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INERTIAL SENSORS BASED WEARABLE MOTION MONITORING SYSTEM

Master's thesis

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KAASASKANTAV INTERTSIAALSETEL SENSORITEL PÕHINEV LIIKUMISE JÄLGIMISE SÜSTEEM

Magistritöö

Juhendaja: Alar Kuusik
PhD
Vanemteadur

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Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

In this modern age, computer and computer system usage is exponentially increasing. Consequently, Human Computer Interaction (HCI) and smart systems, such as patient monitoring systems, wearable healthcare solutions, smart home control systems, are getting more popular day by day. In addition to computers, mobile communication device usage has a huge aggravation. Another important sector is embedded control and measurement systems. It has always been involved in our lives and has always been playing huge role. However, smart systems with embedded devices are other recent trend which is permeating through in every part of our lives.

This thesis will describe mobile device software development for a wearable human motion tracking system. This solution can be used for both health and sport sector. The final outcome of this work is smartphone HCI software enabling home based assessment of patients with progressive neural diseases. Operation and communication principles of original wireless inertial sensors will be presented in the thesis as well.

This thesis is written in English and is 102 pages long, including 4 chapters, 27 figures and 2 tables.

Annotatsioon

Kaasaskantav intertsiaalsetel sensoritel põhinev liikumise jälgimise süsteem

Arvuti ja arvutisüsteemide kasutus kasvab tänapaeval eksponentsiaalselt. Selle tagajärjel inimese ja arvuti interaktsioon (Human Computer Interaction, HCI) ja targad süsteemid, nagu näiteks patsientide jälgimise süsteemid, kaasaskantavad tervise lahendused ja targa kodu kontollsüsteemid, koguvad iga päevaga aina rohkem populaarsust. Lisaks sellele kasvab ka mobiilisete seadmete kasutus jõudsalt.

Teine kiirelt arenev valdkond on sisseehitatud kontrolli ja mõõtmise süsteemid. Sammuloendur on näide sellise süsteemi kohta. Viimastel aegadel on need süsteemid meie elu lahutamatu osa. Sisseehitatud kontrolli ja mõõtmise süsteemidega targad süsteemid on viimase aja trend, mis tungib meie igapäevaellu aina rohkem. Selle kohta võib näitena tuua sammuloenduriga nutitelefoni.

See uurimustöö kirjeldab mobiilse tarkvara arendamist kaasaskantavale liikumise jälgimise süsteemile. Seda lahendust saab kasutada nii tervise kui ka spordi eesmärgil. Uurimustöö lõpplahendus on nutitelefoni HCI tarkvara, mis võimaldab hinnata patsientide progressiivseid neuroloogilisi haigusi koduses keskkonnas.

Lõputöö on kirjutatud inglise keeles ning sisaldab 102 lehekülge teksti, 4 peatükki, 27 joonist ja 2 tabelit.

List of abbreviations and terms

DPI	Dots per inch
TUT	Tallinn University of Technology
HCI	Human Computer Interaction
ATM	Personal Digital Assistant
IT	Information Technology
ICT	Information and Communications Technology
iOS	iPhone Operating System
EAS	Ettevõtluse Arendamise Sihtasutus (Enterprise Estonia)
IMU	Inertial Measurement Unit
MEMS	Microelectromechanical Systems
RLG	Ring Laser Gyroscope
FOG	Fiber Optic Gyroscope
PDA	Personal Digital Assistant
DBS	Deep Brain Stimulation
NIH	United States National Institutes of Health
FI Wear	Fox Insights Wearables
API	Application Program Interface
BLE	Bluetooth Low Energy
AWS	Amazon Web Services
Amazon S3	Amazon Simple Storage Service
GPIO	General Purpose Input / Output
PWM	Pulse-Width Modulation
OSAL	Operating System Abstraction Layer
PM3	A Power Mode
GATT	Generic Attribute Profile
ATT	Attribute Protocol
BR/EDR	Basic Rate / Enhanced Data Rate
LE	Low Energy

UUID	Universally Unique Identifier
EDF	European Data Format
JSON	JavaScript Object Notation
STS	Security Token Service
SSID	Security Set Identification
SDK	Software Development Kit
IAM	Identity and Access Management
EEG	Electroencephalography
PSG	Polysomnography
EMG	Electromyography
ECG	Electrocardiography
UX	User Experience

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1 Introduction

With the growing technology, the term of Human Computer Interaction (HCI) has started to play a key role for society. It has been perfectly involved to our life. We can see it in almost every sector from entertainment to health. In the 21st century, computers and IT systems are permeating through in every part of our lives. Even if a person does not have a tablet, a computer or a mobile phone, their life is affected with computing. Card payments, ATM machines, coffee machines, library membership cards, bus cards, some smart homes or restaurants are only couple examples of computing and interfaces with computer systems. Therefore, HCI is a crucial factor for developers or IT companies as their users will directly be affected. Usability and safety are the most important two principles of Human Computer Interaction. HCI usability issues are especially important in applications targeting older generations and elderly people. Usability issues are considered as one of the most important blocking factor for wide deployment of home telecare solutions.

The usage of mobile phones or tablet devices is exponentially increasing. It is perfectly adapted to our daily life. There is even a big percentage of elderly people using mobile phones. As a consequence, mobile applications and mobile application development are new trends and they are getting even more popular every day. It does not only make our life easier but also it is a very good way to spend spare time.

The figure (Figure 1) below shows augmentation of the mobile device usage in years.

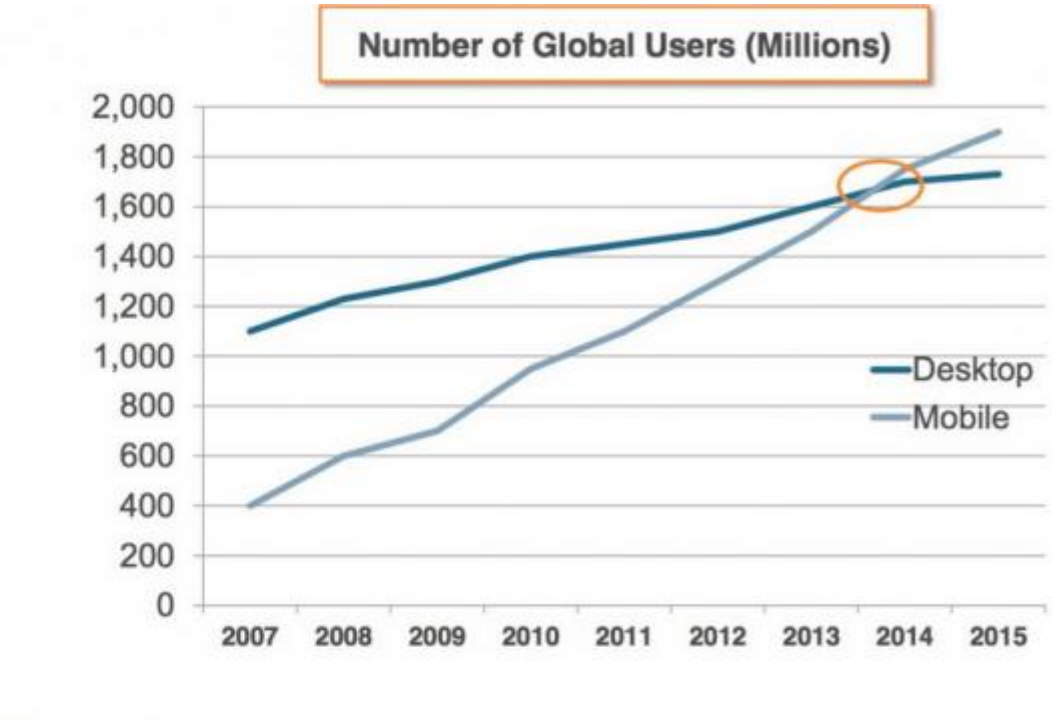


Figure 1 Number of Global Users (in Millions) [1].

Embedded systems have always been playing a crucial role in our everyday life. It was already adapted to our lives before computers and mobile technologies. Furthermore, in this modern age, the usage of embedded systems in health sector is exponentially increasing and it provides huge benefits for both saving lives and helping patients. It also provides huge benefits to monitor health and safety. Especially for elderly people, embedded systems in health sector are very important and helpful.

Current developments are related to existing R/D home telecare project combining wearable sensors, smartphone software for user interaction and back–end server software for sensor signal processing and databasing. This project is sponsored under Norwegian Green-ICT program. Mobile application which is developed and described in the thesis takes sensor data, processes these results and uploads them to cloud server. In backend, after these results are being processed to different format, they are added to the database. After data format is changed and added to database, backend sends these results back to mobile application. User receives a notification and monitors taken test results in the mobile phone. I have implemented this project into two mobile

environments. They are iOS and Android. All details and communications are explained clearly in the below sections.
The technological partners of particular Norwegian Green-ICT project are: Estonian partner is Eliko and the Norwegian partner is Dignio. All project rights are reserved under their licences. Eliko is mostly responsible for hardware development. On the other hand, Dignio is responsible for backend development and all cloud implementations. I have implemented client side mobile applications. My implementations contain iOS application development and Android application development.

Who is Eliko?

Eliko is an Estonian embedded electronics and software development company which has more than 70 clients and partners, more than 100 industrial research and development projects. They have more than 200 publications [2].

Who is Dignio?

Dignio is a Norwegian software development company with an ambition to be a leading health care provider. They are located in Kråkerøy, Norway [3]. They provide Prevent backend service and telemedicine service for health sector. Their services are already widely used in the market [3][4].

What are EAS Services?

Estonian Enterprise (EAS) has been active since 2000. Their long-term and biggest goal is to make Estonia one of the most competitive countries in the world. Therefore, they provide financial assistance, counselling, cooperation opportunities, useful trainings for entrepreneurs [5].

The cooperation possibilities between Norway and Estonia have been raised with the Green Industry Innovation Program. Estonia has started to work and focus on Green ICT based on Transport & Logistics, Production & Trade, Energy Management System and E- Health. This project is a part of E-Health vision.

My Task:

The sensor developments have been completed by Eliko. Telemedicine solution provider Dignio has customized their product according to project needs. My task is to develop mobile application that sends data to Dignio's repository and reads the data from their backend. I have implemented two mobile applications. They are Android application and iOS application. The mobile application reads the sensor data and stores the data results to a temporary file in device memory. Mobile client authenticates with Dignio's backend service. After authentications are done, it uploads the sensor data to repository. Backend service processes the data and sends it back to the mobile client. Mobile client reads the data and shows to end user. Appendix section contains the application screens that are implemented by me.

2 Inertial Sensors

An Inertial Measurement Unit (IMU) contains different components such as accelerometers, gyroscopes, an integrated power supply, a processor and sometimes also magnetometers [6][7][8]. An IMU generally has three gyroscopes and three accelerometers which are installed vertically to each other [7]. Therefore, IMU can produce three-dimensional measurement of specific force and angular rate [6].

An accelerometer measures specific force without an external reference. Likewise, gyroscope measures angular rate without an external reference. If a device measures velocity, acceleration, or angular rate of a body with an external reference or with using environment feature, this device is not an inertial sensor. Inertial sensors measurements are done disrespect to features in the environment [6].

Inertial sensor capability affects the performance of an IMU. If the capability of an inertial sensor is high, than the IMU performance will be higher as well. However, the performance does not only depend on the capability. The error compensation algorithm and true determination of error parameters are also other crucial points to increase the IMU performance.

Although there is no officially agreed definition for low grade, medium grade and high grade IMUs and Inertial sensors, there are some basic examples that can be universally considered in a same way. For example, the inertial sensors, which are used in ships, submarines and spacecraft, can be considered under highest grades of inertial sensors. On the other hand, automation grade can be counted as a lowest inertial sensor grade [6].

2.1 Accelerometers

An overall structure of accelerometers contains one proof mass, two springs, one pickoff and a case.

The figure (Figure 2) below shows these parts at equilibrium state.

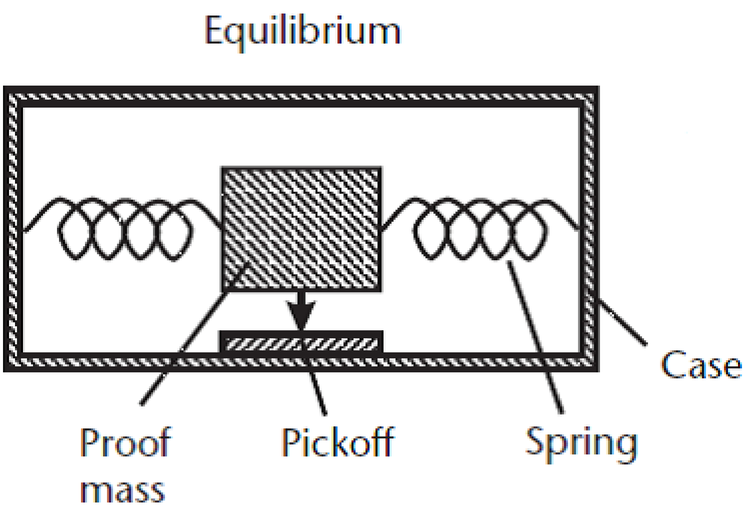


Figure 2 Components of an accelerometer at equilibrium state [7].

A proof mass is attached to two springs. This provides some distinct movement environment for it. Proof mass moves the case [9]. The electrical voltage is generated by pickoff. A pickoff also measures the position of the mass. If an accelerating force applied to the case along the sensitive axis, the proof mass will continue at its previous velocity, as a result, the case will move with respect to the mass with compressing one spring and stretching the other one. This changes the force they relay to the proof mass from the case [6].

A force can be applied to an accelerometer from different sides. Figure 2 and Figure 3 shows the applied force from different sides. In Figure 2, a proof mass moves at the side of the case. On the other hand Figure 3 shows gravitational acceleration. An accelerometer is used to measure gravitational accelerations [10].

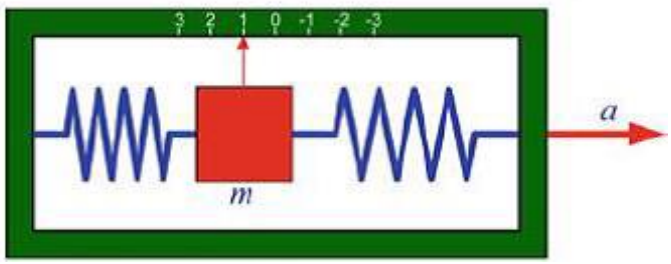


Figure 3 Linear acceleration is applied to an accelerometer [10].

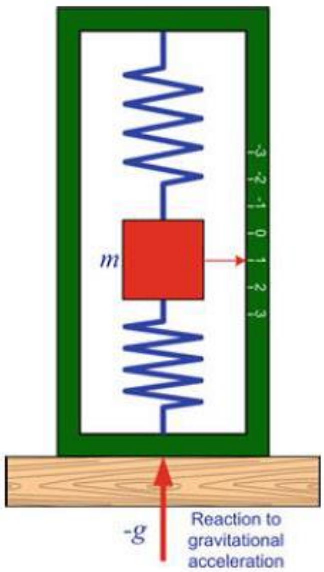


Figure 4 Gravitational force measurement of an accelerometer [10].

The specific force equation is given by; specific force value is equal to, subtracting gravitational force value from the value of the acceleration at the inertial frame.

$$f = specific\ force$$
$$g = gravitational\ force$$
$$a = acceleration\ at\ the\ inertial\ frame$$

$$f = a - g$$

There are three basic types of accelerometers. They are; Capacitive Accelerometers, Piezoelectric Accelerometers and Piezoresistive accelerometers.

A working principle of “Capacitive Accelerometers” is very close to mechanical accelerometers. It uses capacitive sensing techniques to measure the acceleration on a surface. Capacitive accelerometers can sense both static and dynamic acceleration on devices[11].

A capacitive accelerometer is also known as a vibration sensor.

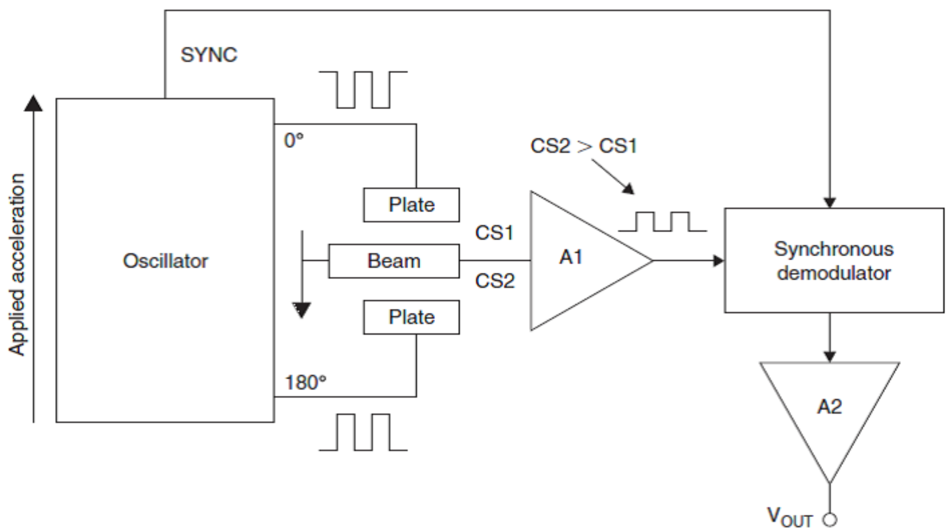


Figure 5 Working principle of a capacitive accelerometer [12].

Figure 5 above shows the block diagram of a capacitive accelerometer.

A piezoelectric accelerometer converts acceleration which is applied to an electrical signal. Based on the applied acceleration, its proof mass changes the position of the accelerometer. These accelerometers are generally used for measuring vibrations [13].

The figure (Figure 6) below demonstrates a piezoelectric accelerometer converts acceleration to electrical signal.

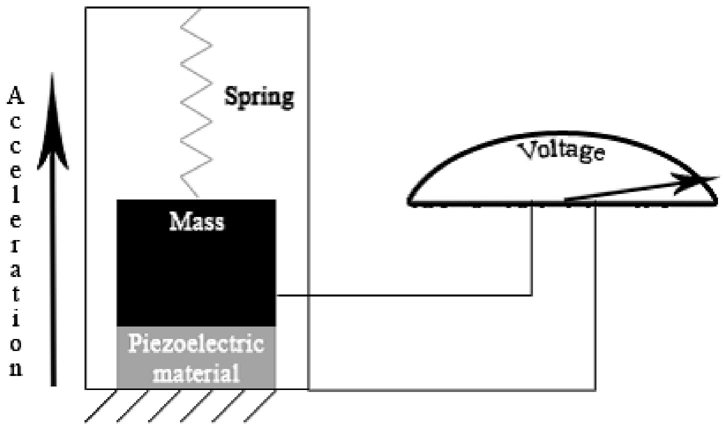


Figure 6 - Applied acceleration trigs voltage generation for piezoelectric material [8].

Piezoresistive accelerometers are commonly used for shock and vibration measurements. A piezoresistive accelerometer measures acceleration of a reference frame to which they are attached [13].

Table (Table 1) below demonstrates the advantages and disadvantages of these three different accelerometer technologies.

Table 1- Advantages/Disadvantages of different accelerometer types [13].

Sensors	Advantages	Disadvantages
Capacitive	• Measures constant (e.g., gravitational) acceleration / Static Acceleration • High accuracy and reliability • Cheap manufacturing with semiconductor technology	• Low resolution /Low bandwidth (nearly 5000 Hz) • Fragile
Piezoelectric	• Large bandwidth • High acceleration range • Cheap manufacturing	• Only for low frequencies • Constant acceleration cannot be measured • No/poor stability • Poor temperature performance
Piezoresistive	• Measures constant (e.g., gravitational) acceleration / Static Acceleration • High acceleration range	• Limited resolution because of resistive noise • Only for low and medium frequencies • Low temperature performance • Supply voltage required

2.2 Gyroscopes

A gyroscope measures the angular rotational velocity of a moving platform. It measures rate of change as well as the accelerometer. However, they measure the rate of change for different things [14]. Attitude parameters of gyroscope (such as roll, pitch and yaw) are calculated based on its measurements. Thus, if full navigation parameters need to be gathered, than accurate gyroscope measurements should be used [15].

Optical Gyroscope, Mechanical Gyroscope, Quartz Gyroscope and Microelectromechanical Systems (MEMS) Gyroscopes are four main categories that exist in gyroscope technology.

The figure (Figure 7) below demonstrates the evaluation of both accelerometer and gyroscope technologies.

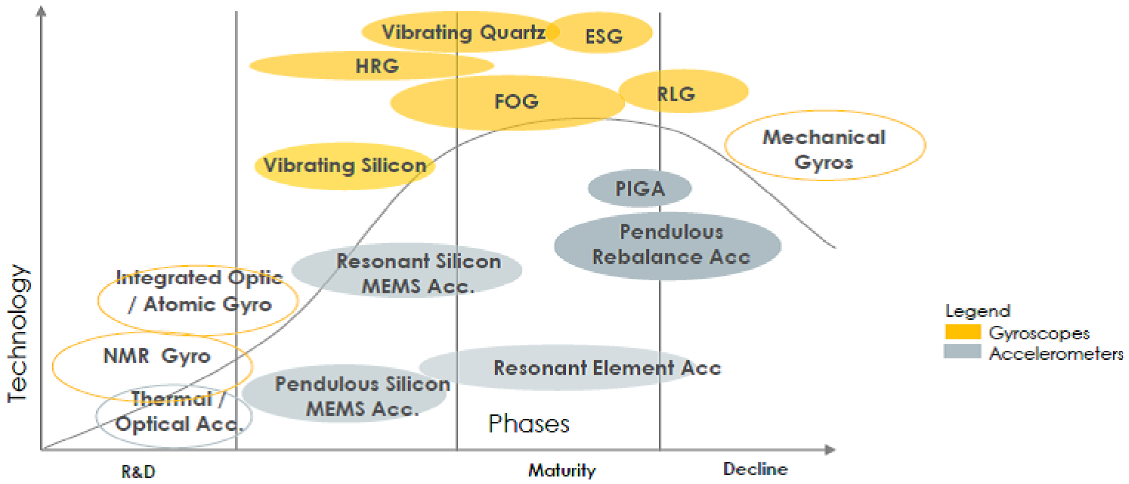


Figure 7 Development of accelerometer and gyroscope technology [15].

In order to measure angular rate, “Mechanical Gyroscopes” use Coriolis force. They are stimulated by high rotation and vibration

Coriolis acceleration is related to angular rotation which can be sensed. It is always perpendicular to both linear motion axis and rotation axis [15].

$$ac = -2V * \Omega$$

$$V \ is \ Linear \ Velocity$$

$$\Omega \ is \ rotation \ velocity$$

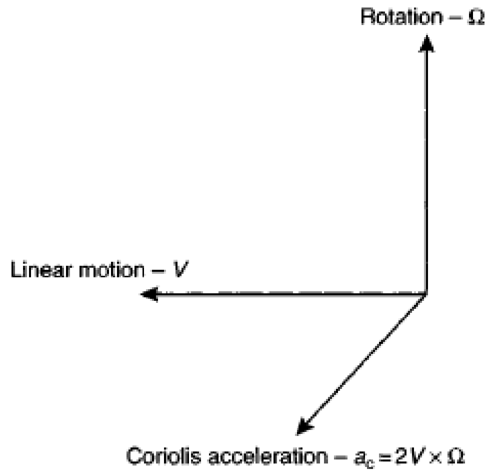


Figure 8 Coriolis acceleration which is generated by linear motion and rotation[15].

There are three sub-categories for Mechanical (MEMS gyroscopes) which are tuning fork, vibrating plate and resonant ring gyroscopes. Tuning fork gyros vibrate in different directions. When rotation happens, tuning forks move away from the sensing element or come closer because of the Coriolis acceleration [15].

The figure (Figure 9) below shows the working principle of tuning fork gyroscope.

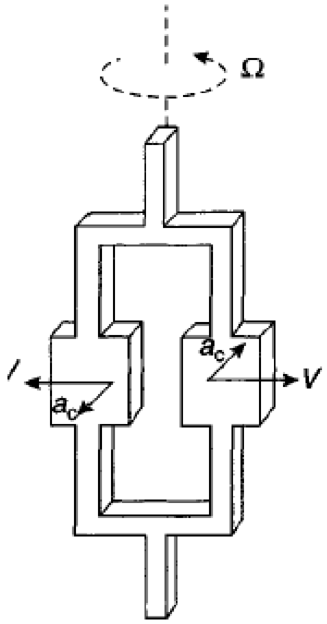


Figure 9 A structure of a simple tuning fork [15].

Vibrating plates in other words, “Vibrating Piezeoceramic Cylinders” are also used to detect the angular motion in resonant ring [15]. As a sensing element a disc resonator or a metal disc is used. It generates a resonance in the ring structure. When the sensor is rotated energy is coupled from another mode for example primary mode to secondary mode. This action generates a voltage that is related to angular motion [15].

Below Figure 10 shows the general structure if resonant ring gyroscope.

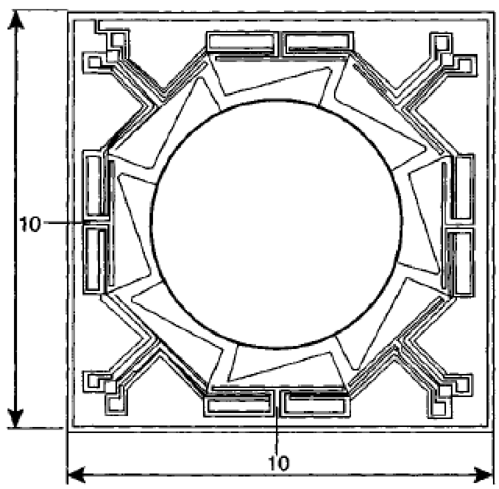


Figure 10 Structure of resonant ring gyroscope [15].

In order to measure angular motion, an optical gyroscopes use “Sagnac Effect” [15]. If a rotation occurs in a direction of the light, then total path of laser beam increases and it will be leaded by the rotation in the opposite direction [7][15].

The figure (Figure 11) below shows the Sagnac effect for a rotating system.

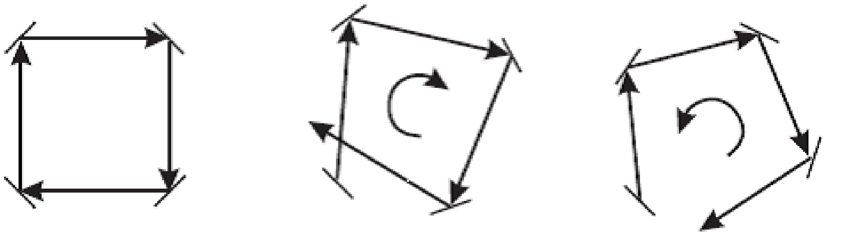


Figure 11 Sagnac effect for a rotating system [7].

A light beam rotates around the path and it is reflected by all of the mirrors so it returns to its initial point. At least three mirrors are used in a triangular shaped laser path [15]. Optical oscillations are produced when transmitter laser beam is in the phase with the received one. These two laser beams track two different directions. For example, if one laser beam tracks clockwise then the other laser beam tracks counter clockwise in a Ring Laser Gyroscope (RLG). When sensor is in the stable position, these two laser beams have the same frequency [15]. When a sensor is rotated to the one direction, because of the Sagnac effect, both laser beams will have different path lengths.

As well as the RLG, the measurements of the Fiber Optic Gyroscopes (FOG) are based on the Sagnac effect. There are two different light beams from broadband source. They rotate in different directions in the fiber optic coil [15]. In order to produce an interference pattern second beam splitter mixes two beams. The resulting intensity of the interference pattern is being sensed by photo-detector. Both light beams are in phase and interference pattern is in the maximum amplitude while sensor is in the stationary position. When the sensor is rotated around an axis, light beams patrol, one light beam patrols larger than the other one [15][7].

Table (Table 2) below demonstrates the advantages and disadvantages of these three different gyroscope technologies.

Table 2 Advantages/Disadvantages of different gyroscope technologies [6][7][10].

Sensor Type	**Advantages**	**Disadvantage**
MEMS gyro	• Size is small • It is cheap • Very suitable for aided navigation	• The performance range is limited • The bias repeatability performance is very low
FOG	• It is very suitable for strapdown applications. • It is very durable. • It has a very small residual bias. • No moving parts exist.	• The electronic parts are too complex. • It is very sensitive to change in temperature
RLG	• It is very suitable for strapdown applications. • It is stable in different temperature • Simple electronics	• It is expensive • It requires high voltage

2.3 Inertial and Wearable Sensor Applications and Studies in the Focus of Health Sector and Human Activity Recognition

In this project, we have implemented a system which can help users to monitor health results from mobile phone. The wearable sensor, which was developed by Eliko, is an inertial sensor. Inertial sensors have been used in different projects in human activity recognition. Our system is not only useful and helpful in sports sector but it is also crucial and valuable in health sector.

Reference [16] shows the detection of postural sway and also sit-to-stand transfers regarding to different perspective and different categories. It describes the "Accelerometry" which is very practical and common method to monitor human movements. In addition to monitoring a range of different movements which includes gait, postural sway and falls and sit-to-stand transfers it has mostly been used to measure physical activity levels. Additionally, it has always been useful to identify and classify subject movements.

In reference [17], the results of energy outgoing levels have been described. The energy expenditure levels were calculated based on the sitting, lying down, eating and desk job working. On the other hand, that research does not contain the activity categorisations. It contains amplitudes of human body movements. Also the research describes the range of frequencies in detail.

Reference [18] shows the activity context of the user. These activities are based on sitting, standing, running up and down the stairs, running and walking. In this research, it has been clearly described that, with using accelerometer based sensors in the wrist, playing some instruments, shaking hands, typing on a keyboard, writing on a board, waving and also other similar activities can easily be identified.

In reference [19], everyday activities can be easily recognized by using five small wireless bi-axial accelerometers. In this work, in order to detect physical daily activities such as free walking, walking with carrying some items, working at a desk, sitting and relaxing, eating, drinking, watching TV, reading, running, writing, typing on a keyboard, bicycling, training, stretching, playing sportive games, scrubbing, vacuuming, folding laundry, washing hands, brushing teeth, lying down, jumping, climbing stairs, riding an escalator and riding the elevator and so on, algorithms are developed and utilized. Users have worn accelerometers in a right way such as non-dominant thigh, non-dominant upper arm, ankle, right hip, and wrist. Under laboratory and semi-naturalistic conditions, without researchers' support, observation, help and their lead, the acceleration data from 20 subjects were collected. Subjects performed daily activities without anyone supervising or leading them. The algorithms were tested and utilized. Four different classifiers such as decision tree, decision table, naïve Bayes classifier and instance-based learning were used. It has been clarified and identified that Decision trees' result is the best activity recognition rate among these four classifiers.

In reference [20], walking, standing, sitting, lying down, bicycling, climbing up and climbing down the stairs and the other daily physical activities have been considered. It has been considered that, it is possible to measure accelerometer signals with using a data acquisition system which should be portable and usable. Three single-axis accelerometers which are one tangential, one radial on the sternum and one tangential on the thigh have been used. In order to detect dynamic activities, standard deviation, mean, cycle time and signal morphology can be used. On the other hand, orientation of the sensors can also be used to detect the static activities.

The reference [21] is mostly devoted to the elderly people. Inertial sensors and wearable sensor concept were used to monitor nine daily activities. They are: Sit-to-stand, stand-to-sit, sitting, walking, running, falling down, lying, lying-to-stand and stand-to-lying. The research contains activity recognition system based on the wearable sensor module. It is developed especially for the elderly people. In that reference, author proposed a system which contains three main modules which are sensor module, gateway and the personal digital assistant (PDA) phone. Sensor module with other words, 3-D accelerometer is worn to left side of the waist. A gateway is used to transfer the data to PDA. Motion categorisation and monitoring is done by PDA phone.

The method in reference [22] shows how to detect falls with using tri-axial accelerometer. In this research, a tri-axial accelerometer has been located on the head level. It has located in a hearing-aid housing which is behind the ear. The main difference from other fall detectors is, this accelerometer based fall detector is located on the head level. In this research, only one subject was used for experiments. All the experiments were tested on an elderly subject for natural, unexpected and unintentional falls. However, during the experiment, any single unintentional fail has not been occurred.

Especially during posture changes, acceleration triggers too many false alarms. Therefore, velocity is used as a threshold. Consequently, to detect falls, this research contains three thresholds. They are, on horizontal plane acceleration, on 3-D velocity and on 3D acceleration [22].

Recently, in the health sector, there have been some common wearable motion monitoring systems based on inertial sensors effectively in use. Some of the most important wearable motion monitoring sensor applications in the health sector are; BioSensics, Telemedicine and FoxInsight. They are the most important and common applications in the market.

Telemedicine

Telemedicine is one of the most common wearable inertial sensors in the health sector which was developed by Kinesia technology. The technology provides tools to automatically measure motor symptoms for patient care assessment [23]. Users can either take the tests at home or in the clinic. A standard patient kit contains two major parts. It has motion sensors and wireless or 3G tablet PC guide. Kinesia Telemedicine system has 3 sub products which are Kinesia ONE, Kinesia 360 and Proview.

- Kinesia ONE is a very common product which is in-use for Parkinson's disease. In order to measure movement disorders, it uses a wireless sensor and an App. They measure Tremor, Dyskinesia and Bradykinesia [24].
- Kinesia 360 is another sub product which is commonly used to measure Parkinson's disease. As a difference from Kinesia ONE, this product uses wearable sensor and a mobile application to measure Parkinson's disease perpetual during the all-day [24][25]. This product measures mobility, tremor and dyskinesia [25].
- Another useful and common Kinesia product is ProView. During the deep brain stimulation (DBS) programming, the product monitors quantitative motor symptom severity responses for Parkinson's disease. An electrode places in a specific area of a brain in DBS. Afterwards this implantation, in order not to

cause a side effect or side effects, stimulation settings are adjusted to a comfort level [23][26]. Kinesia ProView is a common and very useful medical device that is able to record, analyse and display the kinematic data which is from patients who has movement disorders. ProView provides users reports which show how motor symptoms and side effects respond to DBS in details as the stimulation settings are adjusted during the programming session to a comfort level [26]. The system contains three hardware components. They are tablet, charging pad and Finger Sensor. The tablet is a mobile device which is used to record and display data at different combinations of DBS settings. The finger sensor can be charged with using charging pad. The finger sensor is a sensor unit which gathers and transmits the motion data to the mobile device (tablet) when the motor tasks are being performed by the patient [26][27].

The figure (Figure 12) below shows the Kinesia Proview tuning map screen example report data.

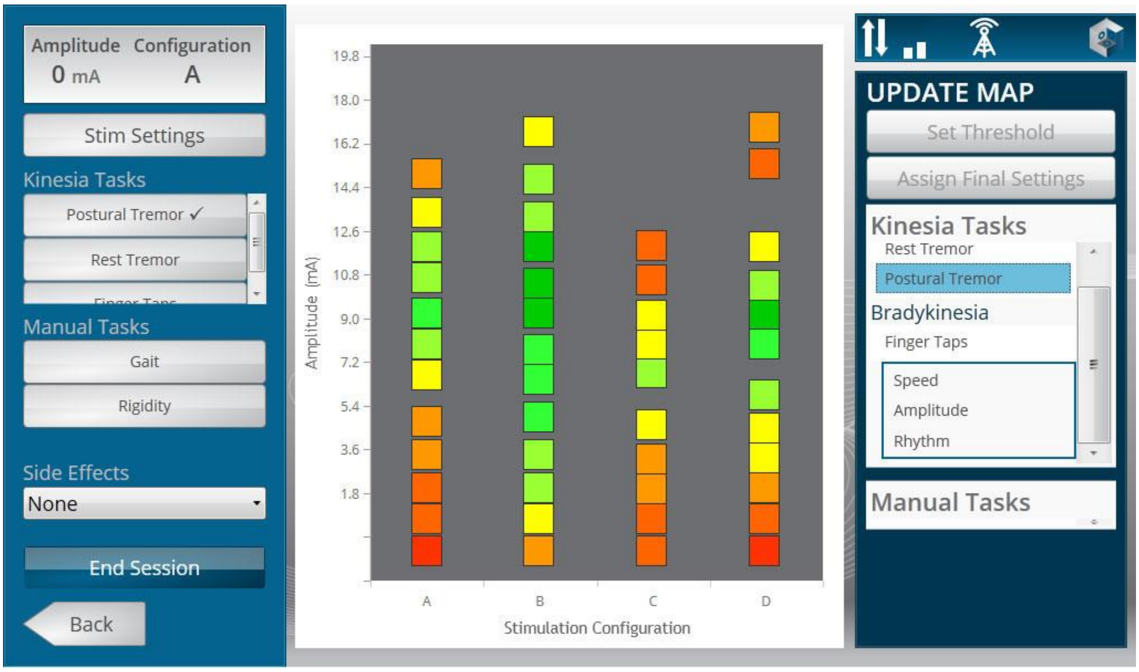


Figure 12 Kinesia Proview tuning map screen example report data [26][27].

BioSensics

BioSensics is another common wearable inertial sensor in the market. Their wearable sensor solutions are able to address most of the biggest challenges in the healthcare. They have four sub-products which are PAMSys, LEGSys, BalanSens and ActivePERS [28].

- PAMSys: This product is used to monitor physical activities. PAMSys-Xtended option provides users to monitor multiple sensors. With using a single wearable sensor, one can monitor posture such as sitting, standing, walking, or lying down, postural transitions such as duration and time of occurrence, gait (such as duration, number of steps, cadence and falls [28][29].
- LEGSys: This is another wireless wearable product developed by BioSensics. This easy-to-use wearable sensor provides quickly analyse gait in almost everywhere. Limited working space is sufficient to measure gait. It generates reports automatically to show patient progress over the measurable goals. The software of the product is compatible on Windows, Mac and Android operating systems [28][30].
- BalanSens: This is another portable wireless Bluetooth system which measures sway index, sway velocity and sway area. This sensor is lightweight and affordable. The reports can be generated automatically [28][31].
- ActivePERS: ActivePERS is another BioSensics product based on fall detection and human activity recognition and monitoring. United States National Institutes of Health (NIH) has supported the development of this product. Additionally it has collaborated and still in collaboration with Arizona Medical School and Center on Aging. The validated algorithms are preventing the false alarms on fall detection [28][32].

Fox Insight Wearable Sensors

Fox insight wearable sensor system contains two basic units. They are Smartwatches and Smart Phones. Smartwatches are used to gather, process and transfer the data. Smart phones are used to monitor the sensor data results. Fox Insights wearable studies are dedicated to Parkinson’s disease [33]. Fox Insights Wearables (FI Wear) asks people who have Parkinson's disease to participate in their study to increase the understanding of the intricacy of the Parkinson's disease. Participants were asked to join daily activities using FI Wear technology. People who join these experiments wear the smartwatch and continue doing their daily activities. These experiments are used to measure usual daily activities of the people with Parkinson's disease [33][34]. Currently, Fox Insight is released only for Android Mobile Phones. However, iPhone users will also soon be able to participate with using their mobile phones. Everyone (with or without Parkinson's disease) can participate in these experiments to increase the understanding the Parkinson's disease and to increase the success of the study [33][34].

3 System Structure

The overall system structure contains hardware development, backend server API development and the client side developments. Client side contains two native mobile application developments which are iOS and Android.

Prevent server application developments and all the other backend developments were done and will be done by Dignio. All mobile platforms will be communicating with the same backend. Currently, this project is set to be released only on iOS and Android platforms. Dignio provides telemedicine solution and Prevent backend. Dignio Prevent backend is already in-use. The usage of this application can be found in the market. Prevent backend provides a platform for their clients to monitor end user activity. In other words, Dignio Prevent backend allows you to keep, monitor and track the data of your users [3]. The combination between their telemedicine solution and Prevent backend development that is used in our system is similarly used by their other clients in the market. However, Dignio has configured the services based on our project needs. First, the mobile software which is implemented by me generates sensor data and places results in a temporary file in the mobile device memory. After all the authentications between mobile software application and Dignio's backend are done. The mobile software uploads the sensor data to cloud repository. They store and process the sensor data to their backend. Afterwards mobile application reads the data from their backend and shows the result to the users of the system.

Hardware development has been successfully done by Eliko. They have developed BLE sensor device which can be connected to mobile devices via Bluetooth.

My task for this system is to develop smart phone software, in other words mobile applications which send the sensor data to Dignio's data repository. I implemented the communications between sensor and mobile phone and also the communications between mobile application and the Prevent backend. The modules that have been developed by me are described and shown in the appendix section. These implementations include, mobile authentications (the login authentications between mobile client and Dignio's backend), AWS (Amazon Web Service) authentications, Amazon S3 (Simple Storage Service) upload to store the sensor data, and reader class for the processed data (to show the results in the mobile application). Screenshots of my implementations can be found in the Appendix section. The client side mobile application developments contain two separate app developments which are iOS and Android.

3.1 Overall Sensor Information

Sensor has a power ON/OFF button on it. If the device is ON, the green LED on the sensor will always be blinking at 1 Hz. If a user presses the power button and hold it at least one second, the red LED will be flashed and the device will be turned off after below steps are done;

- The 100 g sensor device and the MPU6050 device will go to the sleep mode and MPU6050's PWM clock will be stopped.
- GPIO outputs will be set to low state and input pull-ups are disabled.
- All current connections will be terminated and the device will no longer be advertising as a connectable device.
- CC2590 range extender chip's control pins will be set low so it will go to the sleep mode.

- TI Operating System Abstraction Layer (OSAL) will be notified to enable deepest sleep mode PM3 and all the periodic tasks will be de-activated.
- All interrupts will be disabled except from external button interruption which will be enabled to allow wake-up.

In order to turn ON the device, the user should press and hold again the switch button at least one second. Green LED will start blinking at 1 Hz again and all the above steps will be reversed. It will be advertising as a connectable device again.

After every ON/OFF process the connection between host and device will be lost. Therefore in order to communicate, host should be connected to the device again.

If the battery voltage level drops under 3.6 volts, the red LED will be flashed for two seconds and then the device will be switched off. All power-down steps will be activated.

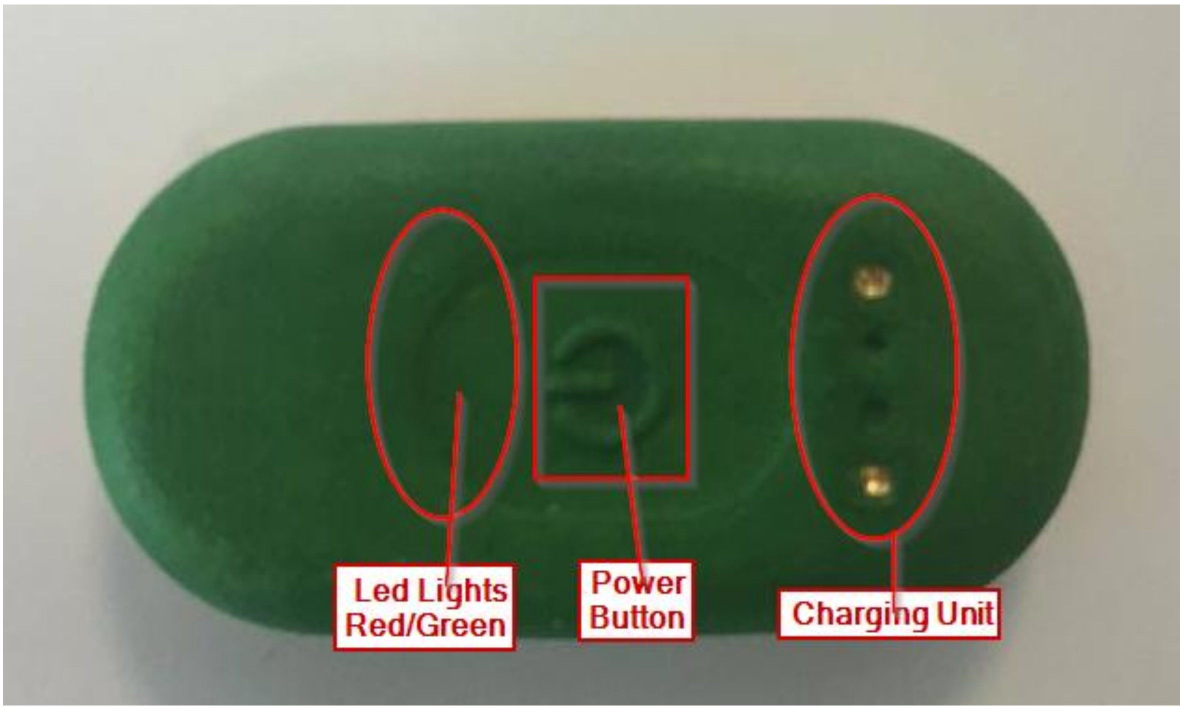


Figure 13 BLE Wearable Sensor.

At the first usage, user needs to log in to the system. The login information will be kept in the system unless user logs out. In order to connect to BLE sensor, device Bluetooth has to be turned on. In the configuration window, user can configure sensor settings and connect to a sensor.

In the main page, user will see test options as a menu item and configuration settings as option button.

If battery notifications are enabled on the mobile device, user can monitor the battery level of the sensor device. Battery configuration has to be completed and host needs to enable this attribute. After enabling it, once in every second, host device will be notified about the battery information.

3.2 Hardware Communication

The Generic Attribute Profile (GATT) was used to provide the communication between sensor/sensors and the mobile device. Generic Attribute Profile was implemented and updated on top of the Attribute protocol (ATT). GATT is stored by the ATT and it establishes framework and all the other common operations to transport the data. The GATT has simple server-client communication. It defines server role and client role. Neither of these two GATT roles is necessarily tied to any specific GAP roles. However, it can be specified by other layer profiles. It is possible to use both GATT and ATT in both BR/EDR (Basic Rate / Enhanced Data Rate) and Low Energy (LE). Nevertheless, it is an obligation to implement both of them in LE[35].

The GATT layer of the BLE Protocol Stack is designed to be used by the application for data communication between two connected devices. From a GATT standpoint, when two devices are connected, they are each in one of two roles:

• GATT Client – This is the device that is reading/writing data from/to the GATT Server.

• GATT Server – This is the device containing the data that is being read/written by the GATTClient.

In this project, the BLE wearable sensor is the GATT Server, offering the data for reading and writing. Mobile device (iOS and Android) is GATT client.

Figure 24 below shows the Bluetooth network topology.

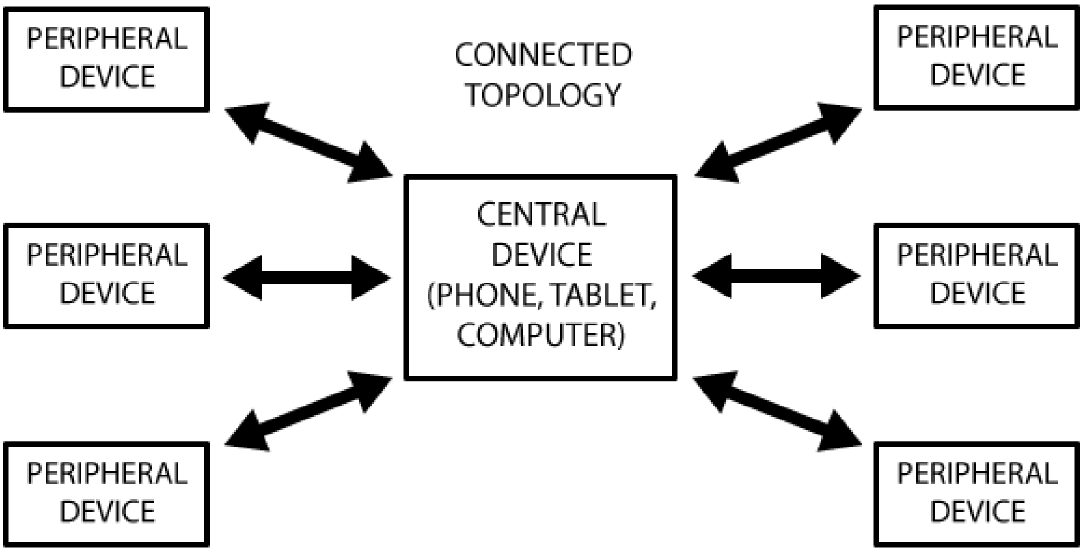


Figure 14 Network Topology BLE peripheral device and central device [36].

GATT server receives and stores the given commands and confirmation from the client (GATT client). The server also stores the data transported over the attribute protocol and accepts the request (protocol request). Server is responsible for sending responses to request as soon as they are configured. When all the specified and configured events occur on the server side, GATT client receives indications and notifications [35].

Attribute Protocol transports the attributes as “Characteristics” and “Services”. Characteristics can only contain a single value. Any number of descriptors, describe the characteristic value. On the other hand, Services may contain a lot of those characteristics [35].

In order to make the value understandable to the user, the descriptors of the characteristic can be used to show the characteristic value descriptions [35].

3.2.1 GATT Service - Characteristic Profile Hierarchy

The structure can be specified by the GATT profile according to data statuses. It specifies the data structure on regarding to profile data changes.

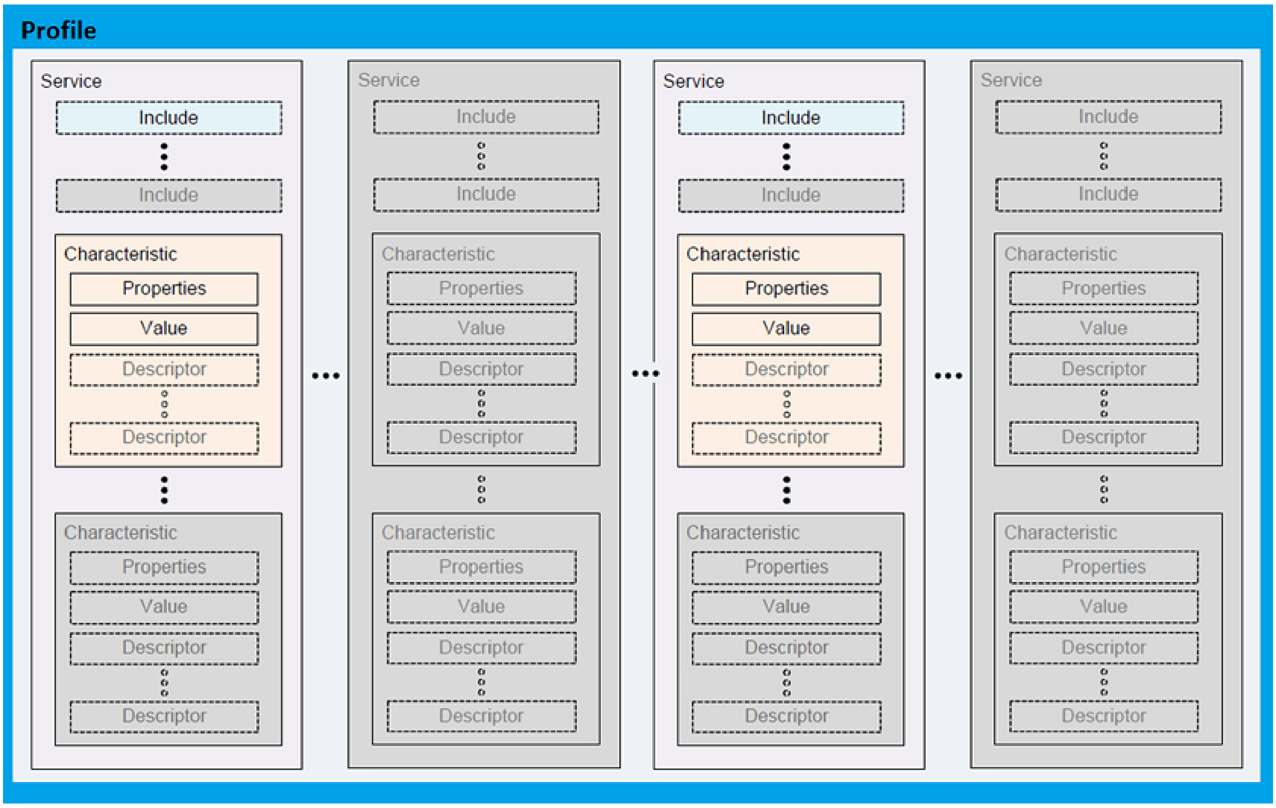


Figure 15 GATT-Based Profile Hierarchy [35].

The structure above in Figure 15 defines characteristics and services which are basic elements that are used in a profile. The highest level of the hierarchy above is a profile A profile is composed of either one or several services which are necessary to fulfil a use case. This can be filled either in one service or more services depending on a use case. Additionally, a service is composed of either as a reference of the other services or it can be comprised of characteristics. Every characteristic can consist of a value or may contain optional information about the value. A value, descriptors, characteristics and the service and sometimes a profile data are all stored in attributes on the server [35][36][37].

Characteristic

A definition of the characteristic contains a value, characteristic properties, and a characteristic declaration. In a service, characteristic is used as a value. This value is used with information which shows how to represent and/or display a value, how to access this value and information about its configuration [35].

Service

As described above, a service can either contain a set of characteristics which will structure it or it can reference other services [35]. It is a data collection and all the related behaviours are to either accomplish a device portion or a device feature or to create a certain function,

It is divided into two types. The first type is “Primary Services” and the other is “Secondary Services” [35].

- Primary Service: As it is clear from its name, it provides the primary functionality of a device.
- Secondary Service: A secondary service has to be referenced from one or more primary services on the device. It provides a subsidiary functionality of a device.

A service may reference other either primary or secondary services [35].

Referenced Services

A service can be referenced by another service. If a service is referenced by another service, the whole referenced service will be part of the new service which includes characteristics and any nested referenced services. This referenced service will still be an independent service [35][36]. There is no boundary or range to use referenced services and nested references. A referenced service can either be used as a part of the referencing service or it can be used as a method which contains a definition of the other service [35].

3.3 The communication between sensor and the mobile device

Google provides a public API for the Bluetooth GATT Profile for Android developers. This public class, which is provided by Google, gives an opportunity to enable communication with Bluetooth smart or Smart Ready Devices [38].

In order to connect mobile device with BLE sensor, first in the application side, a call back method "BluetoothGattCallback" has to be created. Afterwards, to get an instance from this public class, the method connectGatt(Context, boolean, BluetoothGattCallback) should be called [38].

3.3.1 Some of the public methods from the API

Google provides public methods and constant and all the API documentation to be able to use Bluetooth functionality more precisely in mobile applications.

Below section gives overall information about some of the methods which were used.

abortReliableWrite()

It is a public method provided by Google. The return parameter is "void". This means, it returns nothing. When calling this method, it cancels a reliable write transaction for a given device. If one calls this function, all the queued characteristic write operations for a given remote device will be discarded. This method requires Bluetooth connection [38]. During the initial setup or during application update on the end-user level, the permission should be accepted by the user.

abortReliableWrite(BluetoothDevice mDevice)

This method was deprecated by Google in API level 19. (Current API level 23). This is a public method [38]. This method uses “BluetoothDevice” parameter which lets user to create a connection with the respective device or query information about it [39]. So, in other words, unlike abortReliableWrite() this method takes a parameter from respective or existing device [38]. This can be name, address, class, and bonding state.

beginReliableWrite()

This is a public method. The return parameter is “Boolean.” Which means this method will return either “true" or “false.” If the reliable write transaction has been successfully initiated, it will return true, otherwise it will return false [38].

This method can be used to initiate a reliable write transaction for a remote device which is already given or will be given [38].

close()

As it is clear from its name and type, this public method can be used to close this Bluetooth GATT client. It returns void [38].

connect()

This public method is used to connect back to remote device. If the connection has been lost or dropped, this method can be used to re-connect to a remote device. If the target device is out of the Bluetooth range, the re-connection process will be triggered once the device is back in range [38].

The return parameter is “boolean”. If the connection attempt is successfully initiated, this method will return “true”, otherwise it will return false [38].

disconnect()

This public method is used to disconnect an established connection. This method can also be used to cancel a connection attempt which is currently in progress. The return parameter is void. Therefore, this method returns nothing [38].

This method requires “Bluetooth” permission from end-user during the initial setup and during the new release update [38].

.

discoverServices()

This public method discovers services which were offered by a remote device as well as their characteristics and descriptors. The return parameter is “boolean”, it returns true if the remote service discovery is started. Otherwise, it returns false [38].

executeReliableWrite()

This is another public method. The return parameter is “Boolean.” This method executes a reliable write transaction for a given remote device. It will return true, if the request to execute the transaction is sent. Otherwise it will return false [38].

getDevice()

This public method returns the remote Bluetooth device. This method uses “BluetoothDevice” parameter which lets user to create a connection with the respective device or query information about it [38].

getService(UUID uuid)

With using this method, one can restrict Bluetooth devices in the project based on the user unique ID (UUID) values.

If the requested UUID is supported by the remote device, this method will return a BluetoothGattService. If there are multiple instances in the same service, it will return the first instance of the service. If the requested UUID is not supported by the remote device, it will not return any service [38].

This method requires Bluetooth permission. During the initial setup or end-user level project update, this request has to be accepted by the end user [38].

getServices()

This public method returns a list of the GATT services which were offered by the remote device. In order to use this function, one should be sure that the entire service discovery should be completed for the given Bluetooth device. If service discovery has not successfully performed yet, this function would return an empty list. Otherwise, it returns the list of services on the remote device [38].

This method requires a Bluetooth permission which has to be accepted by the end-user during the initial setup or while updating the project [38].

readCharacteristic(BluetoothGattCharacteristic characteristic)

This public method is used to read the requested characteristic from the remote device. The return type is “boolean”. If the read operation is successfully initiated, it will return true. Otherwise, it will return false. This is an asynchronous operation where the results will be read and reported by another method “onCharacteristicRead”[38].

This method takes a parameter BluetoothGattCharacteristic. It represents a Bluetooth GATT characteristic. A GATT characteristic is a basic data element which used to create a GATT service. A characteristic contains a value, a GATT descriptors and additional information [40].

This method requires Bluetooth permission which needs to be accepted by the end-user during the initial setup or updating the project [38].

readDescriptor(BluetoothGattDescriptor descriptor)

This is another public method which reads the descriptor value from the Bluetooth remote device. The callback method “onDescriptorRead” will be triggered to signal the result of the operation as soon as the read operation is successfully done [38].

This method has a parameter “BluetoothGattDescriptor”. It refers to a descriptor value read from the associated remote device. It can be used either to control certain behaviour of the characteristic or describe the features of the characteristics [37].

This method also requires the Bluetooth permission from the end-user. To use the application end-user needs to accept this permission during the initial setup and/or while updating the application [38].

writeCharacteristic(BluetoothGattCharacteristic characteristic)

This is a public method. The return parameter is “boolean”. As it is clear from its name, this method is used to write a given characteristic and its values to the associated remote device. If the write operation is successfully completed, it will return true. Otherwise it will return false. It takes a parameter “BluetoothGattCharacteristic”. In order to report the result of the write operation, a callback function “onDescriptorWrite” will be triggered.

Bluetooth permission is needed for this method as well. In order to use application, end-user needs to accept this permission either in the initial setup or in the update process [38].

writeDescriptor(BluetoothGattDescriptor descriptor)

This is another public method. The return parameter is “boolean”. This method is used to write the descriptor value to the remote device. If the write operation is successfully completed, it will return true. Otherwise, it returns false [38]. It has a descriptor parameter “BluetoothGattDescriptor” which is used to write the value to associated remote device.

It can either be used to control certain behaviour of the characteristic or describe the features of the characteristics [37]. It has a callback function “onDescriptorWrite” which can be used to report the result of the write operation [38].

Similar to other methods, this method requires Bluetooth permission too. In order to use the application, end-user needs to accept this permission in the initial setup and during the update process [38].

3.4 The Communication between Mobile Client and Backend (Prevent API)

Overall backend communication structure contains 8 main steps. Client needs to connect to server. When the EDF is generated, client uploads the EDF to bucket. File needs to be read, processed and parsed to JSON format. Backend script sends the parsed file to Prevent.

Ordered steps are;

1. Client asks Prevent for AWS STS credentials.
2. Prevent authorizes client and asks AWS STS for credentials.
3. AWS STS returns the credentials.
4. Prevent returns the credentials to the client.
5. Client uploads EDF file to Amazon S3.
6. An automatic event reads the uploaded EDF file.

7. The EDF processing script downloads the EDF file and processes it using measurement program.
8. The EDF processing script sends in the measurement results to Prevent.

Figure 16 below shows visual demonstration about overall system structure.

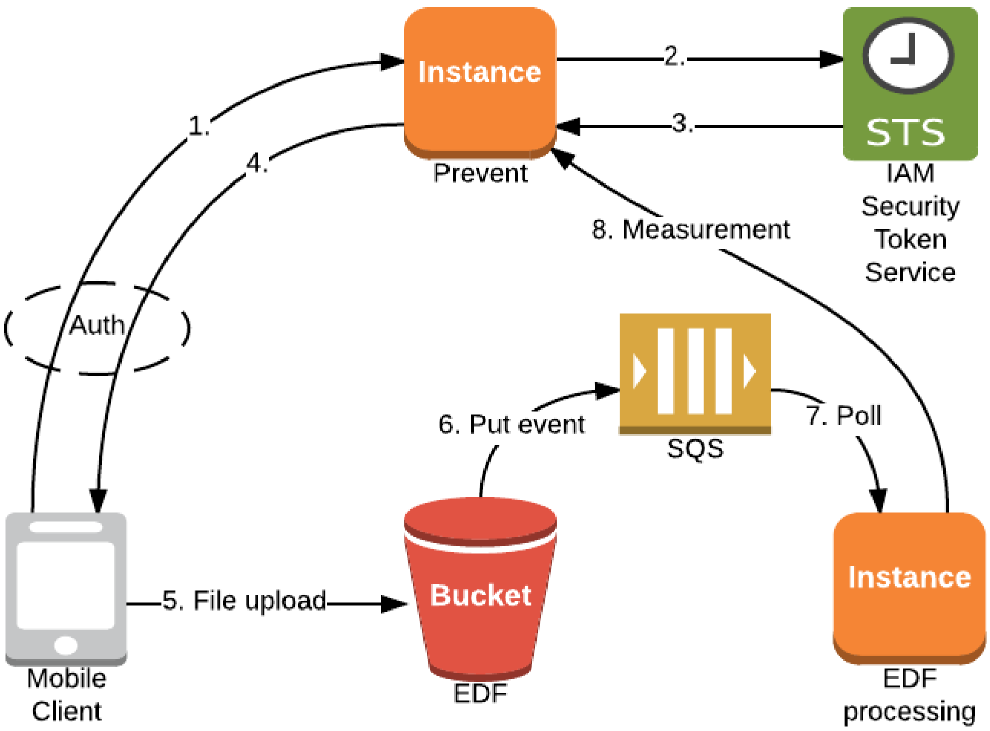


Figure 16 Visual demonstration for Backend Communication.

When a user runs the application for the first time, login page will be shown. This login page will not be shown again unless user logs out. User needs to input login credentials correctly. After user logs in to the system, the main page will be shown.

If a user clicks on the start button near related test, user will be re-directed to the test screen where all the necessary test instructions are written. In this screen, user can either start test or turn back to main screen. After user successfully completes the necessary tests, results will be generated as an EDF file. First, this file will be located in a temporary folder in the mobile device memory. In the meantime, mobile client will connect to bucket via AWS security token service. After authentication is successfully done, EDF file will be uploaded to bucket. Bucket login and account belongs to Dignio. If other upload requests are also sent, all the requests will be queued. Amazon S3 upload settings and implementation have been done according to Dignio bucket login settings. After EDF file is successfully uploaded to bucket, the automatic event from server will read the uploaded file first, and then EDF processing script will process and parse this file. The file will be parsed as a JSON object. These JSON objects will be sent to mobile device. JSON parser class is used to convert JSON objects to string format. In the result page, user will receive these test results as a text format.

The below Figure 17 use case diagram gives overall information about login and logout processes.

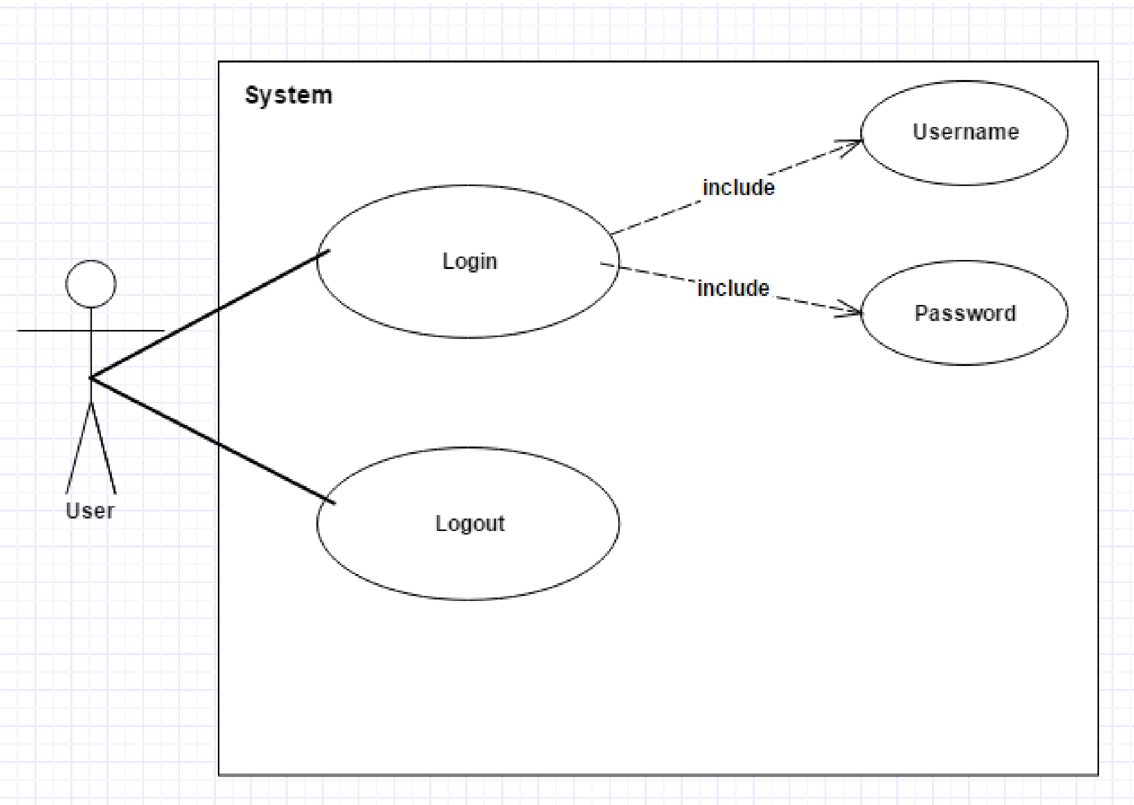


Figure 17 A Use Case Diagram for Login.

The activity diagram on Figure 18 below shows the simple logic behind the login process. Login checks have been implemented according to Prevent server documentation.

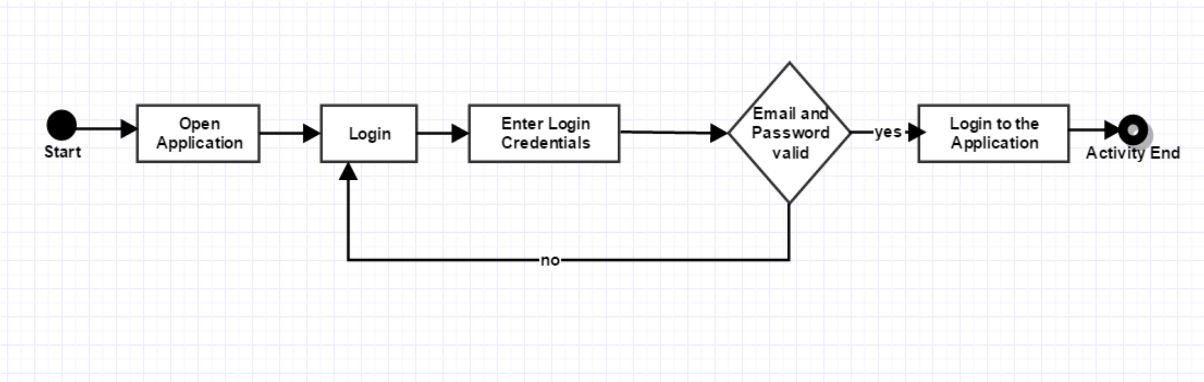


Figure 18 Activity Diagram for Login.

This is a token-based authentication. The session will be kept in the cookie storage until user kills the application or logs out. The logic behind keeping session alive is simple cookie-based logic. The logic is, while checking all cookies in the cookie storage array, if a cookie name is equal to current cookie name then the current cookie value will return to the session when called. Current cookie name can be gathered with using isEqualToString method and checking the SSID information in it.

Figure 19 below shows the logic behind how to keep the session alive.

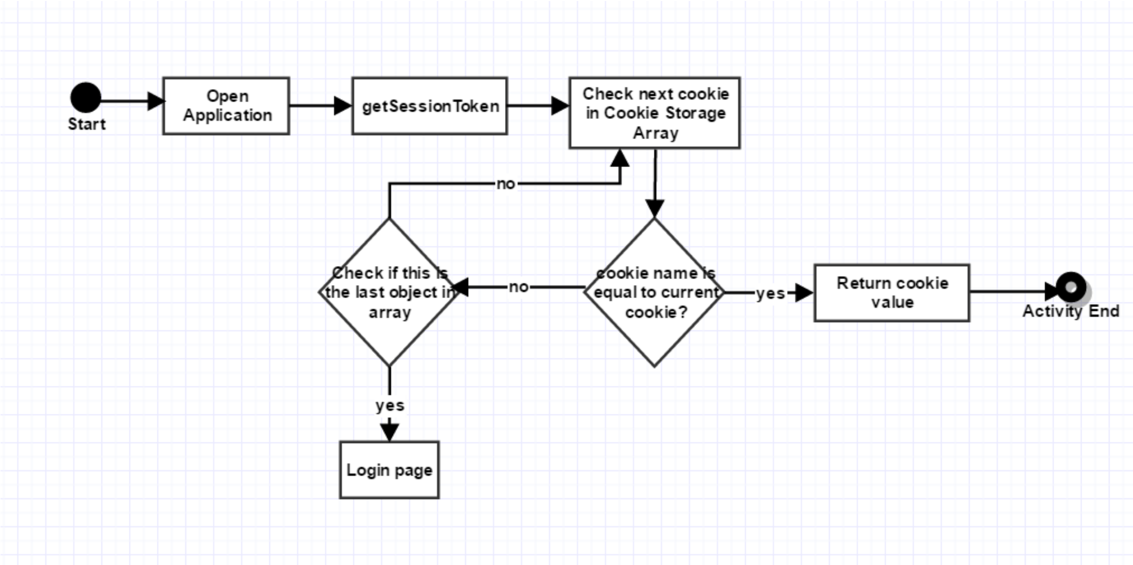


Figure 19 An Activity Diagram about the Logic behind Keeping the Section Alive.

3.4.1 Overall Information about Amazon S3 Upload and AWS

Amazon Simple Storage Service (Amazon S3) is a cloud based web service which provides cloud storage to developers. When compared to other cloud solutions, Amazon S3 is more secure, durable and scalable. Amazon mobile SDK provides mobile application developers an easy usage and direct access from application side [41].

In order to upload a file into the S3 one should sign into AWS first. Then a bucket has to be created. Uploading an object from Android is simple as it is already described in amazon documentation. Android SDK allows developers to use Amazon Web Services in a very simple way. The method manager.upload is used to upload a file to a bucket.

An example usage of that method is;

```
manager.upload("bucket_name", "MasterThesisFiles/" + fileName, file)
```

First parameter is the bucket name. In this project Dignio created a bucket and that bucket name was used to upload a document to an existing bucket. This way of use is more convenient if the file needs to be uploaded to an exact location. For example, in this example, this file will be uploaded under the folder MasterThesisFiles. With this method, user can also rename the file which needs to be uploaded.

However, from security and performance perspective, adding authentication credentials inside of the upload method is more preferred. Therefore the usage below is better for uploading such files,

```
manager.upload("bucket_name", AppConstants.AWS_ACCESS_KEY_ID, file)
```

The first parameter is bucket name, the second parameter is an access key for AWS authentication and the last one is the file.

In order to get an “Access Key ID” and/or “Secret Access Key” one should open the IAM console. Identity and Access Management (IAM) is a web service which allows developers to control who can use their AWS resources. This service does not only help developers to allow others to use AWS resources but also allows developers to manage what resources can be used. It also helps them to manage how those resources can be used [42]. So, to get an Access Key ID and Secret Access Key, one should click on “Users” option under the navigation bar in the IAM console. Under “Security Credentials” tab, there is an option “Create Access Key” which has to be chosen. In this step the option “Show User Security Credentials” will be shown, when this option is clicked the Access Key ID and Secret Access Key will be generated [41].

After having the Access Key ID (in this project this ID is provided by Dignio), the value should be added to the upload method above.

The flow chart below on figure 20 shows S3 upload process.

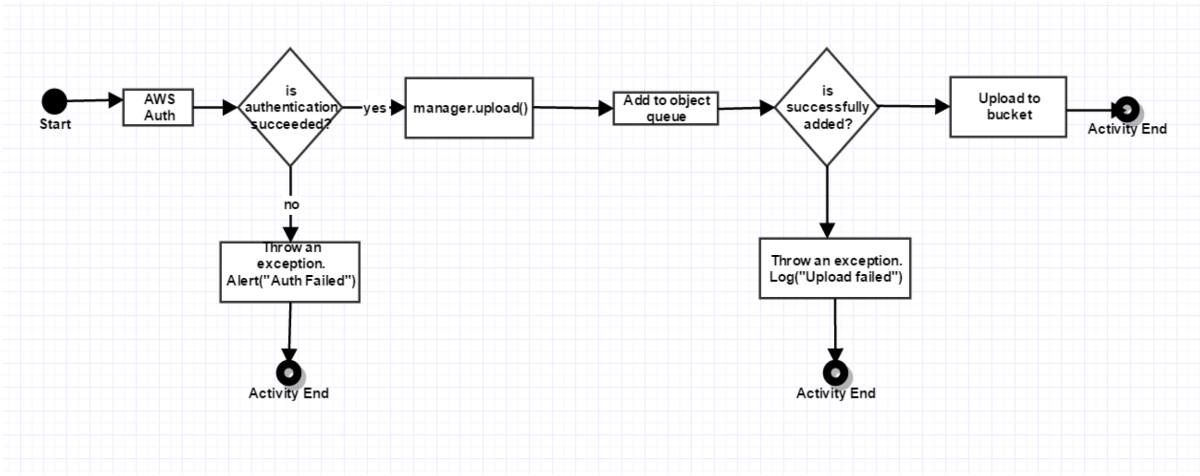


Figure 20 An Activity Diagram about S3 Upload.

3.4.2 Overall Information about the File Type

In this project, European Data format (EDF) is used to upload and monitor the data. After all the necessary tests are done, the mobile application generates an EDF file and saves it to a temporary folder in the device memory. When AWS authentications are successfully completed, the mobile client application uploads the results to a bucket as an EDF file. Since the results will contain huge amount of information the size of these generated files will be very large. This is one of the most important reasons to use EDF as the data format to both store and upload data.

First of all, these results will be generated and stored in the device memory. Although new generation of the mobile phones provide additional spaces and provide some cloud platforms for their users, there will be considerable amount of users of older phones as well. Therefore, the memory storage would be an issue. After every test the device memory would give an alert to user and if there is no place in the device memory, the EDF will not be generated so there will be no results to show.

Additionally, even though users have enough space for large files, this would raise a performance issues in the mobile phones as the memory stage will be filled out with additional files. Battery consumption would be higher as well. Therefore, generating and storing test results in EDF, is the best option for both mobile device performance and application consistency (as more tests can be done and more results can be saved).

Furthermore, uploading smaller files has always been easier and more efficient then uploading larger ones. Therefore, EDF provides efficiency on S3 upload as well.

Moreover, storing smaller data in the server is also more preferable than larger data. It will not only give higher performance and efficiency but also gives a better opportunity to maintain the data. Maintainability is very important. Using the space effectively is also crucial point as cloud storage is used in the backend. These make EDF the best option for server-side as well.

There is only one negative side of using EDF as a data format. If we compare it with JSON files, reading EDF is more complicated. Parsing and sending JSON is very simple compared to any other data type for these kinds of purposes.

The EDF is a very useful and common format for exchange and storage of multichannel biological format and physical signals. This format is widely used in health sector. It is very simple and flexible. It was developed by a few European medical engineers in 1987 and was published in 1992. Afterwards, EDF managed to be the industry standard for EEG and PSG recordings for commercial equipment and multicentre research projects [43].

There are a lot of advantages to using EDF as a data format. Especially in health sector, data transferring, monitoring and also analysing data in a right way is crucial. EDF is the simplest way to transfer data without any data loss. Also implementation of this data format is simple. It is cross platform and does not depend on hardware environment or software environment [44]. Although the file contains many records in the header, it does not take much space. Therefore, uploading, transferring and archiving this data format is both easier and healthier. This data format is accepted as a standard for exchange of electroencephalogram and polysomnogram data between different equipments and labs [45].

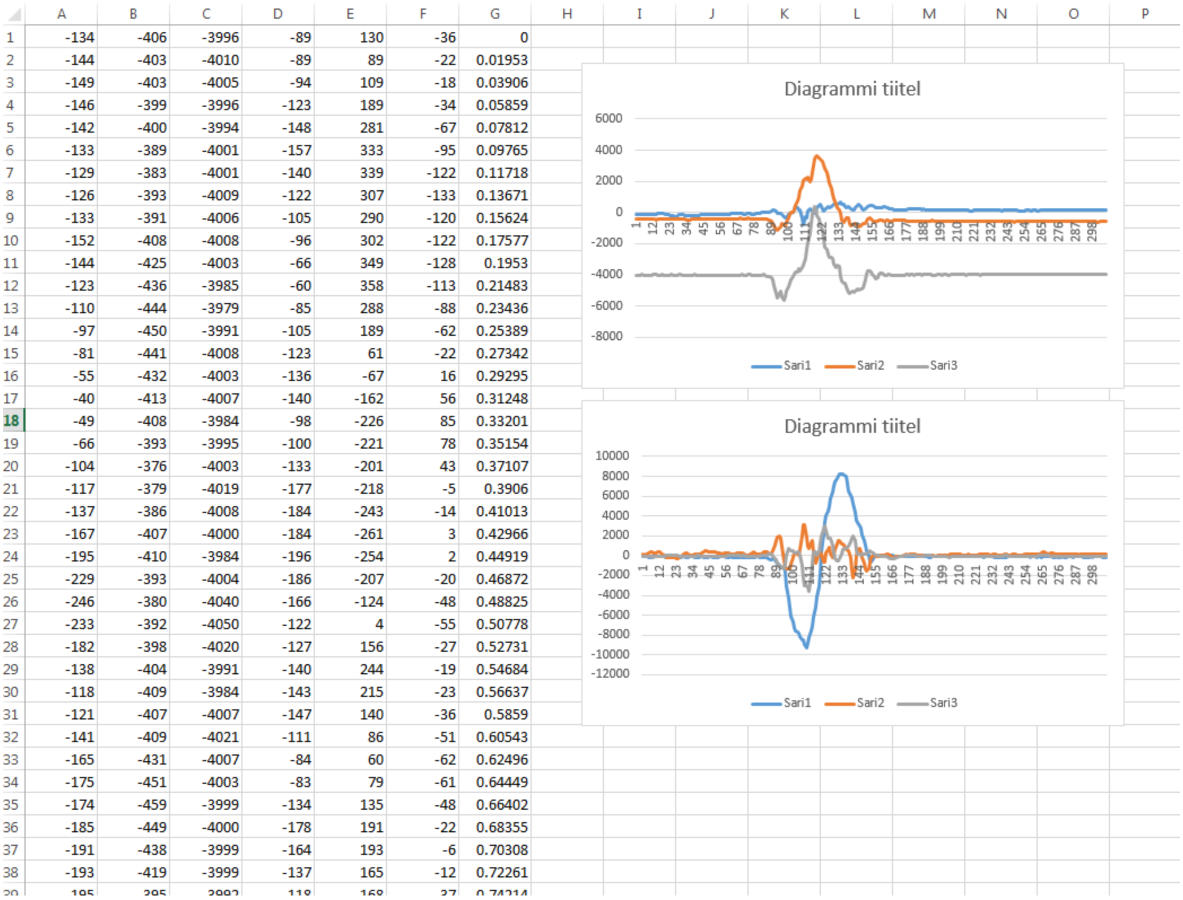
As an extension of an EDF, in 2002 EDF+ was announced. This extension is highly compatible to EDF. All the existing EDF viewers also show and support EDF+ signals. In addition to EDF, EDF+ files can contain annotations, interrupted recordings, stimuli and events. Consequently, EDF+ can store automatic and manual analysis results such as delta plots, QRS parameters and sleep stages [46]. It can also store any medical recording. For example, EDF+ can store EMG, Evoked potentials, ECG or any other medical recordings. If specs are compared, EDF+ specs are stricter then EDF, therefore it enables automatic localization and calibration of electrodes [43]. Additionally, EDF+ does also offer a format for a wide range of neurophysiological investigations. This may become a standard within a few years [45].

Generally, an EDF file consists of data record and a header record [46].

- The data records contain consecutive fixed-duration epochs of the recorded signals

- The header record specifies the technical characteristics of the recorded signals and identifies the patient [46].

Figure 21 below is an example of EDF data which was used in the project.



	A	B	C	D	E	F	G
1	-134	-406	-3996	-89	130	-36	0
2	-144	-403	-4010	-89	89	-22	0.01953
3	-149	-403	-4005	-94	109	-18	0.03906
4	-146	-399	-3996	-123	189	-34	0.05859
5	-142	-400	-3994	-148	281	-67	0.07812
6	-133	-389	-4001	-157	333	-95	0.09765
7	-129	-383	-4001	-140	339	-122	0.11718
8	-126	-393	-4009	-122	307	-133	0.13671
9	-133	-391	-4006	-105	290	-120	0.15624
10	-152	-408	-4008	-96	302	-122	0.17577
11	-144	-425	-4003	-66	349	-128	0.1953
12	-123	-436	-3985	-60	358	-113	0.21483
13	-110	-444	-3979	-85	288	-88	0.23436
14	-97	-450	-3991	-105	189	-62	0.25389
15	-81	-441	-4008	-123	61	-22	0.27342
16	-55	-432	-4003	-136	-67	16	0.29295
17	-40	-413	-4007	-140	-162	56	0.31248
18	-49	-408	-3984	-98	-226	85	0.33201
19	-66	-393	-3995	-100	-221	78	0.35154
20	-104	-376	-4003	-133	-201	43	0.37107
21	-117	-379	-4019	-177	-218	-5	0.3906
22	-137	-386	-4008	-184	-243	-14	0.41013
23	-167	-407	-4000	-184	-261	3	0.42966
24	-195	-410	-3984	-196	-254	2	0.44919
25	-229	-393	-4004	-186	-207	-20	0.46872
26	-246	-380	-4040	-166	-124	-48	0.48825
27	-233	-392	-4050	-122	4	-55	0.50778
28	-182	-398	-4020	-127	156	-27	0.52731
29	-138	-404	-3991	-140	244	-19	0.54684
30	-118	-409	-3984	-143	215	-23	0.56637
31	-121	-407	-4007	-147	140	-36	0.5859
32	-141	-409	-4021	-111	86	-51	0.60543
33	-165	-431	-4007	-84	60	-62	0.62496
34	-175	-451	-4003	-83	79	-61	0.64449
35	-174	-459	-3999	-134	135	-48	0.66402
36	-185	-449	-4000	-178	191	-22	0.68355
37	-191	-438	-3999	-164	193	-6	0.70308
38	-193	-419	-3999	-137	165	-12	0.72261

Figure 21Example EDF data

3.5 An Overall Information about the Mobile Application

This section contains the mobile application which was implemented by me. Detailed screens for both Android and iOS applications can be found in the Appendix sections.

3.5.1 Login Page

In order to use the system, one should login at the first time of use. These authentications are necessary for the initial use. Session will be alive until user logs out. The Figure 22 below shows the login pages for both iOS and Android applications.

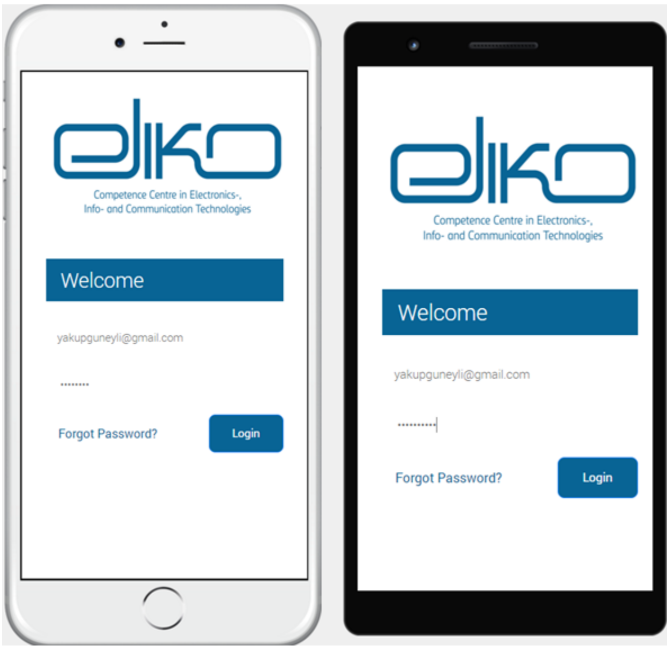


Figure 22Login Screen- iOS and Android.

3.5.2 Main Page – Tests Page

This page includes all tests, configurations option, logout option and a button to write the results to database.

Logout button: When the button is clicked, user will be logged out. User will redirect to the “Login Page” which is shown in the Figure 22.

Configurations button: When it is selected, user will be directed to Figure 24.

Tests: User can take the test via blue plus icon near the test. If a test has already taken, then the icon near this test would be green. If a user clicks on this green icon, the result page about the related test will show up.

Send Icon: If all of the given tests are not completed yet, this icon will be grey. When it is selected, the alertbox will show up. If all tests are successfully completed, this icon will be green. If this green send icon is clicked, a confirmation message box will be shown. If the user accepts the confirmation then the results will be written to database and screen will be cleared.

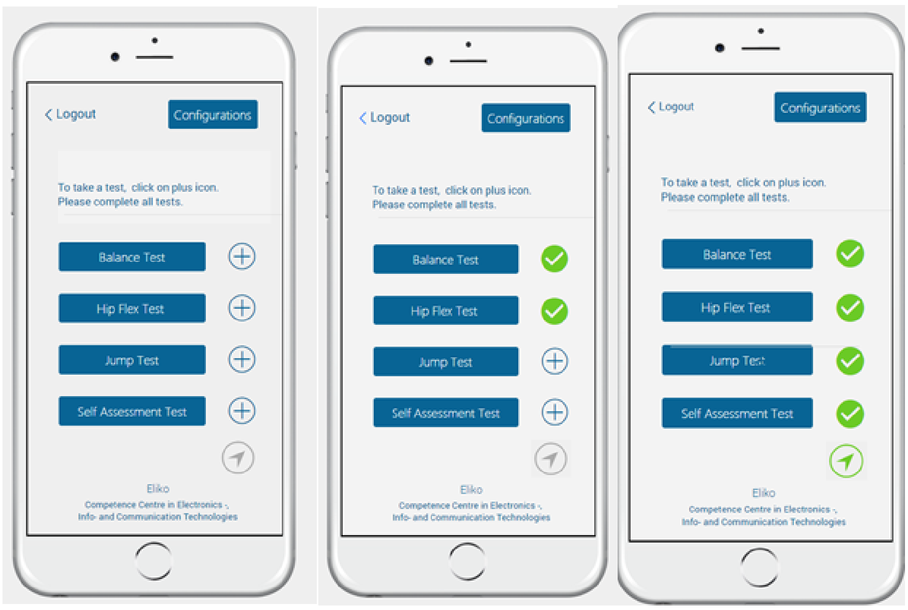


Figure 23Test Pages

3.5.3 Configurations Page

This page contains paired sensors, a button to "log out", a button to turn back to tests page, a button to add/pair with a new BLE sensor and a button to show previous test results.

The Figure 24 shows the overall configurations page. If any sensor number is selected, "Paired Sensor Configuration Page" below will be shown. If "Back" button is clicked, user will be relayed back to tests page. If a user clicks on "Logout" button, the application will be stopped, user will be logged out and the Login Page Figure 21 will be shown. If a user clicks on "Results" page, last five results will be listed. In order to pair with a new device, one should click on the blue plus icon. When it is clicked, application will start searching for a new BLE device.

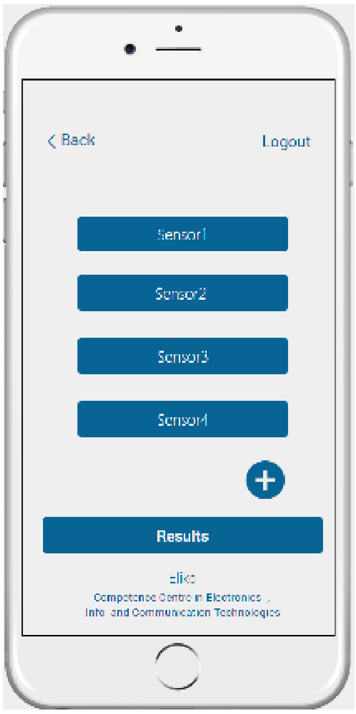


Figure 24 Configurations Page

3.5.4 Paired Sensor Configurations Page

This page contains IMU configurations and 100g Sensor configuration options for paired sensor. IMU Configurations contains; “Sample Rate”, “Range of Accelerometer” and “Range of Gyroscope” dropdown options. 100g Sensor Configurations contains a dropdown option to set 100g Sensor Range.

When the button “Back” is clicked, user will be relayed back to configuration page Figure 24.

Sample Rate: This dropdown option contains the value of “50 Hz” and “100 Hz”. As a default 50 Hz is selected.

Range of Accelerometer: This dropdown option contains values “2g”, “4g”, “8g” and “16g”. As a default 2g is selected.

Range of Gyroscope: This dropdown option contains “250°/S”, “500°/S”, “1000°/S” and “2000°/S” values. As a default “250°/S” is selected.

!00g Sensor Range: This dropdown option contains “100g”, “200g” and “400g” values. As a default “100g” is selected.

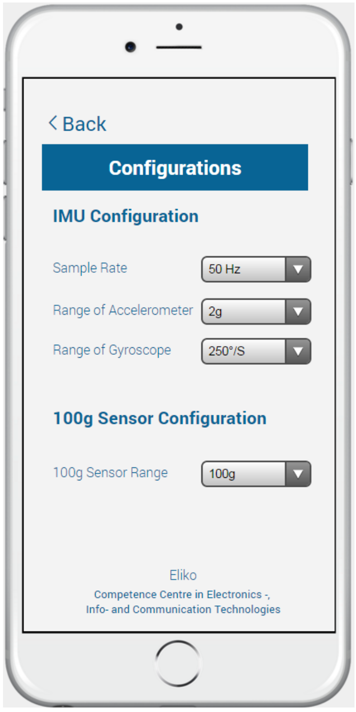


Figure 25 Paired Sensor Configurations.

3.5.5 Taking a Test

From the application side, logic behind taking a test is same for all given tests. When a user clicks on the blue plus icon near a test in the main tests page, shown in Figure 22, the instruction page will show up (Figure 25). This page contains instructions for the selected test, a "Back" button to turn back to main screen and a "Start" button to start a test. In order to take a test one should click on the "Start" button.

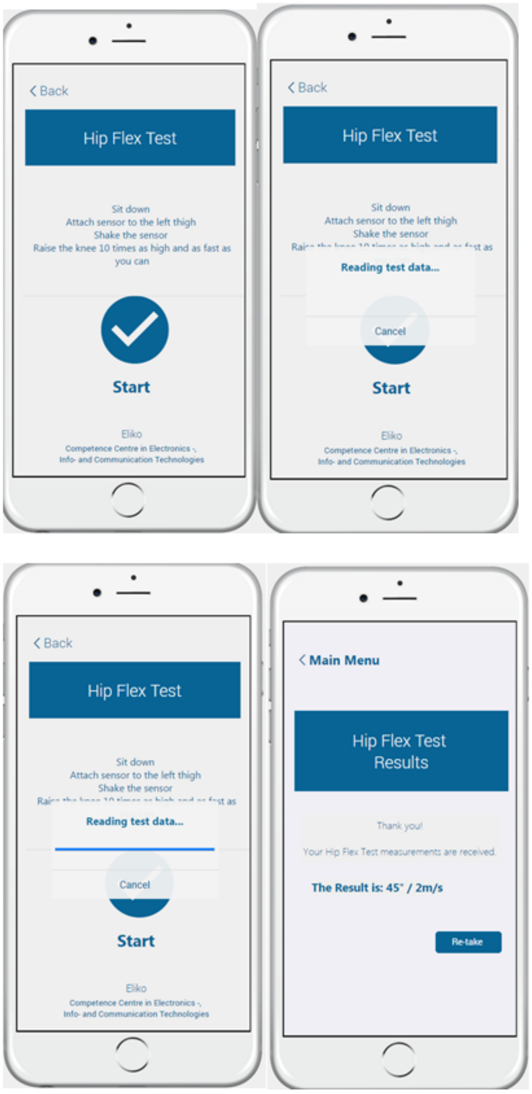


Figure 26 Taking a Test.

3.5.6 The results page

One of the results can be seen in the last part of the Figure 26. All test results are explained in detail in the appendix section. Appendix section contains screens for both iOS and Android applications. User can reach this page either right after completing the necessary test or from main screen with clicking green plus icon near related test.

This page contains the details about the result, a button to turn back to the main page and a button to re-take the test. If a user clicks on the “Re-Take” button, previous results will permanently be deleted and a new test process will start (Figure 26).

3.5.7 Saving the results

In order to save the test results and clear the test page, one should click on the “Send” button in the main page (Figure 27). If all tests are completed, after pressing this button a confirmation message box will be shown. Detailed screens are available in the appendix section. If all the necessary tests are not successfully completed, then the an alertbox will show up when the button is clicked,

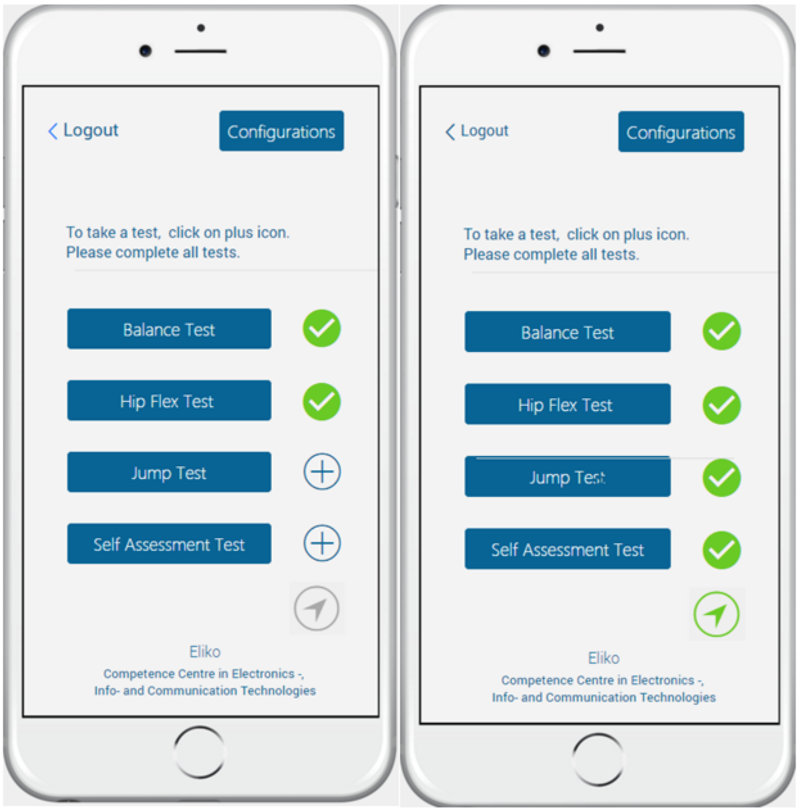


Figure 27How to Save the Results.

If all the necessary tests are already taken, the button color will be green. If some of them are not successfully completed then the button will be grey.

4 Summary

Embedded systems have always been playing significant role in our daily lives. These systems are perfectly placed in almost every sector such as home electronics, entertaining sector, health sector, smart home and constructions and so on.

Currently, as it is described in the previous sections, mobile device usage is significantly high. The community includes both adults, youth generation, elderly people and even children. As a consequent, mobile application development is a new trend which has been followed by many developers. Furthermore, during the development process, following HCI procedures and delivering usable product is another crucial factor in this sector.

IT systems in health sector is another growing trend which saves lives and helps many people to live in a better way. It does not only provide elderly people and patients easier life but also can be used as in treatments.

In this project, I developed mobile device software for a wearable human motion tracking system. My implementations provide incorporation between two recent and important trends which are mobile systems and the embedded control and measurement systems. Unifying these two important trends for health sector provides huge possibilities especially for elderly users and patients. I have implemented this software for both iOS and Android devices. While implementing this software, I took into account user experiences (UX) and HCI. This provides usability. Therefore, users from every age can easily understand and use my software. In the design phase, I paid regard to minimalism and fresh concepts. These two concepts provide readability and usability. This easy-to-use software is very beneficial for especially elder users. Consequently, I have implemented user friendly and maintainable software which provides value in the market. My software includes reading the sensor data, uploading data to cloud server and reading the data from backend. My implementations provide an opportunity to expand the project for the future phases. This project is very useful for both health and sports sector. The outcome of my development is smartphone HCI software enabling home based assessment of patients with progressive neural diseases.

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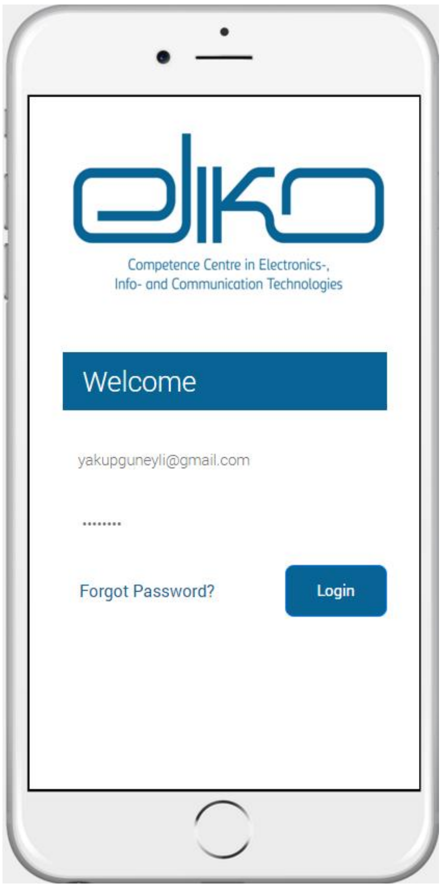
Appendix 1 – iOS Application Screens

Login Page

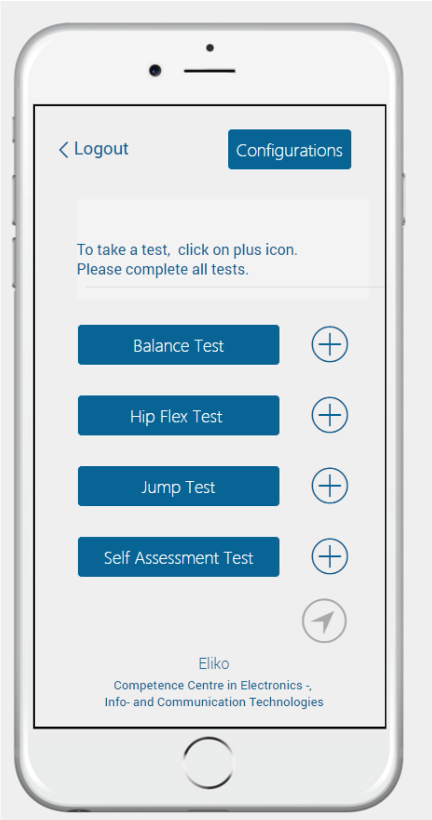
The figures below show the login page for iOS application.



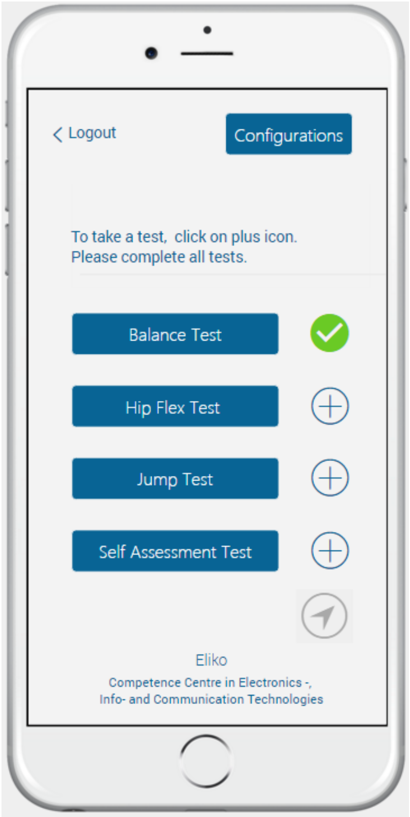
In order to use the system, one should login in the first time use,

Test Page – Main Screen

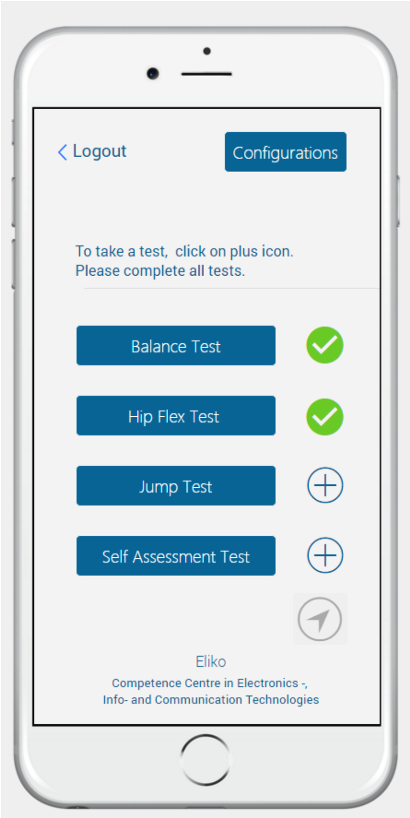
Figure below shows the initial screen after the login. Currently, none of the given tests is taken.



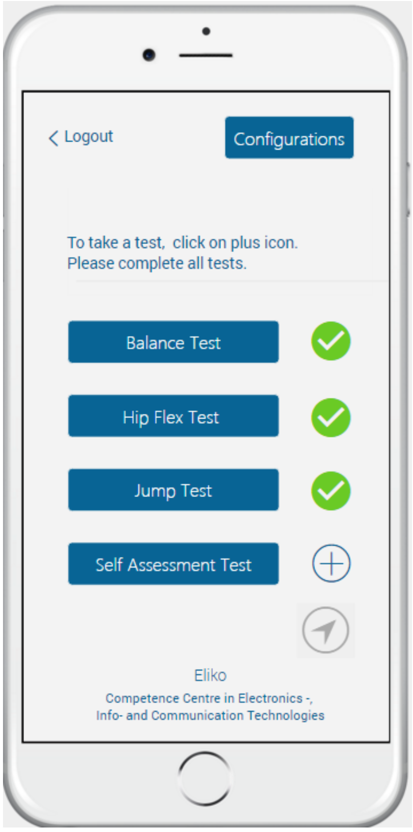
The figure below is another demonstration for the main page. As it is understandable from the icons, only balance test has been completed. Other tests are either not attended or not successfully completed. If a user clicks on the “Send” icon, which is currently grey, an alertbox will show up.



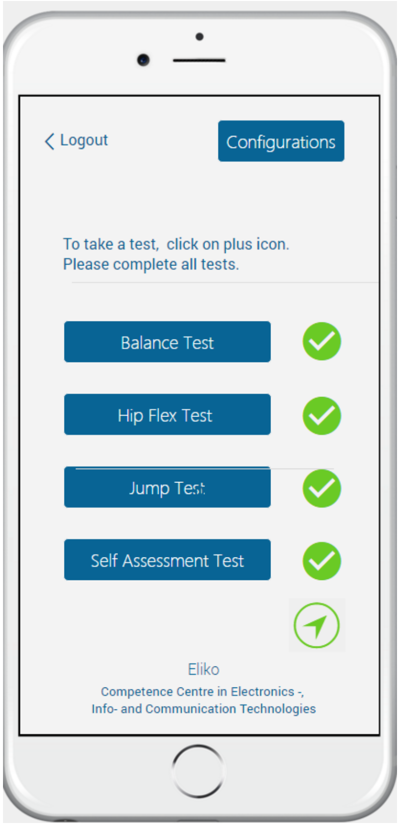
The figure below shows the Tests Page. As it is clear from the icons next to tests, only Balance Test and Hip Flex Test are taken. When other two tests are completed, the send icon will be green and results can be written to database. User can monitor and re-take the taken tests. If a user clicks on the green icon near taken tests, then the user will be re-directed to results page.



The figure below is another demonstration for the Tests page. As it is clear from the icons next to tests, Balance Test, Hip Flex Test and Jump Test are successfully completed. A user can monitor the taken results with clicking green icons near the related test. Green icons will lead the user to a result page for the taken test. Only Self-Assessment Test is missing in this screen. If a user intents to send the results to database and clean the screen, the alert message will show up. In order to write the results to results database and clean the screen, one should take all the given tests.

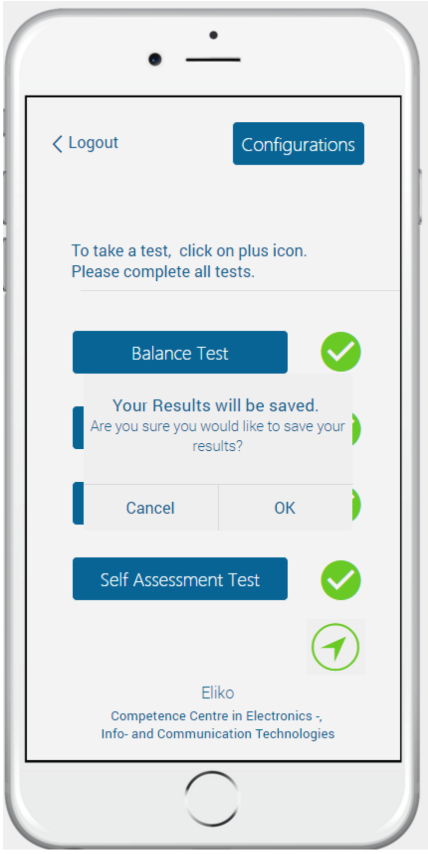


The figure below shows the Tests Page where all the tests have successfully been completed. User can monitor any test results with green buttons near tests.

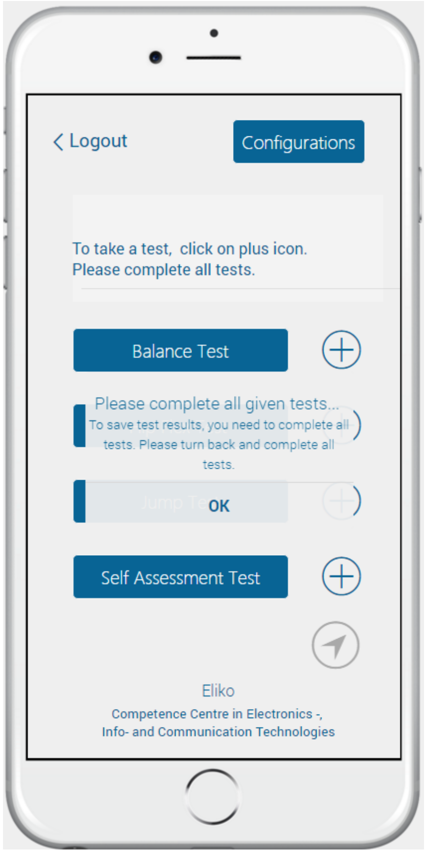


If a user clicks on "Send" icon, the confirmation message box will be shown. If user accepts the confirmation message then all the test data will be sent to backend and the screen will be cleaned up.

Below figure shows the confirmation message box when user clicks on the green "Send" icon.



If a user clicks on this “Send” icon, before completing all the given tests, then system will notify the user with showing alertbox. The alertbox below will notify user to take all of the given test.



Configurations Screen

In the configurations screen there are buttons for paired sensors, a button to Log out, a button to turn back to Tests Page, a button to add a new BLE sensor and a button to show previous test results.

If a user clicks on “Back” button, then the main page which is Test Page will be shown. If a user clicks on “Logout” button, the application will be stopped, user will be logged out and the Login Page will be shown. If a user clicks on “Results” button, last five results will be listed. In order to pair with a new sensor device, one should click on the blue plus icon. When it is clicked, application will start searching for a new BLE device.

If a user clicks on the sensor names or after a new pair, a screen for the sensor data configurations will show up. This page contains following components.

A “Back” button: Leads user back to the Configurations Page.

Sample Rate: This is a dropdown option which contains the value of “50 Hz” and “100 Hz”. As a default 50 Hz is selected.

Range of Accelerometer: This is a dropdown option which contains “2g”, “4g”, “8g” and “16g” values. As a default 2g is selected.

Range of Gyroscope: This is a dropdown option which contains “250°/S”, “500°/S”, “1000°/S” and “2000°/S” values. As a default “250°/S” is selected.

!00g Sensor Range: This is a dropdown option which contains “100g”, “200g” and “400g” values. As a default “100g” is selected.

Taking a Test

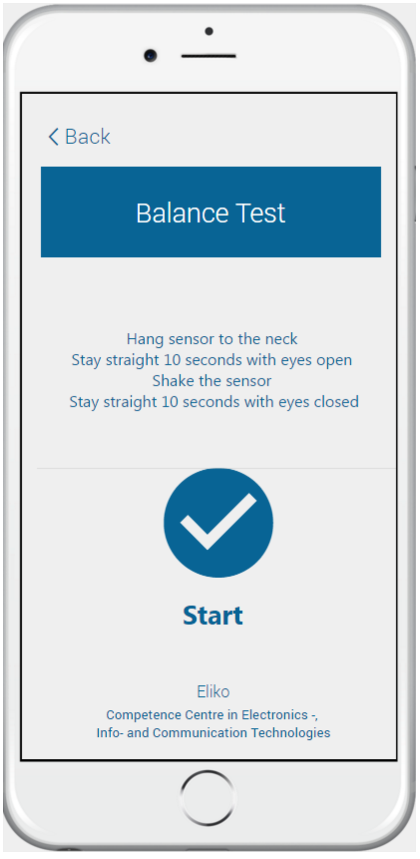
After a user logs in to the system, the Tests Page will be shown. User can take any test with using the plus icon near the test.

Taking the Balance Test

In order to take Balance Test, the below steps should be completed.

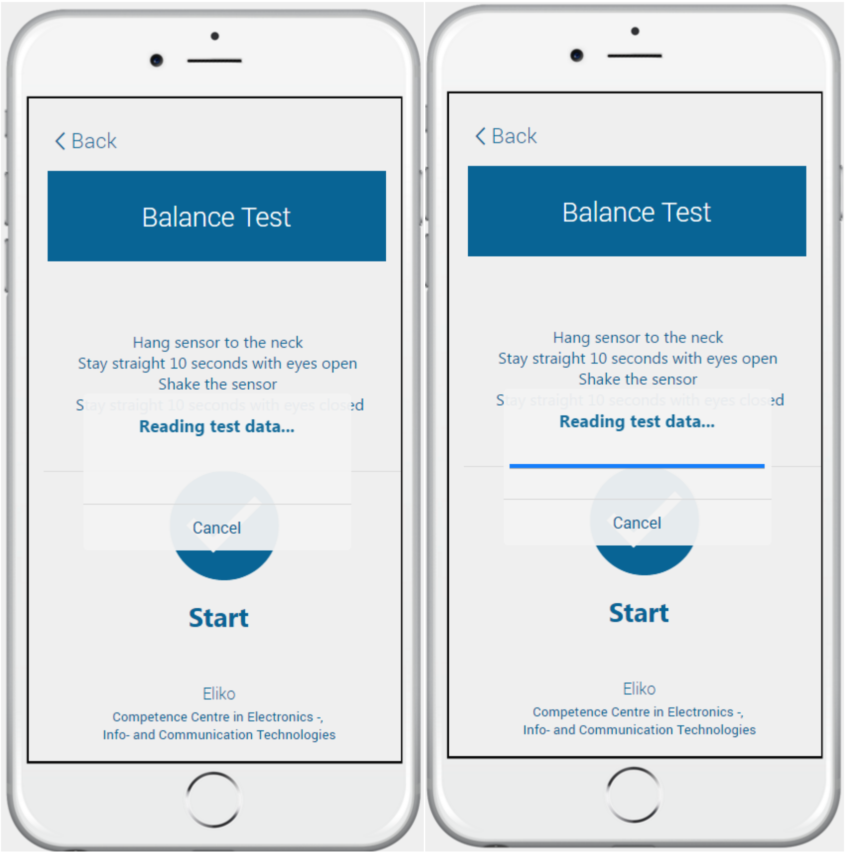
After the login, a user needs to click on the plus icon near Balance Test.

The below screen will be shown.



This screen contains a “Back” button, “Start” button and test instructions. Test instructions are very important to take the test correctly. “Back” button leads the user to turn back to the previous page. “Start” button starts the test. While sensor data is reading there will be a process bar and a cancel option as a message box.

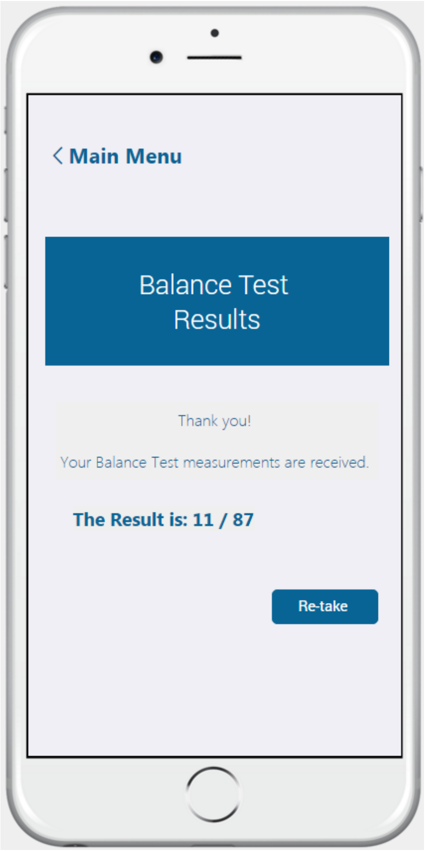
If the user clicks on the “Start” button, the test will start.



If the user clicks on the “Cancel” button, reading sensor data process will be cancelled.

If the test is successfully completed, the following page will show up. For any reason data is not successfully read, user is directed to the previous page, where the test instructions are written will be shown.

In the results screen below, user can monitor the taken test results. This screen contains a button to turn back to the main menu which is the Tests Page, a button to re-take the same test and result information.

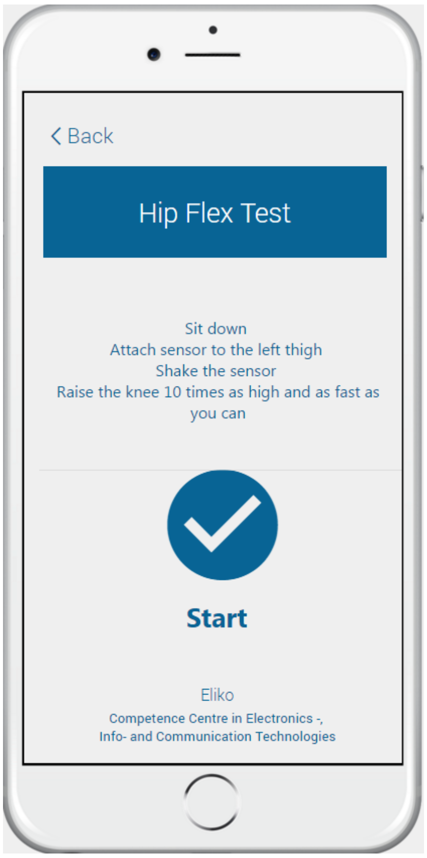


Taking the Hip Flex Test

In order to take Hip Flex Test, the below steps should be completed.

After login, a user needs to click on the plus icon near Hip Flex Test.

The screen below will be shown.



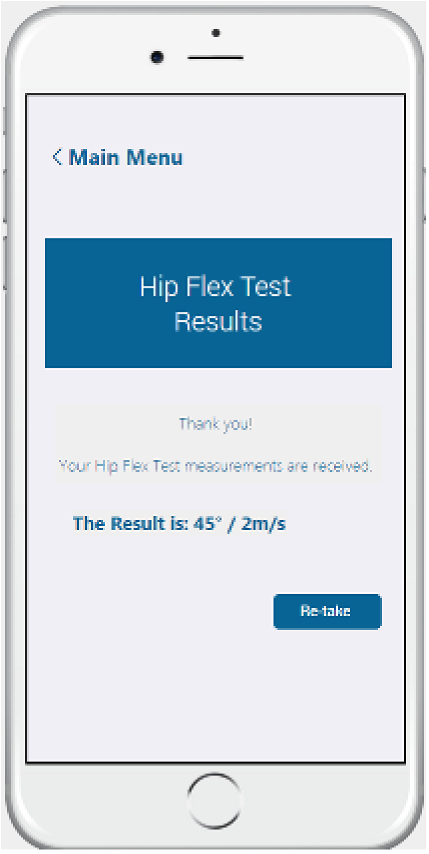
This screen contains a “Back” button, “Start” button and test instructions. Test instructions are very important to take the test correctly. Back button leads the user to turn back to the previous page. “Start” button starts the test. While sensor data is reading there will be a process bar and a cancel option as a message box.

If the user clicks on the “Start” button, the test will start.

If the user clicks on the “Cancel” button, reading sensor data process will be cancelled.

If the test is successfully completed, the following page will show up. For any reason data is not successfully read, user is directed to the previous page, where the test instructions are written will be shown.

In the results screen below, user can monitor the taken test results. This screen contains a button to turn back to the main menu which is Tests Page, a button to re-take the same test and result information.

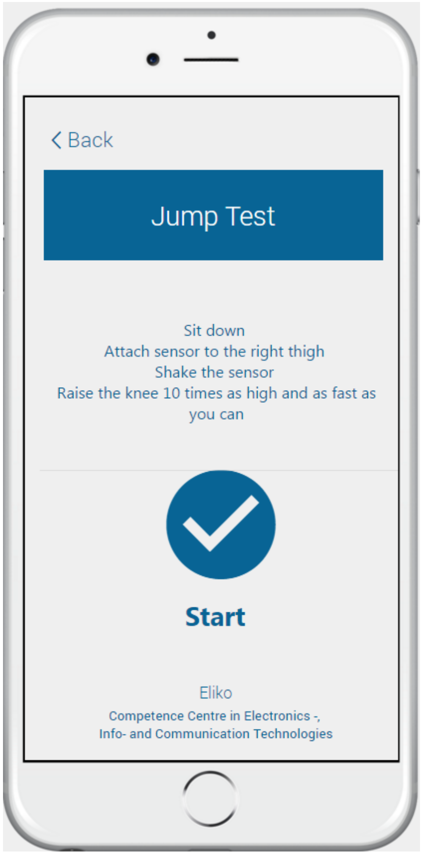


Taking the Jump Test

In order to take Jump Test, the below steps should be completed.

After login, a user needs to click on the plus icon near Jump Test.

The screen below will be shown.



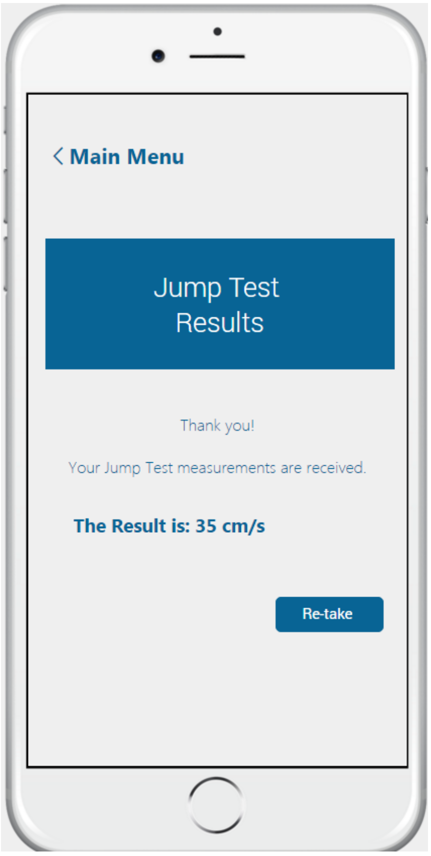
This screen contains a “Back” button, “Start” button and test instructions. Test instructions are very important to take the test correctly. Back button leads the user to turn back to the previous page. “Start” button starts the test. While sensor data is reading there will be a process bar and a cancel option as a message box.

If the user clicks on the “Start” button, the test will start.

If the user clicks on the “Cancel” button, reading sensor data process will be cancelled.

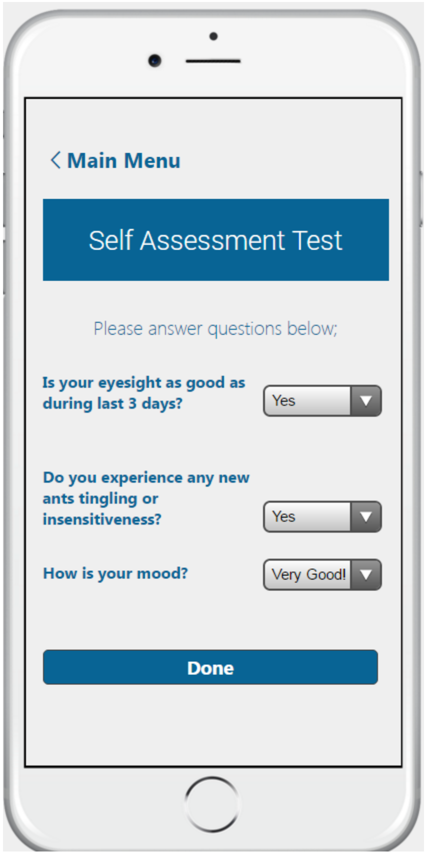
If the test is successfully completed, the following page will show up. For any reason data is not successfully read, user is directed to the previous page, where the test instructions are written will be shown.

In the results screen below, user can monitor the taken test results. This screen contains a button to turn back to the main menu which is Tests Page, a button to re-take the same test and result information.



Taking the Self Assessment Test

In order to take the Self Assessment test, one should click on the plus icon near the test in the main screen which is Tests Page. Afterwards, following page will be shown.



The Self Assessment Test Page contains, three dropdown menu options, one button to turn back and one button to confirm answers.

Main Menu Button: This button leads user to main menu which is Tests Page.

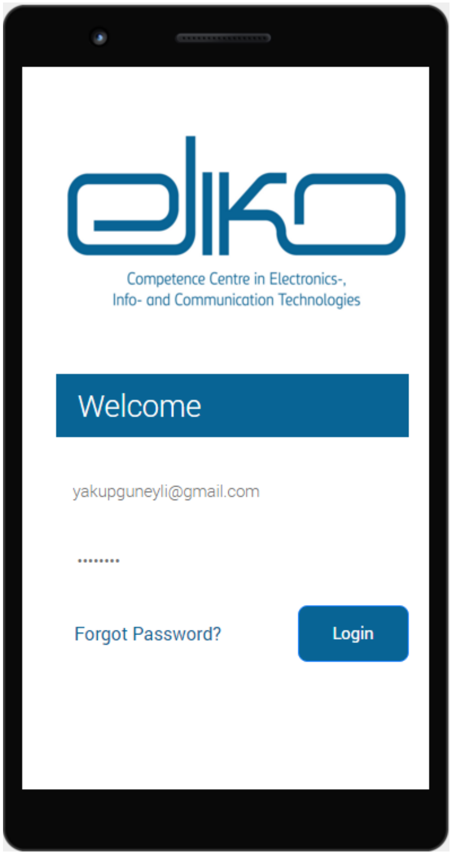
First two questions are YES/NO questions. A user should pick one in order to complete the test. The last question "How is your mood" contains three answers. They are "Very Good!", "As Usual!" and "Bad!"

The button "Done" saves the result and redirects user to main page which is Tests Page.

Appendix 2 – Android Application Screens

Login Page

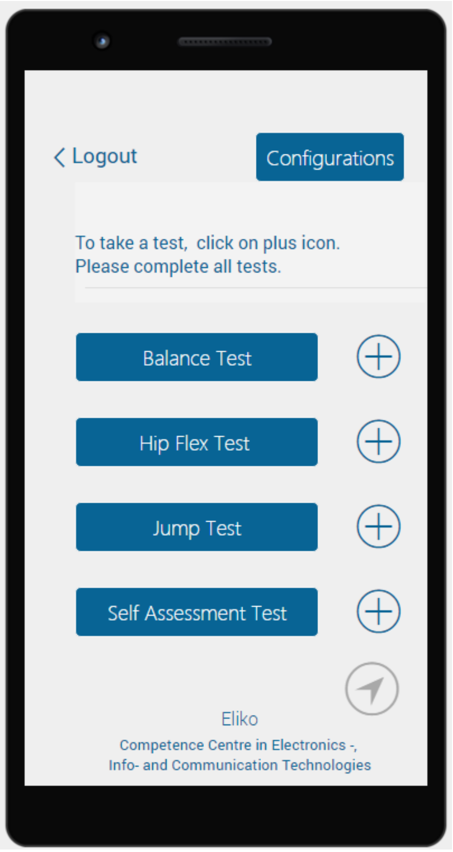
The figure below shows the login page for Android application.



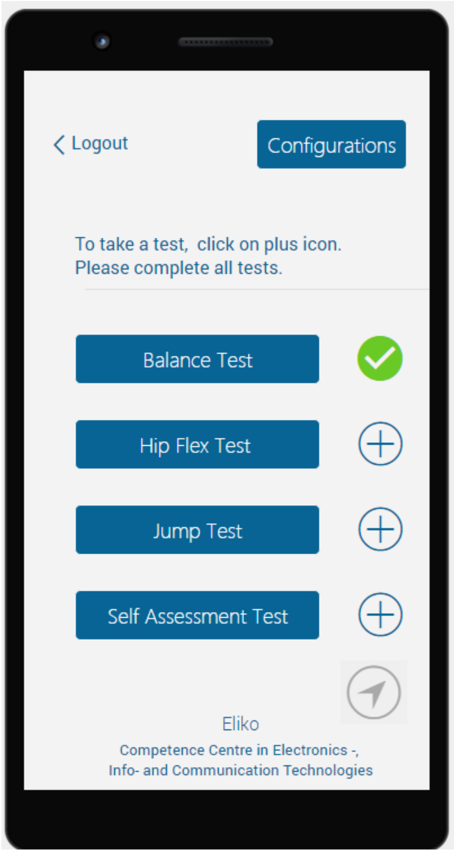
In order to use the system, one should login in the first time use,

Test Page – Main Screen

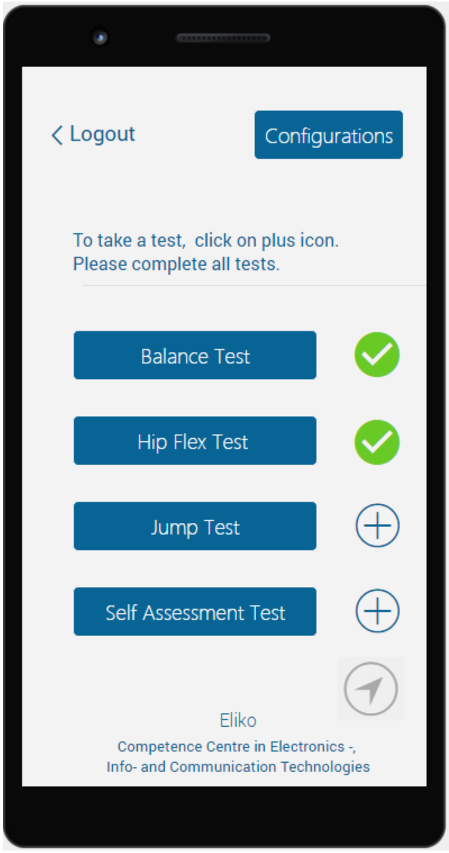
Figure below shows the initial screen after the login. Currently, neither of the given tests is taken.



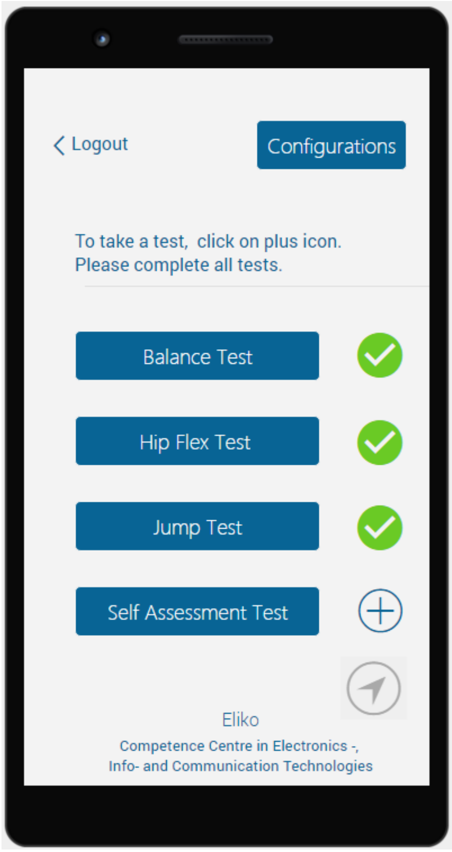
The figure below is another demonstration for the main page. As it is understandable from the icons, only balance test has been completed. Other tests are either not attended or not successfully completed. If a user clicks on the "Send" icon, which is currently grey, an alertbox will show up.



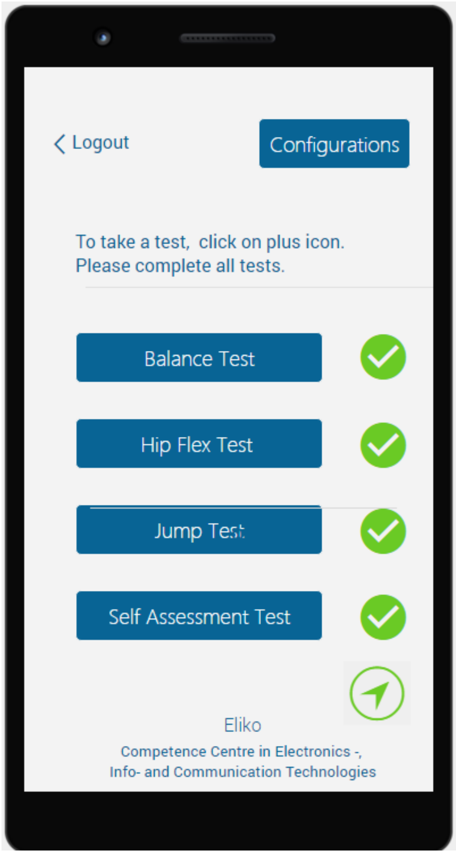
The figure below shows the Tests Page. As it is clear from the icons next to tests, only Balance Test and Hip Flex Test are taken. When other two tests are completed, the send icon will be green and results can be written to database. User can monitor and re-take the taken tests. If a user click on the green icon near taken tests, then the user will be re-directed to results page.



The figure below is another demonstration for the Tests page. As it is clear from the icons next to tests, Balance Test, Hip Flex Test and Jump Test are successfully completed. A user can monitor the taken results with clicking green icons near the related test. Green icons will lead the user to a result page for the taken test. Only Self-Assessment Test is missing in this screen. If a user intents to send the results to database and clean the screen, the alert message will show up. In order to write the results to results database and clean the screen, one should take all the given tests.

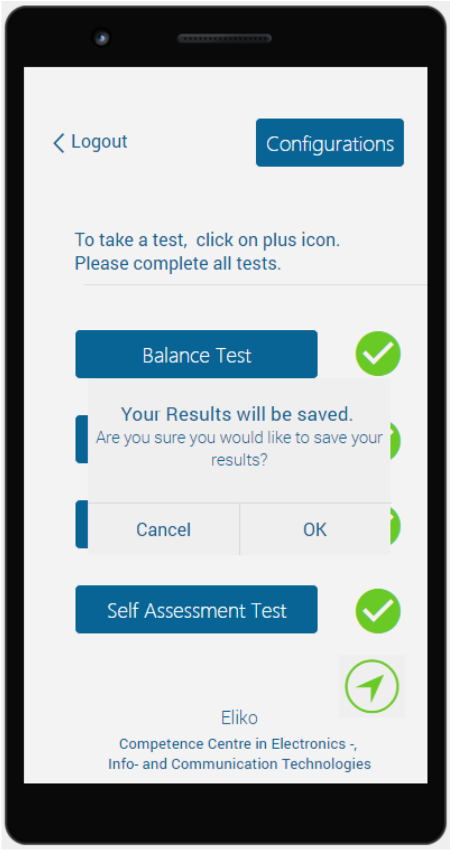


The figure below shows the Tests Page where all the tests have successfully been completed. User can monitor any test results with green buttons near tests.

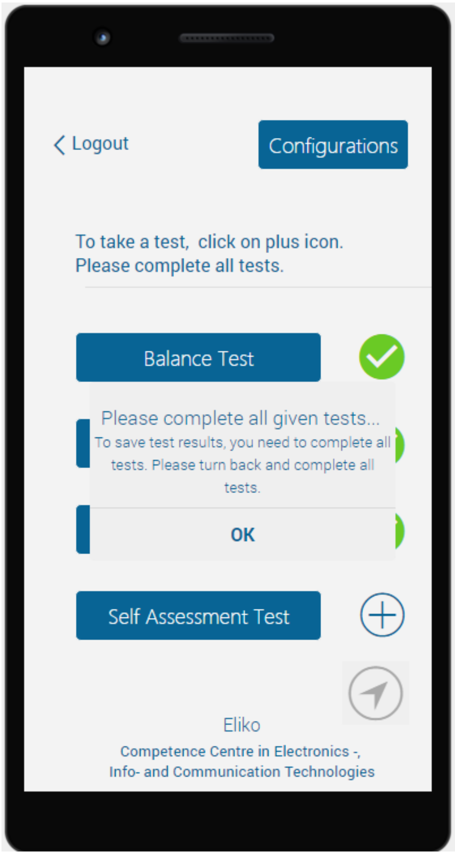


If a user clicks on "Send" icon, the confirmation message box will be shown. If user accepts the confirmation message then all the test data will be sent to backend and the screen will be cleaned up.

Below figure shows the confirmation message box when user clicks on the green "Send" icon.



If a user clicks on this “Send” icon, before completing all the given tests, then system will notify user with showing alertbox. The alertbox below will notify user to take all of the given test.



Configurations Screen

In the configurations screen there are buttons for paired sensors, a button to log out, a button to turn back to tests page, a button to add a new BLE sensor and a button to show previous test results.

If a user clicks on “Back” button, then the main page which is Test page will be shown. If a user clicks on “Logout” button, the application will be stopped, user will be logged out and the Login Page will be shown. If a user clicks on “Results” page, last five results will be listed. In order to pair with a new sensor device, one should click on the blue plus icon. When it is clicked, application will start searching for a new BLE device.

If a user clicks on the sensor names or after a new pair, a screen for the sensor data configurations will show up. This page contains following components.

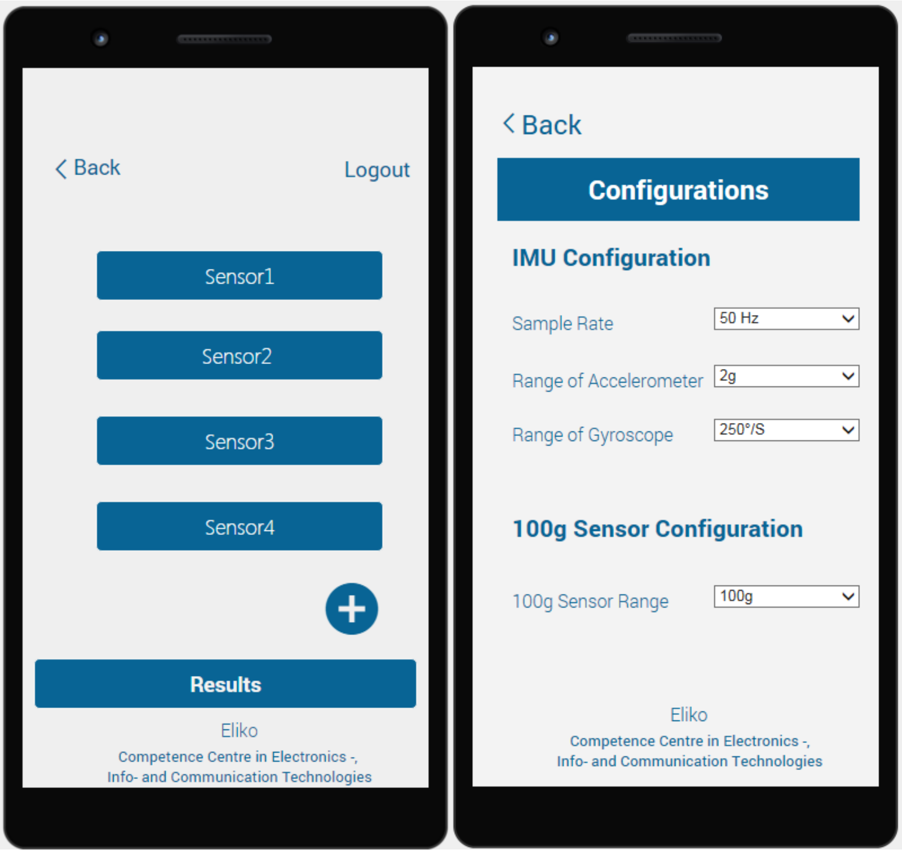
A “Back” button: Leads user back to the “Configurations Page”

Sample Rate: This is a dropdown option which contains the value of “50 Hz” and “100 Hz”. As a default 50 Hz is selected.

Range of Accelerometer: This is a dropdown option which contains “2g”, “4g”, “8g” and “16g” values. As a default 2g is selected.

Range of Gyroscope: This is a dropdown option which contains “250°/S”, “500°/S”, “1000°/S” and “2000°/S” values. As a default “250°/S” is selected.

!00g Sensor Range: This is a dropdown option which contains “100g”, “200g” and “400g” values. As a default “100g” is selected.



Taking a Test

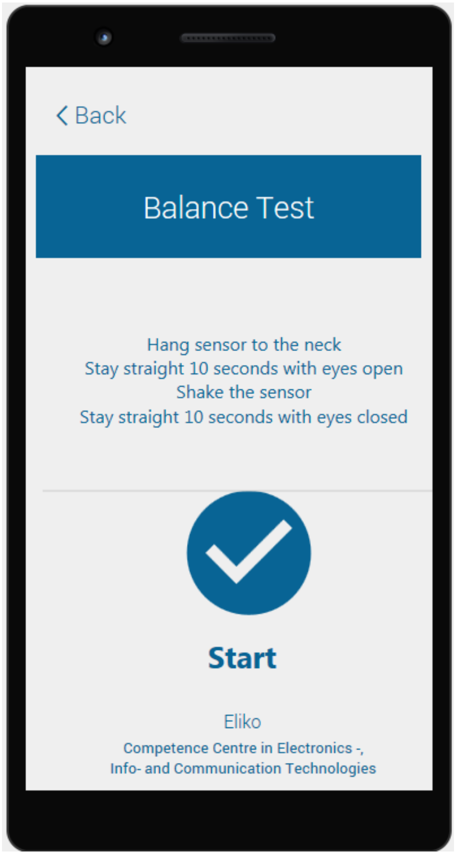
After a user logs in to the system, the Tests Page will be shown. User can take any test with using the plus icon near the test.

Taking the Balance Test

In order to take Balance Test, the below steps should be completed.

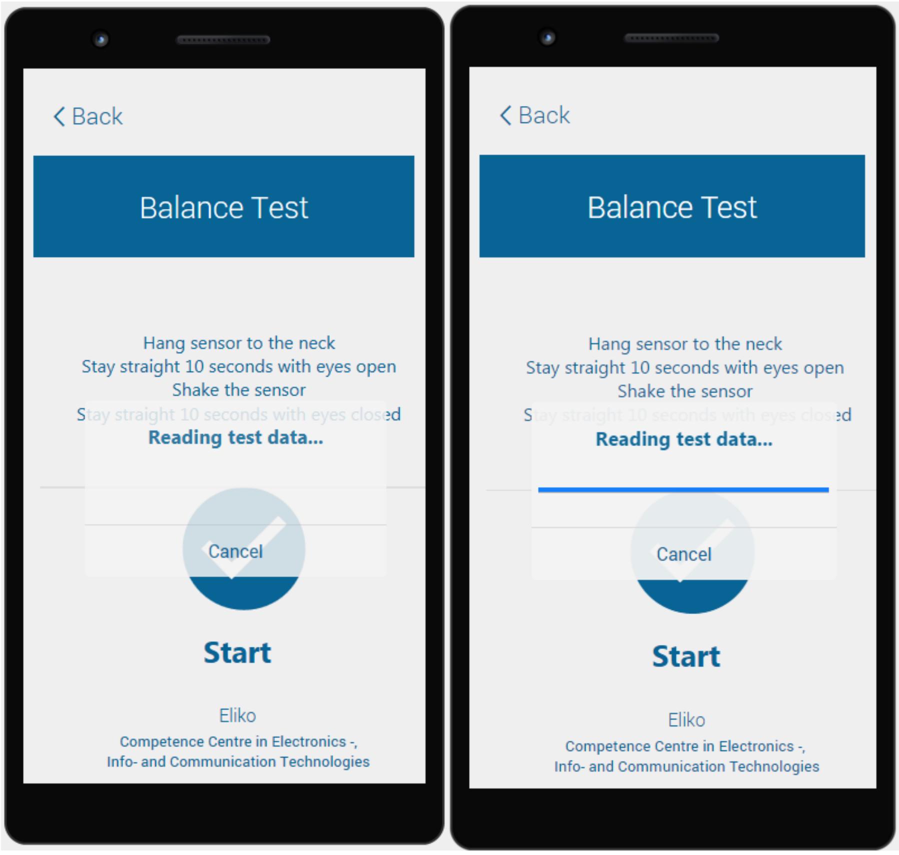
After the login, a user needs to click on the plus icon near Balance Test.

The below screen will be shown.



This screen contains a "Back" button, "Start" button and test instructions. Test instructions are very important to take the test correctly. Back button leads the user to turn back to the previous page. "Start" button starts the test. While sensor data is reading there will be a process bar and a cancel option as a message box.

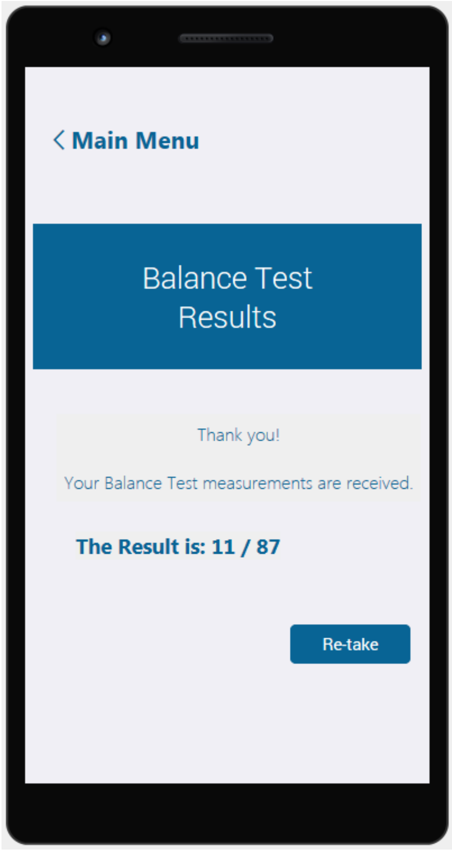
If the user clicks on the start button, the test will start.



If the user clicks on the "Cancel" button, reading sensor data process will be cancelled.

If the test is successfully completed, the following page will show up. For any reason data is not successfully read, user is directed to the previous page, where the test instructions are written will be shown.

In the results screen below, user can monitor the taken test results. This screen contains a button to turn back to the main menu which is Tests Page, a button to re-take the same test and result information.

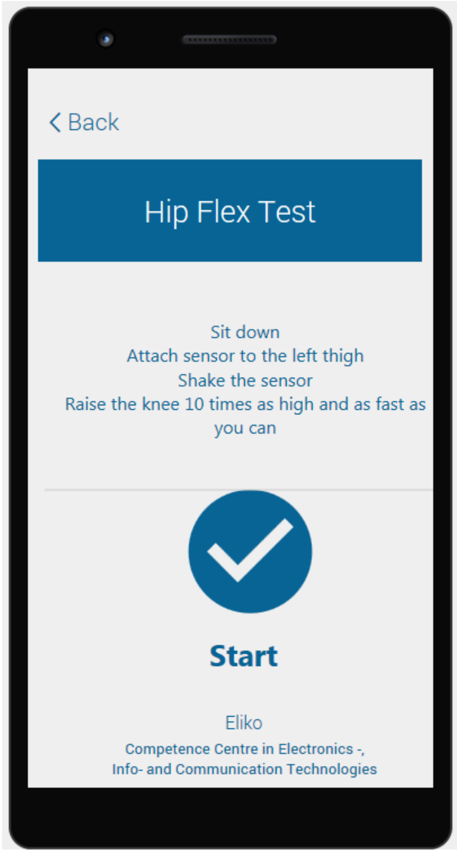


Taking the Hip Flex Test

In order to take Hip Flex Test the below steps should be completed.

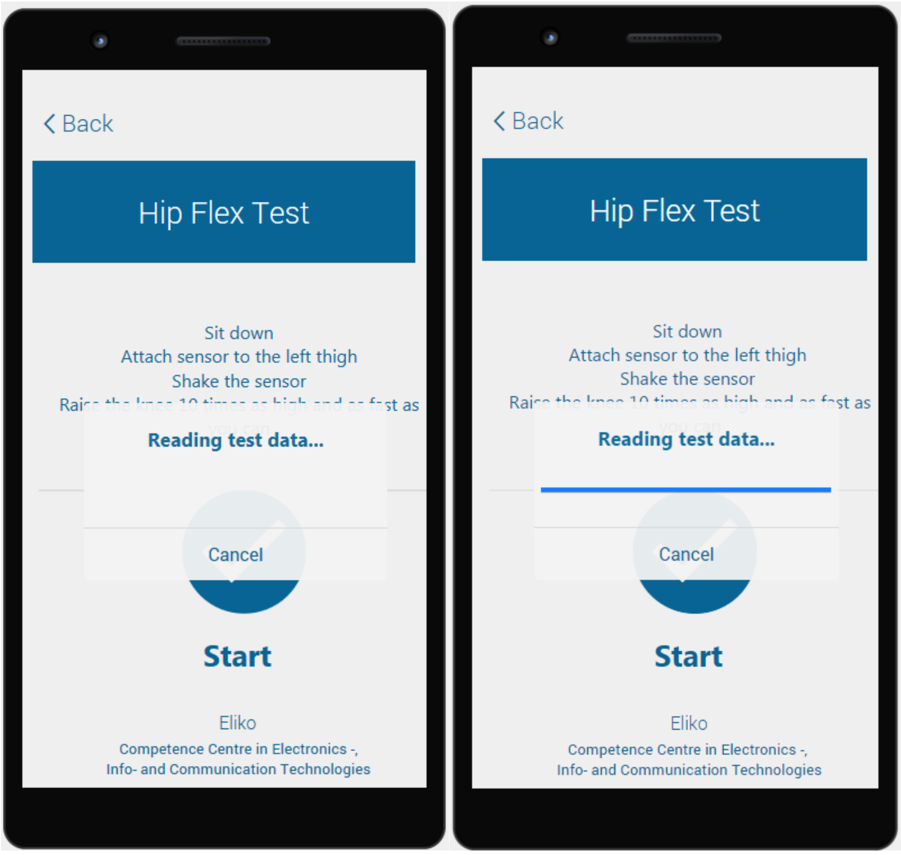
After login, a user needs to click on the plus icon near Hip Flex Test.

The screen below will be shown.



This screen contains a “Back” button, “Start” button and test instructions. Test instructions are very important to take the test correctly. The “Back” button leads the user to turn back to the previous page. “Start” button starts the test. While sensor data is reading there will be a process bar and a cancel option as a message box.

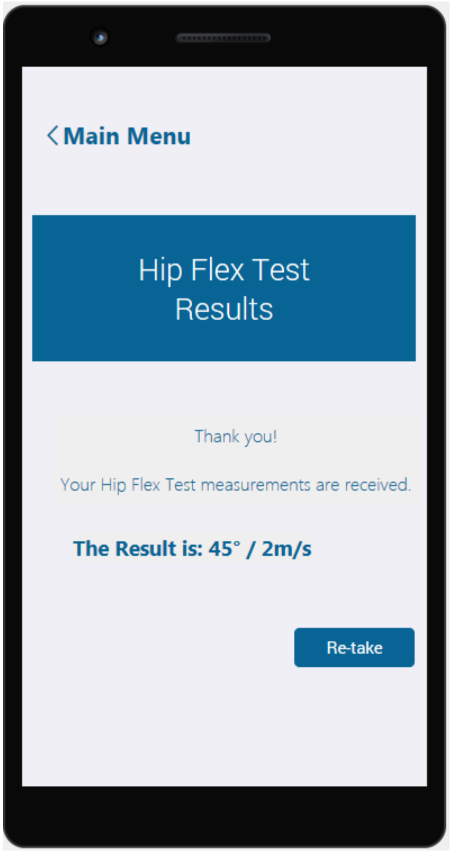
If the user clicks on the “Start” button, the test will start.



If the user clicks on the "Cancel" button, reading sensor data process will be cancelled.

If the test is successfully completed, the following page will show up. For any reason data is not successfully read, user is directed to the previous page, where the test instructions are written will be shown.

In the results screen below, user can monitor the taken test results. This screen contains a button to turn back to the main menu which is Tests Page, a button to re-take the same test and result information.

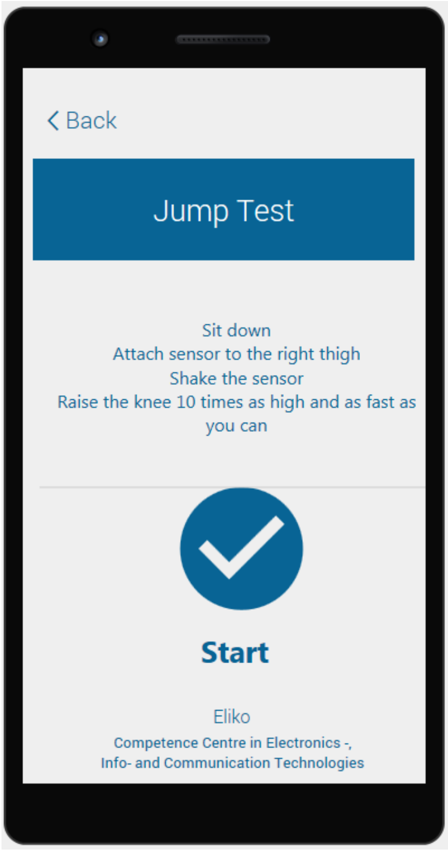


Taking the Jump Test

In order to take Jump Test, the below steps should be completed.

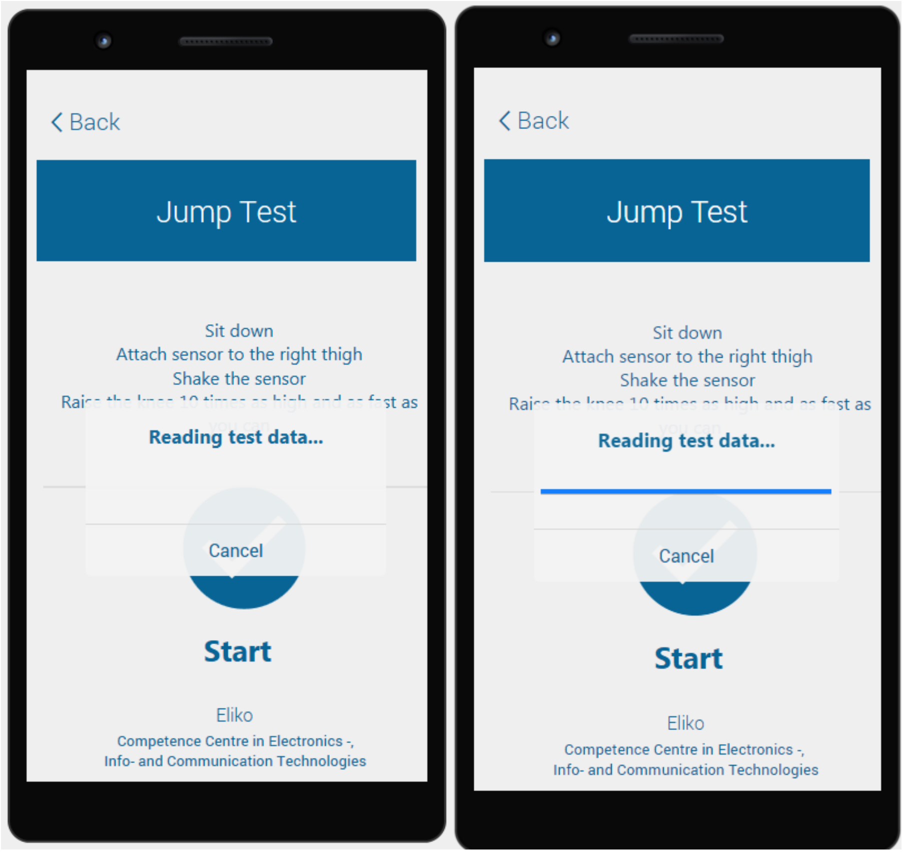
After login, a user needs to click on the plus icon near Jump Test.

The screen below will be shown.



This screen contains a “Back” button, “Start” button and test instructions. Test instructions are very important to take the test correctly. Back button leads the user to turn back to the previous page. “Start” button starts the test. While sensor data is reading there will be a process bar and a cancel option as a message box.

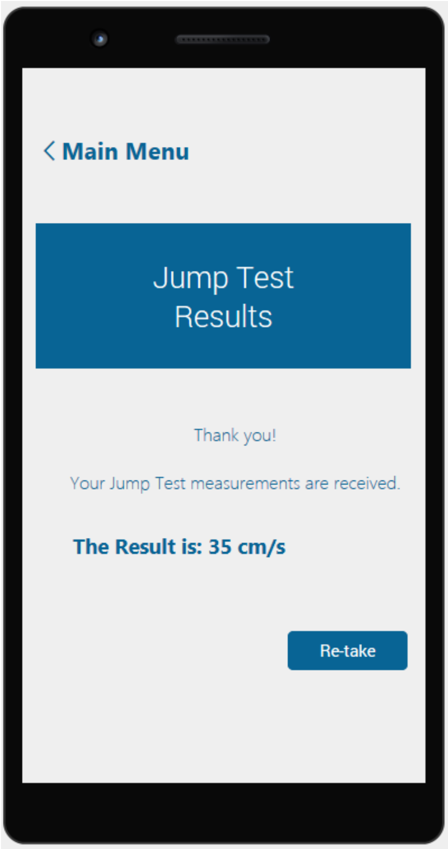
If the user clicks on the “Start” button, the test will start.



If the user clicks on the “Cancel” button, reading sensor data process will be cancelled.

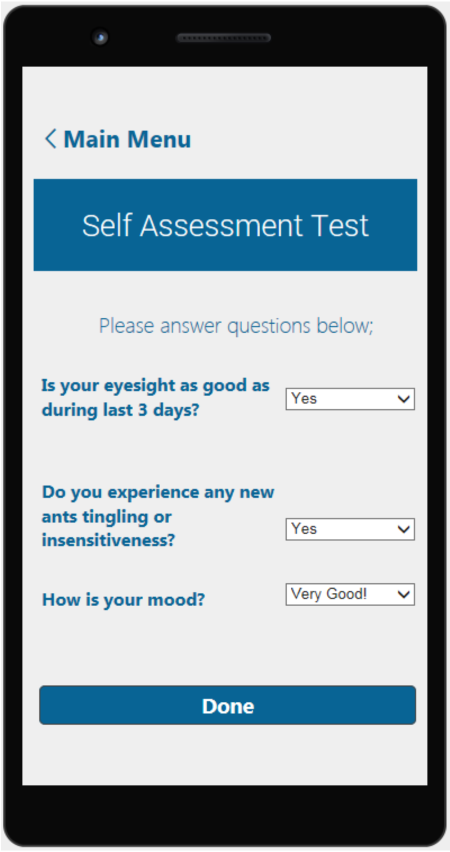
If the test is successfully completed, the following page will show up. For any reason data is not successfully read, user is directed to the previous page, where the test instructions are written will be shown.

In the results screen below, user can monitor the taken test results. This screen contains a button to turn back to the main menu which is Tests Page, a button to re-take the same test and result information.



Taking the Self Assessment Test

In order to take the Self Assessment test, one should click on the plus icon near the test in the main screen which is Tests Page. Afterwards, following page will be shown.



The Self Assessment Test Page contains, three dropdown menu options, one button to turn back and one button to confirm answers.

“Main Menu” button leads user to main menu which is Tests Page.

First two questions are YES/NO questions. A user should pick one in order to complete the test. The last question “How is your mood” contains three answers. They are “Very Good!”, “As Usual!” and “Bad!”

The button “Done” saves the result and redirects user to main page which is Tests Page.