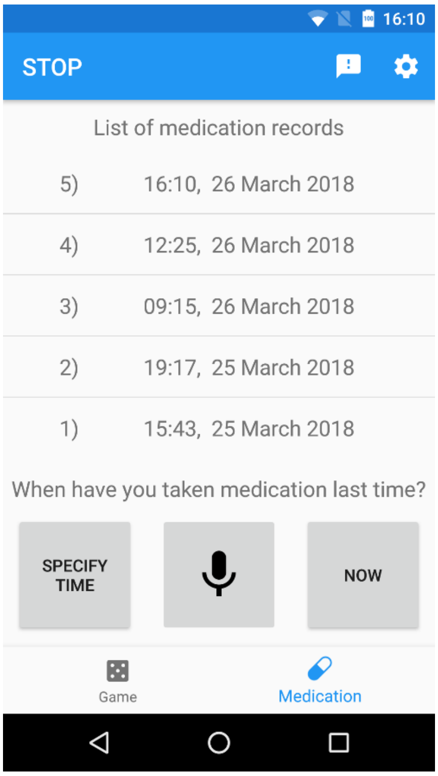

Figure 6. Medication journal interface

4.2 PD measurement

The second research question of the study aims to find out how the combination of smartphone use and gamification can be applied for PD measurement. In this thesis study, this objective is achieved by the combination of data collected from the game and medication journal application components. The medication data is collected with the explicit patient's participation, by manual timestamp recording to the journal. The game related dataset is collected passively by the smartphone, while the user is only required to play a game. During the short-term exercise session, the device collects the following data: game settings, game score, device screen resolution, ball movement samples and sensors samples. The collected dataset is composed to the JavaScript Object Notation (JSON) format (JSON, n.d.). The structure of example JSON record collected with the game is shown in Figure 7. Initially, the data is recorded to the local device's databases, but later it also synchronizes with the remote AWARE server (AWARE, 2018).

```
{
  "gamedata":[
    {
      "ball_radius":150,
      "sensitivity":5.0,
      "device_x_res":1080,
      "device_y_res":1776,
      "samples":[
        {
          "timestamp":1524049885319,
          "ball_x":32.46112,
          "ball_y":4.638977,
          "distance":32.79092110380459
        },…],
      "score":97.89383616266973
    }
  ],
  "accelerometer":[
    {
      "accuracy":2,
      "device_id":"eab82d26-182c-4bdf-8d4a-047fc2b5e94d",
      "double_values_0":0.113922119140625,
      "double_values_1":0.074554443359375,
      "double_values_2":9.538528442382813,
      "label":"",
      "timestamp":1524049885319
    },…],
  "linearaccelerometer":[50],
  "gyroscope":[50],
  "rotation":[50]
}
```


Figure 7. Ball game sampling snapshot in JSON format

4.2.1 Device sensors

The wide variety of inbuilt sensors in smartphones nowadays allows utilizing mobile devices for keeping an eye on patient's state of health. For example, the previous studies by Weiss et al. (2010) and by LeMoyne, Mastroianni, Cozza, Coroian, & Grundfest (2010) have shown that accelerometer sensor can be useful in PD observation. Similarly, studies by Salarian et al. (2004) and Salarian et al. (2007) reports about the use of gyroscope in PD following. Thus, the application for the thesis study was designed in a way to use various sensors provided by Android smartphones.

First of all, "STOP" uses smartphone's accelerometer as the basis for the game component. The movement functionalities of the playing ball that represents user hands activities are implemented with the use of the accelerometer. The application sets the device's accelerometer frequency to one measurement per 20 000 microseconds, so that allows the sensor to make approximately 50 measurement snapshots per second on any device. This frequency produces a smooth game experience for a user and provides an ability to collect a plentiful set of motion data in the background.

Moreover, during the game session, the application activates and collects data from three more sensors: linear accelerometer, rotation, and gyroscope. These sensors do not affect the game experience, so there is no need to set the frequency manually and the application keeps it as default that helps to follow the battery life-friendly orientation. Because of it, the amount of sampling data varies from device to device. The application was tested on three different devices: Nexus 5 and Xiaomi Redmi Pro performs about 5 measurements per second for each sensor, while Meizu MX5 performs 50 measurements during the same period of time. Hence, the final output dataset collected from the game can be different in size and precision. All the records that represent user motion measurements are collected and recorded in JSON format to the device's SQLite database.

4.2.2 Game scoring system

The dataset collected via accelerometer during the game session allows to estimate the level of patient's tremor and transcribe the received numerical data to the score result. Figure 8 represents the schematic explanation of the score computation for a single game snapshot. The accelerometer sensor of a smartphone takes about 50 measurements snapshots per second. Every snapshot represents the different position of the ball on the screen based on the hands' position of the player. Thus, the score for every snapshot is different and is calculated in the following way. Firstly, at the beginning of the game, the application finds out the maximum possible distance that can be covered by the ball (line BC). Then, the distance between the center of the ball and the center of the screen (line AB) is calculated for each snapshot. Finally, the snapshot score is calculated with the formula *(1 – AB/BC)*100*.

The final score for the whole game session is the average of all snapshot scores calculated during the game. Thus, if the player follows the objective of the game and keeps the ball still and close to the center of the screen, the AB/BC quotient tends to 0 and the final score tends to 100, which is the perfect result. If the tremor severity does not allow the player to keep the ball in the center, AB/BC quotient increases and the score tends to 0, which is the lowest result.

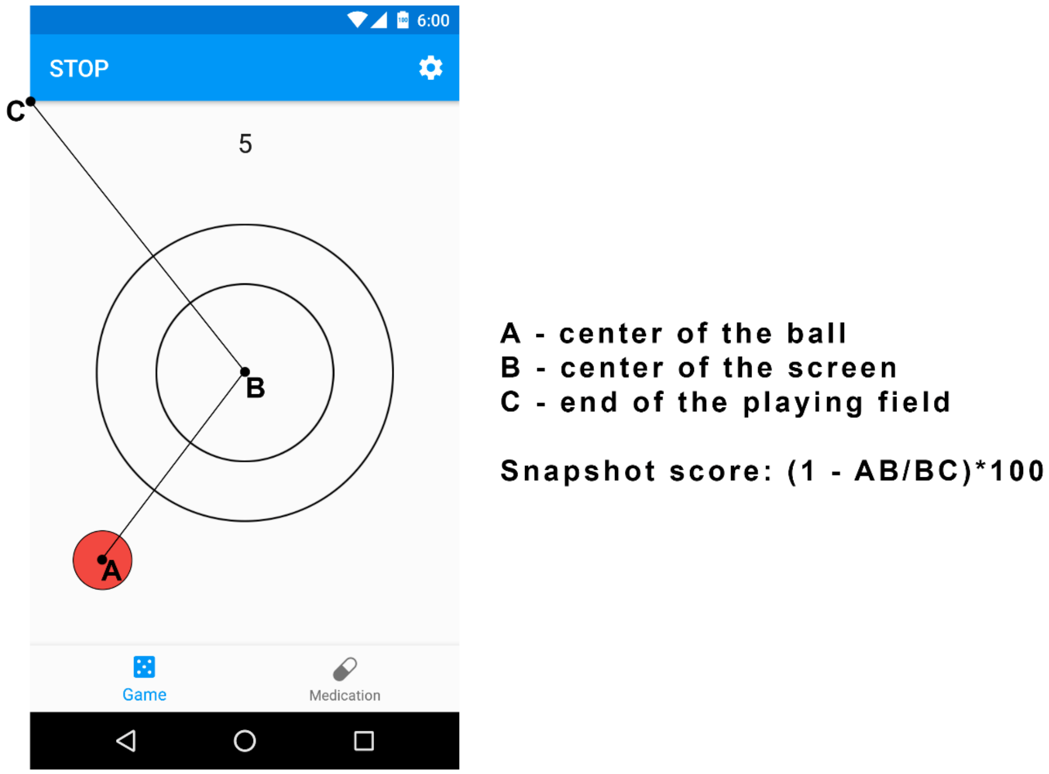

Figure 8. Snapshot score computation

4.2.3 Data collection

In order to measure PD with the smartphone, the application collects the data about the patient's health from different perspectives both in active and passive ways. Firstly, by playing short-term games the user allows the application to measure hands motion. Secondly, by regularly following medication journal recording, a user provides data, that in correlation with game records can provide a picture of medication effectiveness during the day. Moreover, with the use of Android's notifications (Android Developers, 2018a), once per day the patient is offered to answer the questionnaire that asks about the general effects of PD. The current questionnaire has only one question that is "How severe was Parkinson's disease yesterday?" (Figure 9). However, this questionnaire can be clarified and modified during the following working packages of the Project STOP (Center for Ubiquitous Computing, 2018).

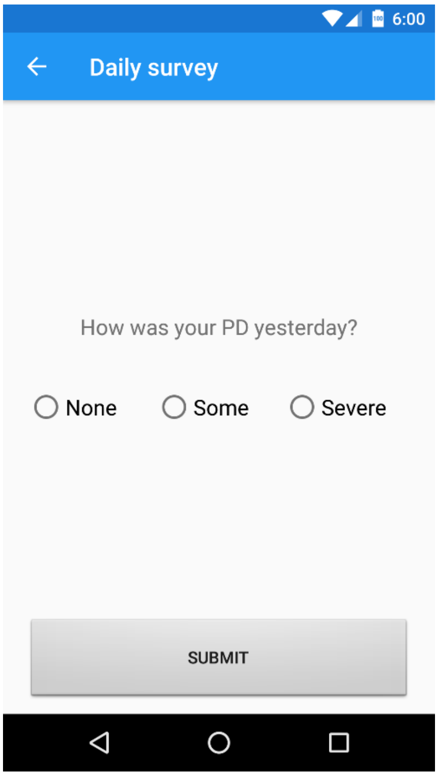

Figure 9. Daily survey interface

All the collected data is composed to the SQLite database and stored locally on the user's device (Android Developers, 2018c). In order to follow the distant observation approach that allows decreasing the necessity of regular clinical visits, the application also regularly, once per 30 minutes, synchronizes all the collected data with the server provided by AWARE framework (AWARE, 2015). The collected data that can be applied for PD measurement is represented in Tables 3-5. Table 3 illustrates the dataset collected via the gamified components of the application that represents the motion-related information of a user. Table 4 shows the dataset collected from the perspective of patient's medication plan following. Table 5 represents the data received via the daily questionnaire about the general user's state of health during the previous day.

Table 3. Accelerometer-based game collected data

Field	Description
_id	Primary key auto-incremented
timestamp	Unix timestamp in milliseconds of sample
device_id	AWARE device ID
data	Ball game data in JSON format: ball size; ball speed; device screen resolution; game score; accelerometer, linear accelerometer, gyroscope and rotation samplings

Table 4. Medication journal collected data

Field	Description
_id	Primary key auto-incremented
timestamp	Unix timestamp in milliseconds when a record is added to a database
medication_timestamp	Unix timestamp in milliseconds when medication has been taken
device_id	AWARE device ID

Table 5. Health state daily questionnaire collected data

Field	Description
_id	Primary key auto-incremented
timestamp	Unix timestamp in milliseconds of record
device_id	AWARE device ID
pd_value	Questionnaire response (none, some, severe)

4.3 User-centered design strategies

The general outcome of this thesis study is a mobile application that can be used for PD patients' health observation. The artifact should collect and provide a sufficient dataset for the further analysis during the following working packages of the Project STOP (Center for Ubiquitous Computing, 2018). For this purpose, it is necessary to take into consideration PD patients' inabilities and apply various user-oriented strategies to the application that make user experience convenient and understandable. Firstly, the application uses Android notification components (Android Developers, 2018a) in order to increase the user's engagement and the medication adherance. Secondly, the application is designed with the consideration of PD patients' health limitations and offers convenient UI design and different data input means. Finally, the artifact design follows continuous development approach and supports users' feedback acceptance for the further application improvements.

4.3.1 Reminder notifications

In order to receive a full picture of PD, it is necessary to follow the patient health sampling regularly, several times per day in terms of the study. Therefore, the application utilizes Android notifications component (Android Developers, 2018a) as a reminder strategy that increases the user's involvement and recalls the patients to use the application on a regular basis. At the moment of a scheduled reminder a device vibrates for a half of a second and the application triggers two different types of smartphone's notifications: the first type of notification shows up once randomly in morning, noon, afternoon and evening and asks user to play the ball game and record the last medication time; the second notification type triggers once per day from 10:00 to 11:00 and runs the daily questionnaire about the health state for the previous day. The example notifications are shown in Figure 10. The notifications are clickable and run the corresponding components of the application when are clicked. Along with the request to play a sampling game, the notification text reminds a user to keep recording the medication timestamps to the journal and thereby increases the medication adherence in general perspective.

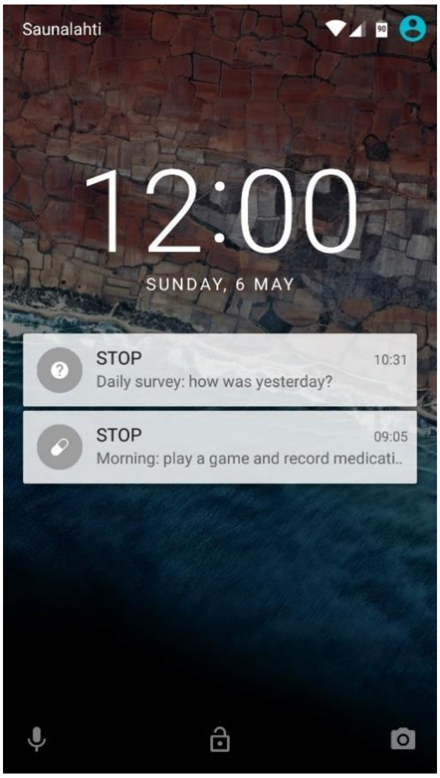

Figure 10. Reminder notifications

Moreover, the application collects the notification statistics that represent the effectiveness ratio of reminders. The collected data can be useful for the analysis of at what time of the day users are willing to use the application and when not. Same as health state related data, notification statistics at first is saved to the device's SQLite database and then is synchronized to the remote AWARE server. The structure of the collected dataset is represented in Table 6.

Table 6. Notification statistics collected data

Field	Description
_id	Primary key auto-incremented
timestamp	Unix timestamp in milliseconds of an event
device_id	AWARE device ID
event	Type of notification state (morning_shown, morning_opened, noon_shown, etc.)

4.3.2 User interface (UI)

The application UI was designed using the guidelines provided by Material Design in order to make the application usability simple and ease the user experience as much as possible (Material Design, 2018c). The two main components of the application, ball game and medication journal, are accessible via bottom navigation bar (Material Design, 2018a). Hereby, the navigation between artifact components can be easily performed just by clicking on the appropriate tab. The helpful features of the application such as game settings, daily survey, and feedback screen are accessible via toolbar component (Material Design, 2018b). Figure 11 shows the navigation elements of the application.

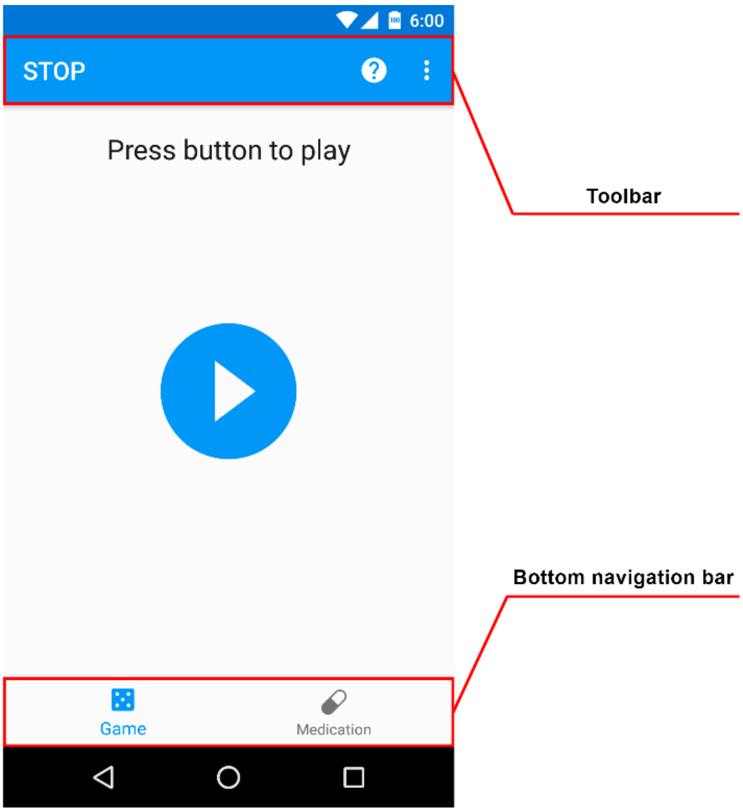

Figure 11. Application navigation elements

The application design takes into account PD patient's inabilities, such as tremor, so the control buttons are implemented in big size and represent the clicking effect with a different color, that makes the experience more understandable. Examples of button size are shown in Figure 9 and Figure 12 and click response is illustrated in Figure 12.

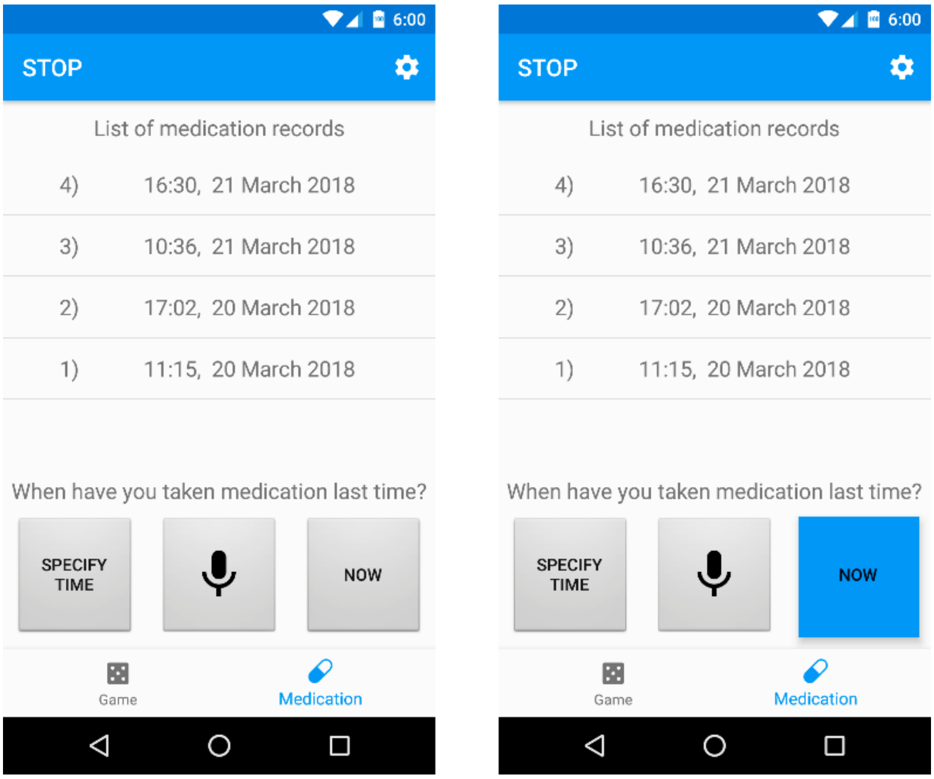

Figure 12. Unclicked and clicked buttons in Medication journal component

4.3.3 Voice input

Along with the manual input, which can be inconvenient for the patients with the severe level of tremor, the application supports the data input by voice with the help of Android's speech recognizing component RecognizerIntent (Android Developers, 2018b). This component transcribes the user's speech into text string format, that in a result is shown on a device's screen. The voice input is available in medication journal and in feedback screen. The voice input in medication journal illustrated in Figure 13 is implemented with the use of natural language processor provided by Wit.ai (Wit.ai, n.d.). After clicking on the "microphone" button, a user has to say when the last medication has been taken. A user does not have to follow any pattern and can mention the timestamp in any convenient format, such as, for example, "two hours ago", "yesterday 10 p.m." or "11th March, noon". A smartphone transcribes the speech to the string, sends it to Wit.ai servers and receive the response in a Unix timestamp format. This approach allows to avoid the complexities with manual input for PD patients and avoid excessive typo errors.

The application is designed for English-speaking patients, so voice timestamp input is available only with English speech. However, Wit.ai supports language processing in 72 languages, so the feature can be improved according to the corresponding requirements of the following working packages of the Project STOP (Center for Ubiquitous Computing, 2018).

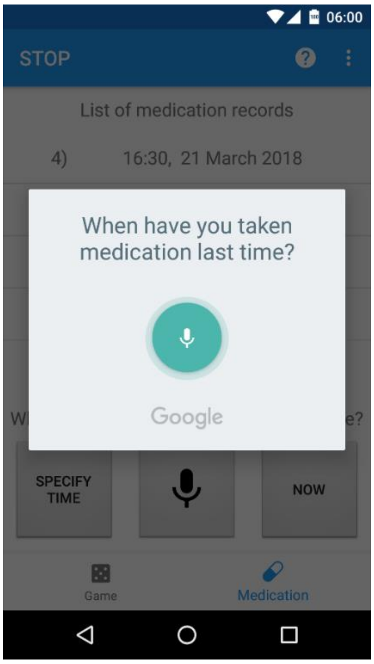

Figure 13. Medication timestamp input by voice

4.3.4 Feedback acceptance

The following working packages of the Project STOP will apply the artifact into use among the PD patients (Center for Ubiquitous Computing, 2018). Thus, the application design follows the continuous development approach and is open to improvements according to users' feedback (Beck et al., 2001). For this purpose, there is a feedback component in the application, whose interface is shown in Figure 14. The feedback screen provides users an ability to share the ideas about the application usage and the possible improvements. The collected suggestions can be taken into consideration in order to increase the quality of the user experience. The feedback component supports manual input and voice input in any language.

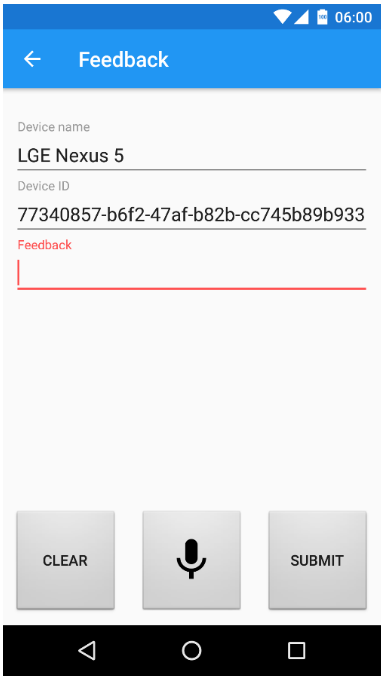

Figure 14. Feedback screen interface

The feedback data collection follows the same manner as health-related and notification ones. By clicking on “Submit” button the user saves feedback to the device’s SQLite database. Later a smartphone automatically synchronizes with the remote AWARE server and sends feedback to it. The structure of feedback collection dataset is represented in Table 7.

Table 7. Feedback collected data

Field	Description
_id	Primary key auto-incremented
timestamp	Unix timestamp in milliseconds of record
device_id	AWARE device ID
device_name	Device manufacturer and model information
feedback	User's feedback

5. Evaluation

The designed artifact provides an ability to perform continuous health state observation via short-term accelerometer-based game sessions. The game component contains a set of customizable parameters which can be modified affecting the flow of the game. Thus, there is a need to perform a pilot study to evaluate the game from the perspective of all the possible setting combinations and select the most appropriate one. The evaluation is performed at the University of Oulu on a group of volunteer participants who have no PD effect on their health. The study provides an understanding how the game is applicable for healthy users and helps to determine the standard game parameters. The defined results will provide an understanding what kind of derivation is expected from the further artifact use among the PD population during the following working packages of the Project STOP (Center for Ubiquitous Computing, 2018).

5.1 Experiments

The experimental study was conducted at the University of Oulu and involved ten participants. None of the participants has any symptoms or conditions of PD. The volunteers were asked to play an accelerometer-based game several times (27 or 9) each time with different parameter combinations. The setting options taken into consideration are represented in Table 8.

Table 8. Game parameters tested in the experiment

Parameter	Options		
Ball size	100 (small)	150 (medium)	200 (big)
Ball speed	1 (slow)	3 (normal)	5 (fast)
Game time	5 seconds	10 seconds	20 seconds

In total, 216 games were played and all the possible 27 parameter options combinations were tested. After each game session, the result was recorded for the further analysis. The game score-related datasets are presented in Appendix A from the perspective of each possible parameter option. Moreover, at the end of each experiment session volunteers answered the questionnaire about the game characteristics. The participants were asked to rank the game in a *1 (low) - 5 (high)* scale with regards the following heuristics: ease of use; user engagement and playfulness; perceived usefulness for PD tracking. The rankings of the heuristics from all participants are shown in Table 9.

Table 9. Evaluation of the game characteristics

Participant №	1	2	3	4	5	6	7	8	9	10
Gender	M	M	M	M	M	M	M	M	M	M
Age	23	25	29	35	35	31	27	41	34	22
Ease of use	5	4	5	5	5	4	5	5	5	5
Engagement, playfulness	4	4	4	4	4	3	4	5	3	4
Perceived usefulness for PD	5	4	5	1	5	4	5	5	4	4

5.2 Results

In order to evaluate the game parameters and scoring system, box plots visualizations (Williamson, Parker, & Kendrick, 1989) are used. The analysis of the general game score dataset collected during the lab evaluation (Appendix A, Dataset 1) provides a general picture how the game can be applied to the non-PD population. Figure 15 illustrates the box plot for the total 216 games played with all the possible setting variations. The figure represents among the all 216 played games, the maximum received score was 99.7, the minimum was 91.2 and 95% of all the received results are in the range from 94.5 and 99.7. The median score result for a player who has no PD symptoms is 97.9 points, the mean score is 97.5 and the standard deviation is 1.48, regardless of the defined setting variations.

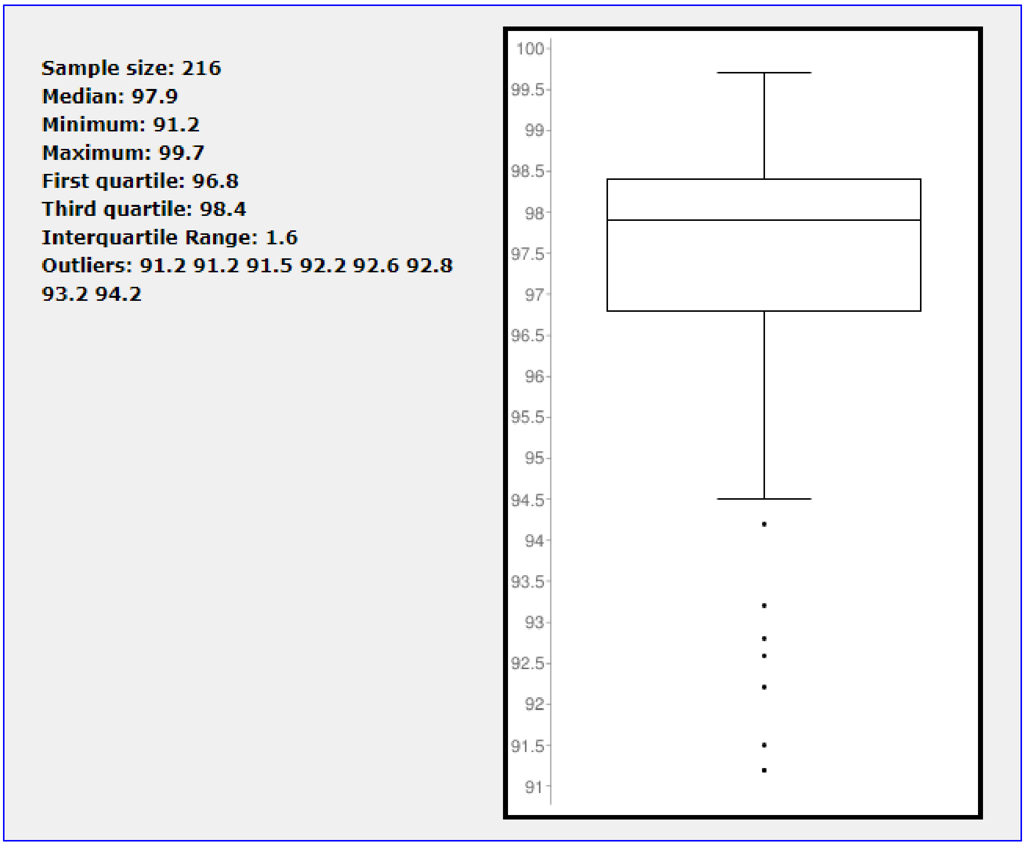

Figure 16. Game score results box plot for the general collected dataset

The further analysis of the datasets 2-10 (Appendix A) allows to determine what game parameters provide the most general results. The box plots illustrated in Figures 16-18 represent the score results depending on the stated parameters. Firstly, the evaluation of the datasets 2-4 (Figure 16) shows that the ball size 150 option dataset has the biggest length of boxplot excluding outliers. The score variation is 4.3 for ball size 100, 5.1 for ball size 150 and 5.0 for ball size 200. Thus, it can be concluded that the option of **ball size 150** provides the most general game score result in the sample.

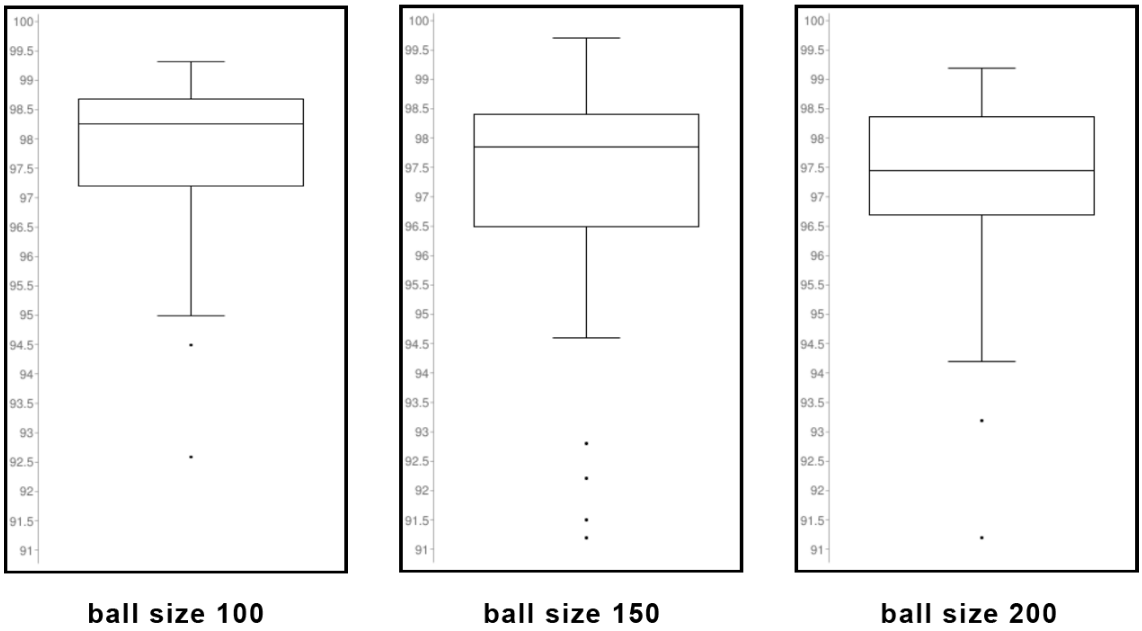

Figure 16. Game score results box plot for the different ball size options

Secondly, the evaluation of the datasets 5-7 (Figure 17) shows that the speed 3 option dataset has the biggest length of boxplot excluding outliers. The score variation is 3.1 for ball speed 1, 4.8 for ball speed 3 and 4.1 for ball speed 5. It can be concluded that the option of **ball speed 3** provides the most general game score result in the sample.

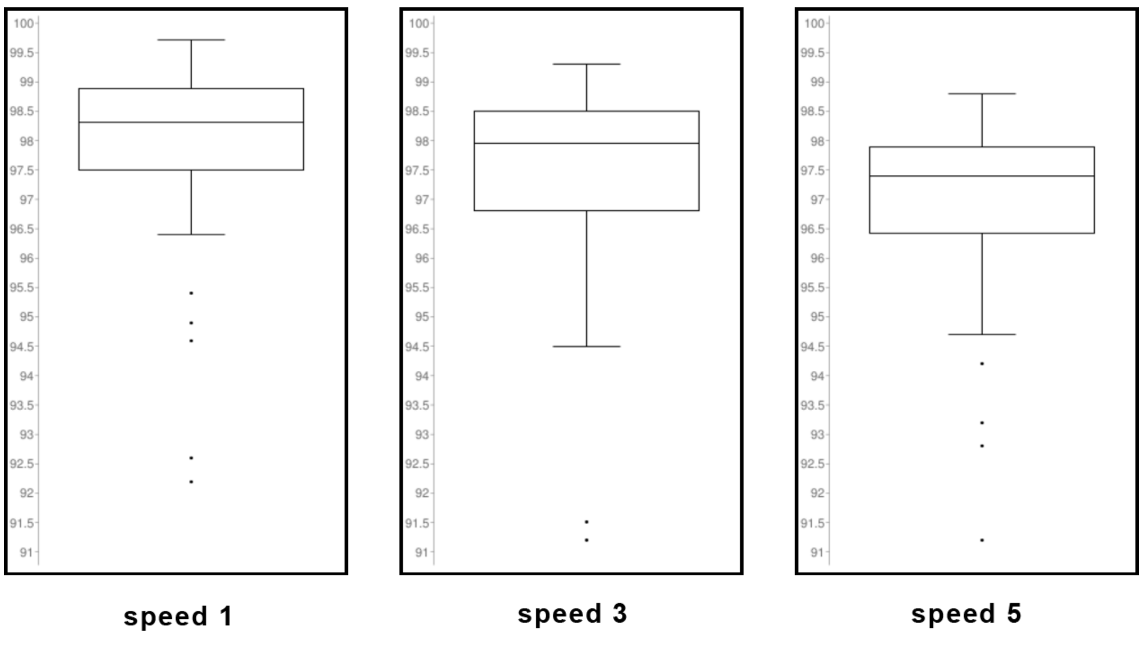

Figure 17. Game score results box plot for the different ball speed options

Thirdly, the evaluation of the datasets 8-10 (Figure 18) shows that the game time 10 seconds option dataset has the biggest length of boxplot excluding outliers. The score variation is 4.6 for 5 seconds option 1, 4.8 for 10 seconds option and 4.6 for 20 seconds option. It can be concluded that the option of **game time 10 seconds** provides the most general game score result in the sample.

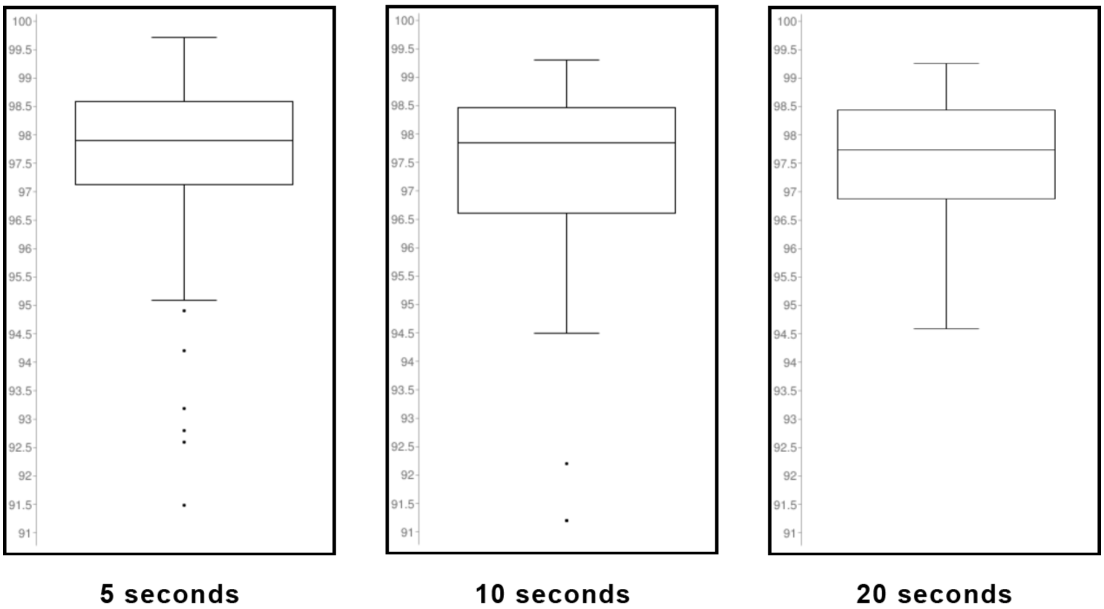

Figure 18. Game score results box plot for the different game time options

To sum up, the evaluation of the game parameters shows that the following games parameters provide the most general results and will be applied for the application as the default settings: **ball size 100**, **ball speed 3** and **game time 10 seconds**. However, the rest of the settings options will be still available in the application settings screen with the purpose to provide the game customization for every user.

The pilot study was conducted in the group of ten volunteers aged from 22 to 41 (Table 9), mean age 30 with standard deviation 6.1. The detailed descriptive analysis of the characteristic related data is presented in Table 10. The game specifications evaluation has shown that from the user perspective the game has the following characteristics:

1) High ease of use – characteristic's mode value 5
2) Above the average engagement and playfulness – characteristic's mode value 4
3) High perceived usefulness for PD - characteristic's mode value 5

Table 10. Game characteristics evaluation analysis

Characteristic	Median	Mean	Mode	Minimum	Maximum	Standard deviation
Ease of use	5	4.8	5	4	5	0.42
Engagement, playfulness	4	3.9	4	3	5	0.57
Perceived usefulness for PD	4.5	4.2	5	1	5	1.23

6. Discussion

This thesis study reflects the iterative development process of the gamified application for regular PD patient observation with the use of smartphones. This chapter overviews the flow of the thesis study, sums the results up from the perspective of the research problem and determines the limitations that can be taken into account and improved in future works.

6.1 Contributions

Initially, based on the specifications of the Project STOP (Center for Ubiquitous Computing, 2018), the focus of this thesis study was on the development of the mobile application that would act as a data collection assistant and retrieve the quantitative data from the various wearable devices. The study aimed at the development of the tool that would collect the data from Android Wear OS smartwatches (Android Developers, 2018d), Myo gesture control armband (Thalmic Labs, 2016) and Texas Instruments IoT SensorTag (Texas Instruments, n.d.). This variety of sampling wearables can collect the motion-related data, observe patient's muscle activity and provide a rich picture of a patient's health conditions. However, the study on the related work has shown that the use of wearable in PD observation has a set of difficulties that cannot be explicitly resolved in the thesis study, namely the short battery life and inconvenience in use that breaks the patient's routine (Vega, 2016; Vega et al., 2017).

On the other side, the study on the related work has shown that it is possible to use gamification in PD observation in order to increase patients' engagement (van der Meulen et al., 2016; Doerr et al., 2017; Mühlhaus et al., 2017). Furthermore, it was found that the topic of combining smartphone usage and gamification in PD observation had not been widely studied yet and there was an opportunity to contribute with the thesis to that domain. Thus, the thesis has finally focused on the development of a new mean of PD observation via the combination of smartphone use and gamification approach. Hence, in order to retrieve the meaningful results, three research questions were defined.

RQ1: How can smartphone capabilities and gamification be leveraged to track Parkinson's disease symptoms?

The outcome of this thesis study is a mobile application that leverages smartphone sensors for patient observation and uses gamification approach as a user engagement solution. Short-term health state sampling sessions are implemented as a simple accelerometer-based game. The application is designed in a way to make the health snapshot collection not a boring exercise process, but a playful one with the corresponding scoring system that represents how successful the player is. The application reminds a patient to regularly follow the measurements and keep recording the medication takings timestamps. Eventually, the thesis artifact utilizes the availability of smartphones in patient's everyday life and provides an ability to use mobile phones as a regular measurement tool. At the same time, the artifact applies gamification as a way to increase the patient's interest in the tool and improve the observation adherence.

RQ2: How Parkinson's disease can be measured using smartphone capabilities and gamification?

The application leverages smartphone's inbuilt sensors in order to evaluate the tremor effect on a patient. During the short game sessions, the application activates devices' accelerometer, linear accelerometer, rotation and gyroscope sensors and collects the data from them. The collected dataset represents the hand movements of a patient that can be used for evaluating the severity of PD at the specific moment of time. Moreover, the gamified component of the artifact evaluates the sampling session in a scoring system that shows how motionless were users' hands during the game: if the user is able to keep the ball still, the score tends to 100, which is the maximum result, that shows that the user does not have any tremor effects. Along with the game sampling, the application measure PD with the daily questionnaire: once per day a user is asked to evaluate how severe was PD for the previous day and submit the result to the application. The datasets collected via game, medication journal and questionnaire components altogether can be used for the evaluation the correlation between the effect of medication and severity of PD during the day. This further analysis will be performed during the following working packages of the Project STOP (Center for Ubiquitous Computing, 2018).

RQ3: What user-device interaction strategies can be used to maximize Parkinson's disease medication adherence?

In order to ease the user experience and maximize its convenience, the artifact design applies a set of user-centered strategies. First of all, the application takes into consideration PD patients' health inabilities, such as tremor. The application control elements are implemented in a big size and have an explicit click response. Moreover, the application's components, that require an input from the user, supports both manual and voice input. Thus, the navigation and input means in the application are accessible for patients with different levels of PD. Secondly, the application uses Android's notification component (Android developers, 2018a) in order to remind a user to use the artifact on a regular basis. When a device triggers a notification, a user is reminded to play a game that samples the PD and record the last medication time. This approach allows to collect the health-related data regularly and at the same time reminds a user about medication takings and increases its adherence.

The gamified component of designed artifact provides users a flexibility in use via the game settings availability that allows modifying the size of UI elements, the speed of the gaming ball and the length of the sampling session. In order to figure out the most applicable settings variation and evaluate the general usability of the application, the lab evaluation study was conducted. Ten volunteer non-PD participants tested the application and evaluated the artifact from the perspective of ease of use, playfulness and engagement, and perceived usefulness for PD. The experiment helped to determine the default settings combination for the game (ball size 100, ball speed 3 and game time 10 seconds) and provided the study with a positive feedback about the application usability. The participant feedback reflects that the artifacts' ease of use and perceived usefulness for PD is high and playfulness and engagement is above average.

Taking all the aforesaid into consideration, it is possible to say that the thesis and the designed artifact contribute to the studying of PD from the perspective of smartphone usability in PD continuous observation. By the combination of smartphone use and gamification approach, the designed artifact allows to observe a patient's states of health in a much more frequent way than occasional measurements in clinical environments.

6.2 Limitations and future work

The significant limitation of this thesis study is its evaluation experiment. The lab study was conducted on a small volunteers group (10 participants), which is enough for the definition of the default game parameters and general game characteristics evaluation but does not provide the understanding how actually the artifact is applicable for PD patients with real health complications. The evaluation of the application is a part of the future work during the following working package of the Project STOP (Center for Ubiquitous Computing, 2018). With the help of The University of Manchester, the artifact will be applied to the group of PD volunteers that are agreed to test the application in the real environment and to evaluate the artifact accessibility from the patient's perspective. The incoming study has already defined guidelines that are represented in Appendix B. The evaluation study requires an agreement from a patient to use the application on the regular basis during two weeks. The continuous use of the artifact will provide a picture of health changes of patients during the defined time frame. Along with the data collection via the artifact, the evaluation study requires a participant to answer the general questionnaire about the use of mobile devices for the following PD observation. The questionnaire is also listed in Appendix B.

The focus of this study was on the development of the artifact for Android devices. However, in order to increase the availability of the application, the version for iOS devices is in development by another member of the Project STOP. The iOS version of the artifact is implemented based on the existing architecture of the Android application. For this purpose, the implementation of the artifact followed continuous development approach with the use of GitHub as a VCS. The source code writing was handled in a readable way with the corresponding explanatory comments. The whole source code is available at the STOP application repository (STOP, 2018). When both applications will be ready to use and polished according to the feedback received from PD patients, the application will be uploaded to Google Play and App Store digital distribution platforms. This will increase the availability of the application worldwide and will increase the scope of the study. Before the uploading to these platforms, the application will be slightly redesigned in order to differentiate PD and non-PD users. The general availability of the artifact will allow everybody to use the application, so that will enrich the data collection domain and will provide a more profound picture both of PD and non-PD populations.

The results of this thesis study can be taken into consideration as the basis for the further researches about the gamification applicability to PD following. The thesis focuses mostly on the observation of patient's tremor effect, however the PD results also in bradykinesia, muscle rigidity and postural instability (Weintraub et al., 2008). Arora et al. (2015) have utilized smartphones for observing the patients' spatial memory, dexterity and tapping speed, voice and walking abilities, but the study has not considered the gamification as a user engagement approach. Thus, the observation on the wide scope of PD symptoms can be implemented with the use of gamification and this thesis study can be helpful and informative for it. Furthermore, from the perspective of the designed artifact, the gamification component can be advanced and developed further. At the moment the application does not introduce any gamified components except scoring system. The further development of the application can make the artifact more playful and introduce more gamification elements, such as achievement system, badges or leaderboard for following the personal game results (Deterding et al., 2011).

This thesis study was completed as a part of the Project STOP and the further research on the subject that extend the thesis domain will continue according to project schedule (Center for Ubiquitous Computing, 2018). Moreover, the results of the thesis and the following studies will be submitted to the several scientific conferences. The study has already been enrolled as a demo participant for MobileHCI 2018, 20th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI, 2018). Furthermore, the study is planned to be presented in The ACM CHI Conference on Human Factors in Computing Systems (CHI 2019, 2018) and in ACM IMWUT UbiComp'19 (ACM IMWUT, 2018).

7. Conclusion

Parkinson's disease is a second most common neurological disorder that affects up to 10 million people worldwide (Vega, 2016). However, the effectiveness of the current way of treatment is not sufficient enough due to the evolving nature of the disease. Today PD treatment is followed by semi-annual clinical observation with the corresponding medication prescription (Vega et al., 2017). But the problem is that the disease symptoms vary from patient to patient and may change several times per day for a person. Thus, there is a need in the development of new means that will allow observing the patients in a more frequent way, that in result will increase the personal medication plan customization accessibility (Sharma et al., 2014).

This thesis study focused on the development of the application for Android devices named "STOP". The application combines the availability of smartphones, leverage its inbuilt sensors to measure the PD during the day, uses gamification approach as a way to engage patients to the artifact on a regular basis, and utilizes smartphones' notification for increasing the patients' medication adherance. The study has shown that it is possible to adapt smartphone use for continuous patient observation by regular health sample takings through the gamified application components. With the help of smartphone's sensors, the artifact measures patient's movement functionalities and keep an eye on the medication adherence. The application is designed in a patient-friendly way and aims at the making the user experience as easy as possible.

The study was mainly focused on the development of the measurement tool and was evaluated on the group of non-PD volunteers. The work on the subject will be continued in terms of the Project STOP (Center for Ubiquitous Computing, 2018). The objectives for the following studies are the evaluation of the artifact in a real environment with the help of PD patients and the estimation of the correlation between the medication takings effect and the changes in movement functionalities of the patients during the day.

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Appendix A: Game components score datasets

Dataset 1: All the played games with various parameter combinations

99.0	98.6	98.9	97.9	99.0	98.4	92.6	99.0
99.2	99.0	98.2	97.5	99.0	97.1	98.3	98.6
99.2	99.0	98.9	97.2	98.3	99.0	97.5	99.0
98.9	97.0	95.1	98.4	98.0	97.4	97.1	98.0
99.3	96.0	94.5	98.4	97.4	97.9	98.5	98.6
98.9	97.5	96.6	98.3	99.0	98.3	98.3	98.4
98.2	96.7	97.1	97.2	98.3	97.2	98.6	98.1
98.3	96.3	95.7	98.7	97.9	96.5	97.9	98.0
98.4	96.3	95.0	98.3	98.2	96.4	98.8	97.7
99.7	98.3	95.4	97.9	98.0	98.4	94.9	99.2
98.8	92.2	97.8	98.7	98.3	98.0	97.0	98.3
99.0	96.5	97.9	98.5	98.6	97.3	94.6	98.9
98.9	98.4	98.9	91.5	98.8	98.3	96.2	98.6
99.1	96.8	97.7	96.5	98.0	97.9	96.1	97.8
98.7	96.3	98.2	95.8	97.2	98.4	95.2	98.6
98.1	98.4	97.4	97.2	97.4	97.7	92.8	97.5
98.1	94.8	95.6	96.5	97.9	96.0	91.2	98.7
98.2	97.4	97.3	96.7	97.7	96.8	96.3	97.9
98.7	97.9	97.9	98.0	97.1	96.4	98.6	99.1
98.4	97.9	98.5	98.5	96.6	96.6	98.7	98.9
98.0	97.5	97.7	97.7	96.7	96.6	98.6	98.4
98.5	97.3	97.6	98.4	96.8	96.8	98.7	99.2
98.5	97.7	91.2	98.3	96.6	96.0	96.7	98.6
98.8	97.9	97.3	96.6	97.0	97.3	98.1	98.4
97.7	94.2	95.5	97.5	97.4	93.2	97.9	97.6
97.6	97.4	94.9	96.6	97.4	94.7	97.0	97.4
97.4	96.6	95.5	97.1	97.3	97.0	97.3	95.0

Dataset 2: Score results for games with ball size 100

99.0	98.6	98.9	97.9	99.0	98.4	92.6	99.0
99.2	99.0	98.2	97.5	99.0	97.1	98.3	98.6
99.2	99.0	98.9	97.2	98.3	99.0	97.5	99.0
98.9	97.0	95.1	98.4	98.0	97.4	97.1	98.0
99.3	96.0	94.5	98.4	97.4	97.9	98.5	98.6
98.9	97.5	96.6	98.3	99.0	98.3	98.3	98.4
98.2	96.7	97.1	97.2	98.3	97.2	98.6	98.1
98.3	96.3	95.7	98.7	97.9	96.5	97.9	98.0
98.4	96.3	95.0	98.3	98.2	96.4	98.8	97.7

Dataset 3: Score results for games with ball size 150

99.7	98.3	95.4	97.9	98.0	98.4	94.9	99.2
98.8	92.2	97.8	98.7	98.3	98.0	97.0	98.3
99.0	96.5	97.9	98.5	98.6	97.3	94.6	98.9
98.9	98.4	98.9	91.5	98.8	98.3	96.2	98.6
99.1	96.8	97.7	96.5	98.0	97.9	96.1	97.8
98.7	96.3	98.2	95.8	97.2	98.4	95.2	98.6
98.1	98.4	97.4	97.2	97.4	97.7	92.8	97.5
98.1	94.8	95.6	96.5	97.9	96.0	91.2	98.7
98.2	97.4	97.3	96.7	97.7	96.8	96.3	97.9

Dataset 4: Score results for games with ball size 200

98.7	97.9	97.9	98.0	97.1	96.4	98.6	99.1
98.4	97.9	98.5	98.5	96.6	96.6	98.7	98.9
98.0	97.5	97.7	97.7	96.7	96.6	98.6	98.4
98.5	97.3	97.6	98.4	96.8	96.8	98.7	99.2
98.5	97.7	91.2	98.3	96.6	96.0	96.7	98.6
98.8	97.9	97.3	96.6	97.0	97.3	98.1	98.4
97.7	94.2	95.5	97.5	97.4	93.2	97.9	97.6
97.6	97.4	94.9	96.6	97.4	94.7	97.0	97.4
97.4	96.6	95.5	97.1	97.3	97.0	97.3	95.0

Dataset 5: Score results for games with ball speed 1

99.0	99.7	98.7	98.6	98.3	97.9	94.9	98.6
99.2	98.8	98.4	99.0	92.2	97.9	97.0	98.7
99.2	99.0	98.0	99.0	96.5	97.5	94.6	98.6
98.9	95.4	97.9	97.9	97.9	98.0	99.0	99.1
98.2	97.8	98.5	97.5	98.7	98.5	98.6	98.9
98.9	97.9	97.7	97.2	98.5	97.7	99.0	98.4
99.0	98.0	97.1	98.4	98.4	96.4	92.6	99.2
99.0	98.3	96.6	97.1	98.0	96.6	98.3	98.3
98.3	98.6	96.7	99.0	97.3	96.6	97.5	98.9

Dataset 6: Score results for games with ball speed 3

98.9	98.9	98.5	97.0	98.4	97.3	96.2	98.7
99.3	99.1	98.5	96.0	96.8	97.7	96.1	96.7
98.9	98.7	98.8	97.5	96.3	97.9	95.2	98.1
95.1	98.9	97.6	98.4	91.5	98.4	98.0	99.2
94.5	97.7	91.2	98.4	96.5	98.3	98.6	98.6
96.6	98.2	97.3	98.3	95.8	96.6	98.4	98.4
98.0	98.8	96.8	97.4	98.3	96.8	97.1	98.6
97.4	98.0	96.6	97.9	97.9	96.0	98.5	97.8
99.0	97.2	97.0	98.3	98.4	97.3	98.3	98.6

Dataset 7: Score results for games with ball speed 5

98.2	98.1	97.7	97.2	97.2	97.5	92.8	97.9
98.3	98.1	97.6	98.7	96.5	96.6	91.2	97.0
98.4	98.2	97.4	98.3	96.7	97.1	96.3	97.3
96.7	98.4	94.2	98.3	97.4	97.4	98.1	97.6
96.3	94.8	97.4	97.9	97.9	97.4	98.0	97.4
96.3	97.4	96.6	98.2	97.7	97.3	97.7	95.0
97.1	97.4	95.5	97.2	97.7	93.2	98.6	97.5
95.7	95.6	94.9	96.5	96.0	94.7	97.9	98.7
95.0	97.3	95.5	96.4	96.8	97.0	98.8	97.9

Dataset 8: Score results for games with game time 5 seconds

99.0	99.7	98.7	97.9	97.9	98.0	94.9	92.6
98.9	98.9	98.5	98.4	91.5	98.4	96.2	97.1
98.2	98.1	97.7	97.2	97.2	97.5	92.8	98.6
98.6	98.3	97.9	99.0	98.0	97.1	98.6	99.2
97.0	98.4	97.3	98.0	98.8	96.8	98.7	98.6
96.7	98.4	94.2	98.3	97.4	97.4	97.9	97.5
98.9	95.4	97.9	98.4	98.4	96.4	99.0	99.1
95.1	98.9	97.6	97.4	98.3	96.8	98.0	99.2
97.1	97.4	95.5	97.2	97.7	93.2	98.1	97.6

Dataset 9: Score results for games with game time 10 seconds

99.2	98.8	98.4	97.5	98.7	98.5	97.0	98.3
99.3	99.1	98.5	98.4	96.5	98.3	96.1	98.5
98.3	98.1	97.6	98.7	96.5	96.6	91.2	97.9
99.0	92.2	97.9	99.0	98.3	96.6	98.7	98.3
96.0	96.8	97.7	97.4	98.0	96.6	96.7	97.8
96.3	94.8	97.4	97.9	97.9	97.4	97.0	98.7
98.2	97.8	98.5	97.1	98.0	96.6	98.6	98.9
94.5	97.7	91.2	97.9	97.9	96.0	98.6	98.6
95.7	95.6	94.9	96.5	96.0	94.7	98.0	97.4

Dataset 10: Score results for games with game time 20 seconds

99.2	99.0	98.0	97.2	98.5	97.7	94.6	97.5
98.9	98.7	98.8	98.3	95.8	96.6	95.2	98.3
98.4	98.2	97.4	98.3	96.7	97.1	96.3	98.8
99.0	96.5	97.5	98.3	98.6	96.7	98.6	98.9
97.5	96.3	97.9	99.0	97.2	97.0	98.1	98.6
96.3	97.4	96.6	98.2	97.7	97.3	97.3	97.9
98.9	97.9	97.7	99.0	97.3	96.6	99.0	98.4
96.6	98.2	97.3	98.3	98.4	97.3	98.4	98.4
95.0	97.3	95.5	96.4	96.8	97.0	97.7	95.0

Appendix B: STOP study guide

STOP

Study guide

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Participant ID: ______________
Start date: ______________
End date: ______________

Consent form

Purpose of this study

The participant is asked to volunteer for a research project studying how the medication affects Parkinson’s disease (PD) patients during the day. The study will use an Android application named STOP with inbuilt ball game that helps to collect inertial data and medication journal that provides an ability to track medication sessions. By collecting data using these two components the study will try to find the correlation between the medication effect and time with the help of mobile devices. The outcome of this study will provide us with a clearer understanding of medication effect on Parkinson’s patients’ state of health during the day, which can have a considerable impact on PD treatment in general.

Collected data

This study collects the following information:

- Mobile device sensors data: there is a ball game exercise in the application that asks PD patients to play a simple game for ten seconds. During a game session, the application collects the mobile device’s gyroscope, accelerometer, linear accelerometer and rotation data
- Medication time data: the application asks the participant to record information about when the last medication was taken.
- Notification data: the application randomly displays a notification four times per day in order to remind participant to play a game and record medication times. The time the notifications are shown and when they are opened is recorded.
- Feedback: the participant is able to provide feedback about the application usage.

Procedures

The participant is enrolled in the study for a period of 2 weeks.

- When the participant visits us on the first day, we will install STOP application on their mobile device, ask a few questions about how they currently use their mobile device and the participant signs this document.
- For the duration of the study, the application will randomly show notification four times per day. When the notification is shown a participant is asked to play a game and record the last medication time to the medication journal.
- By the end of week 2, we will remove the software from the participants’ mobile devices and the participant would be given an Amazon voucher. Lastly, we'll ask participants a few final questions about their data and impressions on the study itself.

Compensation

The participant will be rewarded with 50£ Amazon voucher, given on the last day of the study.

Participant requirements

We require that the participant owns an Android mobile phone or tablet with Android 4.4 or higher, has access to the internet on the device and use it like they normally would. The participant can not uninstall the application we install unless the participant wants to leave the study, which can be done at any given time. If the participant decides to leave the study, the participant should contact us to remove the software currently installed and the Amazon voucher will not be delivered.

Risks

The risk and discomfort associated with participating in this study are no greater than those ordinarily encountered in daily life or while carrying a mobile device.

Benefits

There may be no personal benefit from participating in the study but the knowledge received may be of value to research and possibly PD treatment in general.

Confidentiality

Your data and consent form will be kept separate. Your consent form will be stored in a locked location at the University of Oulu and will not be disclosed to third parties. By participating, you understand and agree that the data and information gathered during the study may be used by the University of Manchester and the University of Oulu and published and/or disclosed by the University of Manchester and the University of Oulu to others for further analysis. However, no private data (name, address, contact information or other personal identifiers) in your consent form will be mentioned in any such publication or dissemination of the research data and/or results by the University of Manchester and the University of Oulu.

The researchers will take the following steps to protect participants' identities: each participant is assigned a number; the data is collected during the study by the number, NOT the name; any data will be stored indefinitely in a secure and password protected location accessed only by authorized researchers.

By signing this document, you are formally agreeing to collect the previously described data and you have been answered all the questions you might have had about this document and the study by the researcher in this room.

________________________________ (date and your signature)

Questionnaire

Participant ID: ________________
Date: ________________

Pre-Study questions:

How do you know when to take medication?

____
____
____
____

Do you use your phone to keep track of your medication?

____
____
____
____

When you get a notification on your device, do you check immediately what happened?

____
____
____
____

How would you describe how you use your phone, for example, do you use it for short periods of time vs long periods of time?

____
____
____
____

Post-Study questions:

What do you think about the idea of medication tracking with the use of mobile devices?

____
____
____
____

Have you followed the scheduled notifications from STOP? (4 times per day, every day)

____
____
____
____

If you were to log your medication with your phone, would you record some other information?

____
____
____
____

Would you like to use a smartwatch to track your medication instead of your phone?

____
____
____
____

Your mobile device is (name and model):

__ Mobile phone: ________________________
__ Tablet: ______________________________

You are:

__ Male, Age: ____
__ Female, Age: ____

Thank you for your time!