TALLINN UNIVERSITY OF TECHNOLOGY
School of Information Technologies
Department of Health Technologies

Daniil Titov 122322YABM

WIRELESS COMMUNICATION PLATFORM FOR BIOSIGNAL MONITORING: LABORATORY WORK PREPARATION

Master`s thesis

Supervisor: Ivo Fridolin
PhD-Professor
Co-supervisor: Deniss Karai
Technician

Tallinn 2018

TALLINNA TEHNIKAÜLIKOOL
Infotehnoloogia teaduskond
Tervisetehnoloogiate instituut

Daniil Titov 122322YABM

JUHTMEVABA SIDE KASUTAMINE BIOSIGNAALIDE MONITOORINGUL: LABORITÖÖ ETTEVALMISTAMINE

Magistritöö

Juhendaja:	Ivo Fridolin
	PhD-Professor
Kaasjuhendaja:	Deniss Karai
	Tehnik

Tallinn 2018

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.

Author: Daniil Titov

(*date*)…………………….....   (*signature*)…………………………

Autorideklaratsioon

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Autor: Daniil Titov

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Abstract

The aim of this master`s thesis was to create manual for a laboratory work as a teaching material that explains principles of wireless network technologies in healthcare. The result of this thesis is an instruction how to setup a secure Bluetooth wireless network for sending biomedical information using Shimmer ECG sensor and a PC. To achieve this aim, firstly, author gives an overview of existing wireless network technologies, which have potential to be used in healthcare: WiFi, Bluetooth, Cellular networks: 3G/4G/5G, WiMAX and ZigBee with real examples and provide some information about secure data sending between medical devices in one network. Secondly, the different Shimmer sensor software solutions are observed and compared, developed a new software solution (Appendix 3), the best one is chosen for the using as a platform for the laboratory work.

As a result, a teaching material for students, who are going to take a course of «*Electromagnetic Fields and Waves*» in Tallinn University of Technology was created (Appendix 5). The laboratory work will help future medical engineers to step into the world of medicine, work with real patient`s data, create and analyze data in a real time, practice teamwork, try a role of a researcher and a patient, learn IT wireless network systems and the basics of programming.

The future use of this master`s thesis could be found as a practical material for students.

This thesis is written in English and is 50 pages long, including 5 chapters, 48 figures, 3 tables and 5 appendixes.

Annotatsioon

Juhtmevaba side kasutamine biosignaalide monitooringul: laboritöö ettevalmistamine

Antud magistritöö eesmärgiks oli luua õppematerjalina kasutatav laboritöö juhend, mis selgitab traadita võrgutehnoloogiate põhimõtteid tervishoius. Selle töö tulemusena valmis laboritöö juhend, mis käsitleb turvalise Bluetooth juhtmevaba ühenduse seadistamist biosignaalide saatmiseks Shimmer EKG anduri ja arvuti vahel. Eesmärgini jõudmiseks esitatakse esmalt ülevaade laialt levinud traadita võrgutehnoloogiatest ja nende rakendamisest tervishoius: WiFi, Bluetooth, mobiilsidevõrgud (3G/4G-4,5G/5G), WiMAX ja ZigBee; samuti kirjeldatakse turvalise andmete saatmise võimalust meditsiiniseadmete vahel ühe võrgu piires. Teiseks, esitatakse ülevaade erinevatest Shimmer tarkvaralahendustest, luuakse uus tarkvaralahendus (Lisa 3) ja valitakse sobivaim laboritöö platvormiks.

Töö tulemusena valminud laboritöö (Lisa 5) on mõeldud Tallinna Tehnikaülikooli üliõpilastele, kes läbivad kursuse “Elektromagnetväljad ja lained biomeditsiinitehnikas”. Laboritöö põhieesmärk on aidata tulevastel biomeditsiini tehnika inseneridel teha esimesed sammud meditsiinis, praktiseerida reaalse patsiendi andmete kogumist ja töötlemist, arendada meeskonnatöö oskusi, mängida nii uuringu läbiviija kui ka patsiendi rolle, õppida tundma traadita võrke ning saada tuttavamaks programmeerimise alustega.

Käesolevat magistritööd saab kasutada õppematerjalina, samuti arendada edasi.

Magistritöö on kirjutatud inglise keeles ning sisaldab teksti 50 leheküljel, 5 peatükki, 48 joonist, 3 tabelit ja 5 lisad.

List of abbreviations

OS	***Operating System-***
PC	***Personal Computer***
RAM	***Random access memory***
CPU	***Central Processing Unit***
JRE	***Java Runtime Environment***
WPAN	***Wireless Personal Area Network***
WLAN	***Wireless Local Area Network***
WMAN	***Wireless Metropolitan Area network***
WCDMA	***Wideband Code Division Multiple Access***
LTE	***Long Term Evolution***
HR	***Heart Rate***
ECG	***Electrocardiography***

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Introduction

Technologies and technical processes have evolved rapidly over last 15 years. People and companies not only use personal computers but also there is a need for collecting, transmitting, storing data and work with information in a real time, using different connections, systems and networks. As interest for technologies grows, cost of the solutions and different devices such as mobile phones, personal computers, tablets started to decrease compare to prices level of a decade ago.

A good example in this regard is healthcare, where new technologies are very crucial for saving people`s life. Wireless systems for medical needs are developing rapidly. Medical devices like blood pressure monitor, ultrasound device and heart rate monitor have been developed as portable.

Different possibilities of wireless networks are available for use in healthcare. For example, 3G/4G/5G, WiFi and WiMax. Healthcare specialists may receive access to patient information anywhere and at any time using healthcare network and systems. Other networks like Bluetooth and Zigbee with wireless sensors give a great possibility for data transmission for medical applications. [1]

The topic of this master`s thesis was chosen on the basis on interest in medical devices , network technologies and the ability to design a teaching material. It is known, that students, who have chosen Biomedical engineering and medical physics speciality, will work in different companies or hospitals. As a part of their work will be a connection of medical device to a network, fix some issues with network and a device.

The theme of this thesis was initiated from actual practical need. Before going to work as an engineer students have to receive some knowledge about working with medical devices and networks. This was also the primary aim of the current thesis by developing a laboratory work, which gives an overview about the wireless networks in healthcare, and helps to acquire some skills about setting up hard- and software for wireless biosignal monitoring.

1 Technical background of the wireless networks.

1.1 Zigbee

Zigbee is a type of wireless personal area network (WPAN), which is based on IEEE 802.15.4 standard and is called Low Rate WPA. These technologies are suited for data sensors, wireless automation or other applications that do not require high data rates, such as high-quality video streaming. Compared to the IEEE 802.11 technology Zigbee operates at much higher data rates and can support bandwidth-intensive applications. [4]

The main idea and advantages of Zigbee include: reliable transfer of data, low cost, short range, low power consumption, simplicity. This is an acceptable user experience. According to IEEE 802.15.4, a standard defining Zigbee the typical technical characteristics are:

- Wireless data rates 20-250 kbps
- Peer-to-peer or star topology operation
- Low power consumption
- 16 channels in the 2.4 GHZ band, 30 channels in the 915 MHz band and 3 channels in the 868 MHz band. [4]

Zigbee has 2 types of the devices: a full-function device (FFD) and a reduced-function device (RFD). Furthermore, at least one FFD should be in a WPAN. RFDs can only operate in one mode. On the other hand, FFDs can operate in 3 modes. According to a standard these modes for FFD are:

- PAN coordinator, which is responsible for PAN setup and netwrok coordinator
- Coordinator, a device, which can relay messages
- Device, which does not relay messages

All FFDs can communicate with RFDs or other FFDs, but RFDs can only communicate with FFDs. That is why, RFDs are simple devices like sensors that send only small data and not control the network among multiple devices. [4]

All devices must communicate via PAN coordinator FFD in the star topology. Star topologies work independently. On the other hand, FFDs can communicate directly to each other, while RFD must communicate with the PAN coordinator only, in peer-to-peer topology. [4]

The ZigBee Alliance Web site (www.zigbee.org) reffers to different products for different industries, which have Zigbee certification like: home automation, lightning, healthcare. Zigbee has own healthcare standard. According to the reference [5] „*Zigbee Health Care offers a global standard for interoperable products enabling secure and reliable monitoring and management of non-critical, low-acuity healthcare services targeted at chronic disease, aging independence and general health, wellness and fitness*"

1.1.1 Zigbee wireless sensors for healthcare

Zigbee wireless sensors is possible to use for purposes like chronic disease monitoring, personal wellness monitoring or wellness activity. A lot of patients have different chronical diseases that require to be monitored. Young or old patients may have diseases like diabetes, asthma, heart problems and sleep disorders. It is needed to monitor these diseases in later stages. [6]

It is possible to measure patient`s bio signals like heart rate, temperature, glucose level, blood pressure and EKG using wireless sensors and store the information with timestamp in clinical information system or in data base for analizing the status of chronical disease. Some examples are illustrated in (Figure 1) [6]

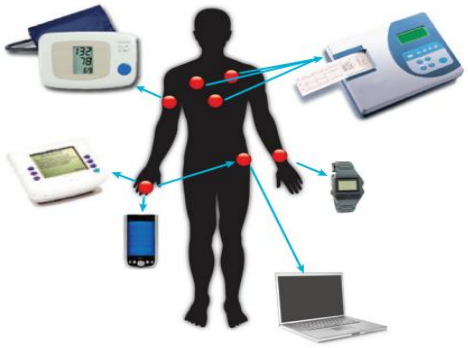


Figure 1. Chronical disease monitoring devices using Zigbee network [6]

1.2 Cellular network

1.2.1 3G/4G network

3G is a third generation of cellular communication network standard. This network was intended to provide a mobile wireless communication globally for users, like voice, messaging, web, video, broadband data. The information transfer rate from 384 kbps up to 1Mbps. Furthermore, according to Global Mobile Suppliers (January 2012), there were more than 424 commercial 3G WCDMA (Wideband Code Division Multiple Access) operators operating in 165 countries, who control over 822.4 million clients. [4]

Long Term Evolution or LTE is the next generation of 3G network technology. So, it can be called 4G cellular. A key characteristics of LTE is: all IP system. Main characteristics of the 4 cellular network:

- Downlink data rates up to100 Mbps
- Uplink peak data rates up to 50 Mbps
- Capacity increased to include at least 200 active users per cell in 5MHz channel bandwidth and at least 400 active users in larger channels
- Flexible bandwidth allocation ranging from below 5MHz up to 20 MHz in cell
- Coverage support of cell ranges up to 5 km with full performance and 30 km with lower performance, and 100 km with degraded performance
- Support for mobility users moving at speed up to 350-500 km/h [4]

The disadvantage of the network is that it works on different frequencies in different countries. That is why some mobile devices like smartphones cannot work in other countries. For example, in Europe 4G works in this frequencies: 700, 800, 900, 1800, 2600 MHz (bands 3, 7, 20), but in In North America 700, 750, 800, 850, 1900, 1700/2100 (AWS), 2300 (WCS) 2500 and 2600 MHz (Rogers Communications, Bell Canada) are used (bands 2, 4, 5, 7, 12, 13, 17, 25, 26, 30, 41). [7]

4G network is widely used in Estonia. In March 2016, Estonian mobile operator TELE2 started to offer clients new service as 4,5G network with data rate up to 375 Mbps and started to update its network for data rate up to 450-600 Mbps. [9]

1.2.2 4,5G network

Huawei company has introduced newer cellular network concept in October 2014. It is called 4.5G or LTE-Advanced Pro. The main characteristics of this cellular network are: data rate up to 1Gbps, capacity increased to include 100 000 connections. [8]

1.2.3 5G network

The fifth generation of cellular network is called 5G and it will be the next standard in mobile communication in 2020. The main characteristics of the future network are: bandwidth up to 10 Gbps, low response time and less power for data transmission. It means, that it would be possible to load a video in 4K format very fast. Telemedicine applications will be possible to realise in practic. [10]

5G network will support 1 million connections per square kilometer. Technical requirements and methods will be defined over 2016-2017 and technical proposals and recommendations will be accepted and developed in 2018/2019. „*The advantage of using higher frequency spectrum is greater bandwidth. But, the cost of deep and wide-area network coverage is too high, so legacy low-frequency networks must coexist with 5G for the long-term to make up for a lack of coverage.*“ [8]

The first 5G network tests in Europe were made in Estonia by Ericsson, Telia and Intel companies. During European Digital Summit, which took place at the end of September

2017, was shown a construction excavator, which was remotely controlled via 5G network. Also, mobile operator Telia and cruise ship company Tallink have tested 5G network for passengers on Silja Europa passenger ship. [11]

1.2.4 Cellular network in healthcare

Estonia is a small high technology country, with relatively high-level healthcare solutions: (I) Every hospital has a Hospital Information System, (II) All country is covered by 4G network according to local cellular network providers Telia, Elisa and Tele2; (III) Every citizen has an ID card as a local passport. The benefits of ID card are: fast access to governmental services, medical services at hospitals and prescriptions on pharmacy.

In order to facilitate mammographical examinations even in rural areas in Estonia here is a mammo bus, operated by Tartu University Hospital. According to schedule it works on certain days in different provinces. Mammo bus has a mobile cabinet for women, who want to check their breasts. [39]

Mammo bus is connected with Hospital Information System. When patient registers for the screening, all needed data is stored in the computer of technician. After the screening the digital x-ray photo will be sent to Estonian Healthcare Photo Bank via 4G network. In different hospitals doctors can discuss this photo with the patient. There are two antennas from Telia and Elisa for providing a strong 4G signal. Because of these antennas the 4G signal is good in the different places of the country. [12].

Another interesting medical device is used in ambulances in Estonia.

The device is called Corpuls3. It has 3 devices in one: monitoring unit, patient box and defibrillator. Patient box has different sensors: 12 lead diagnostic ECG, HR, BR, NIBP, CO_2, 4xIBP, 2xTEMP, SpO_2, PP, PI, SpCO, SpMet and SpHb. While ambulance is going to the hospital all vital signals are possible to send via 3G network to the hospital. All data is possible to see in the browser of the computer. The workflow of the device is possible shown in (Figure 2). According to the manufacturer web page, the device is could be used in emergency medical service; for military use in terrain, sandstorm, in deep snow; in air rescue and in the hospital. [13]

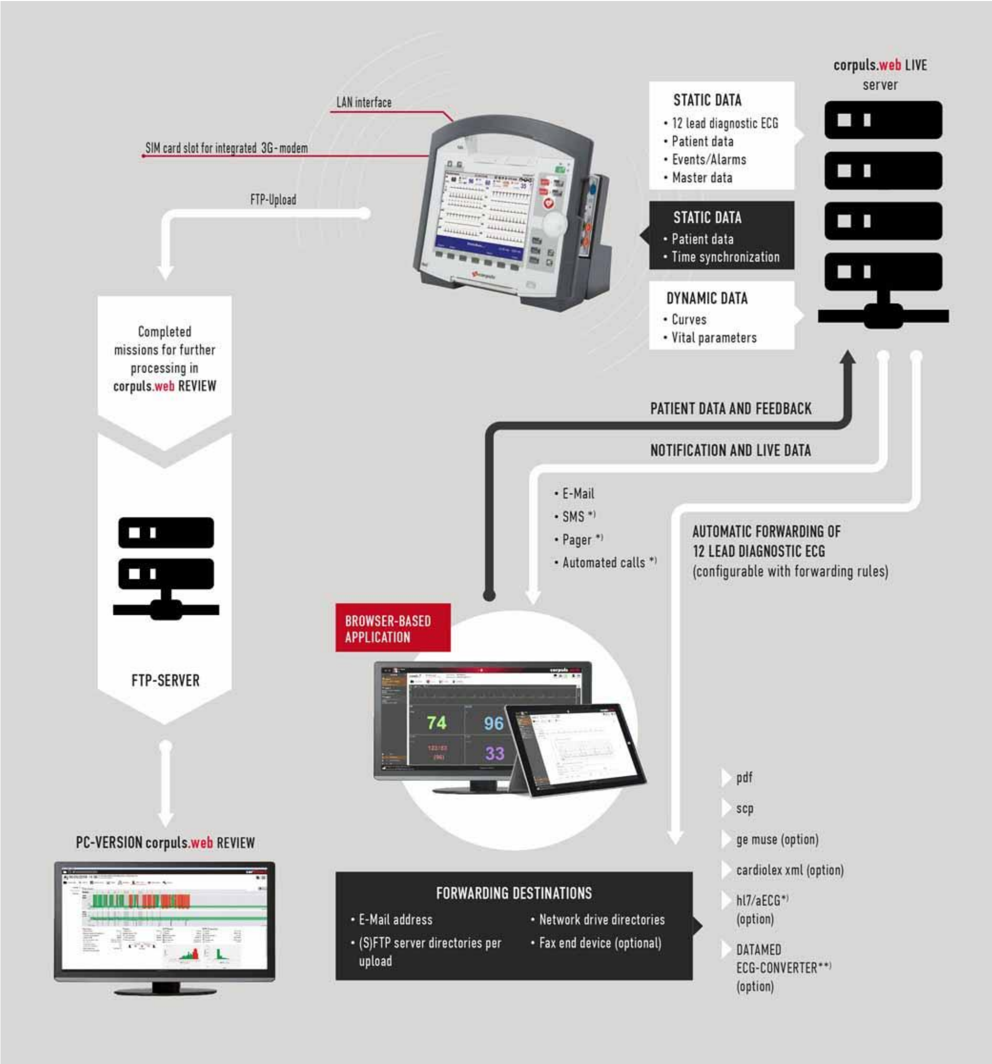


Figure 2. Workflow of the Corpuls3 medical device [13]

In the near future we will have more advanced networks. Ericsson and Imaginalis are working together to create new 5G medical devices. The main idea is to improve remote diagnosis by updating the network. President of the company Imaginalis told: "*With 5G wireless connection, the entire workflow could become very easy and intuitive. That could make it possible to perform a pre-planned surgery by an expert surgeon in Cambridge or Boston, when the system (and patient) is located in another part of the world.*" [14]

1.3 WiMAX

WiMAX is a Worldwide interoperability for Microwave Access (WiMAX). It is a wireless networking standard IEEE 802.16. The main characteristics of this standard are: broadband access up to 50 km for fixed stations, 5-15 km for mobile stations. Secondly, WiMAX can operate between 2GHz and 66 GHz with maximum data rate of 70 Mbps. Furthermore, it is suitable for healthcare, because it can use high bandwidth for transferring high quality medical pictures and provide video conferencing between hospital and patient. [15]

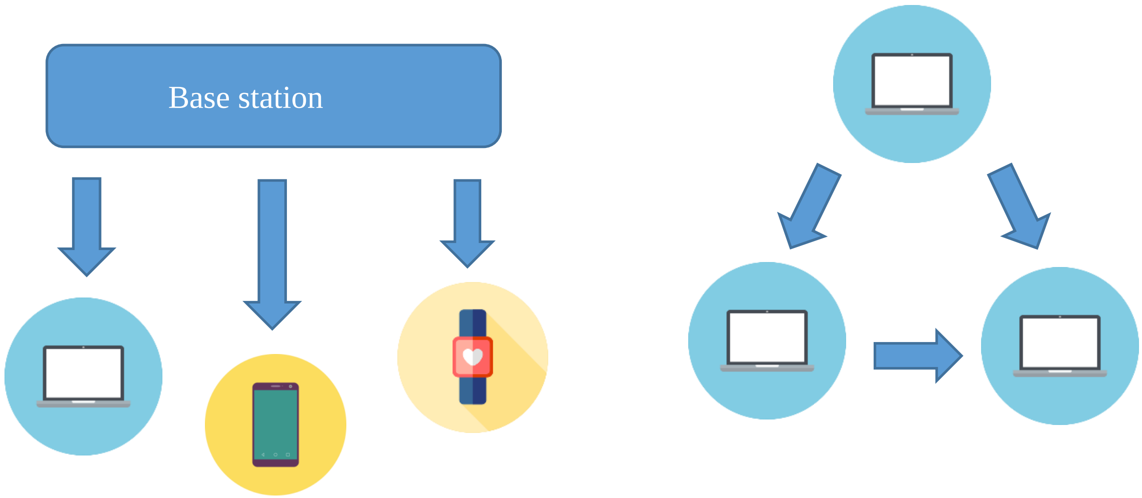
1.3.1 WiMAX network healthcare

Wimax network can be used to connect hospital information system and ambulance car, where economically is not possible to make broadband services. Italy started to use Wimax for syncronising data between ambulances and hospitals from 2008. For the same purposes Wimax started to be used in Taiwan in the Taipei Medical University Hospital, in 2007. It is possible to receive data about patient from ambulance car in real time. [16]

When Macedonia started to develop telemedicine solutions the WIMAX tests were made in 2008. The hospital information system was created. Test video data was sent from ambulance car to the Hospital. Also, the purpose of using of Wimax in Macedonia was to reduce ticket cost and time between patient and doctors. One doctor may work in the capital and another doctor in rural area about 170 km from the capital city. It could be possible to receive analysis and consultation in one hospital. [17]

1.4 WiFi

Wireless Local Area Network or WLAN is the oldest technology standard that has been changed our vision of using wireless networks. IEEE committee named the technology as 802.11 and we know it as WiFi. WiFi had to work in two modes: a) if the base station is present or b) if the base station is absent. In case a) all communications go through the station, which is called an **access point.** If the station is absent, computers may communicate with each other directly. In this case WIFI connection type between devices is called **ad-hoc network**. Figure 3 shows both types of WiFI connection. [2]



(a) (b)

Figure 3 (a) Wireless network with a base station. (b) Ad-hoc network. (Figure was reconstructed and updated for new devices from [2])

The standard received a lot of extensions and revisions like 802.11a/b/g/n/ac. For example, 802.11a operates in the 5GHz band with data rate up to 54Mbps. Other revisions of the standard 802.11b work in the 2,4GHz with data rate up to 5.5 to 11 Mbps. Also, the standard 802.11g works in the same frequency 2,4 GHz, but the data rate increased up to 54 Mbps. [3]

The newer standard 802.11n came in June 2007. It can work on the 2,4GHz or 5GHz frequency with data rate up to 150 Mbps. [4]

Originally WiFi specification included a set of security for privacy and authentication WEP algorithm. Unfortunately, it was not so secure. Then, engineers developed another algorithm, which was called WiFi Protected Access (WPA). WPA made the standard 802.11 more secure. This algorithm is evolving. [3]

Nowadays a lot of hospitals use WiFi connection. According to Tom Carpenter´s book [18], „*Hospitals can benefit from wireless LAN technology in order to have roaming access to patient records as well as pharmacy information. Medical prescriptions can be sent to the hospital pharmacy directly from patient`s rooms, and nurses can give instant digital feedback using PDAs.*“

1.4.1 WiFi network in healthcare

WiFi stations and adapters are relatively cheap. A lot of hospitals have a WiFi connection.

A very interesting medical device is a mobile ultrasound which is called SonoSite iViz from Fujifilm company in (Figure 4).

Figure 4. SonoSite iViz mobile ultrasound (*http://medicaldealer.com/wp-content/uploads/2016/06/fujifilmsonosite.jpg*)

According to manufacturer information, the device is used in crowded places, vehicles where is no extra place. System and transducers were drop tested from 3ft. The tablet has High Resolution display. It means, that the quality of the picture is on high level. It is easy to use. Transducers can be used for different applications: abdominal, cardiology, lung, breast, nerve, vascular and etc. The workflow is available in (Figure 5*).* After the screening, doctor can save the image and send it to the server via WIFI network. [19]

SonoSite iViz ultrasound device can be used in military services, in catastrophical cases and at the hospital.

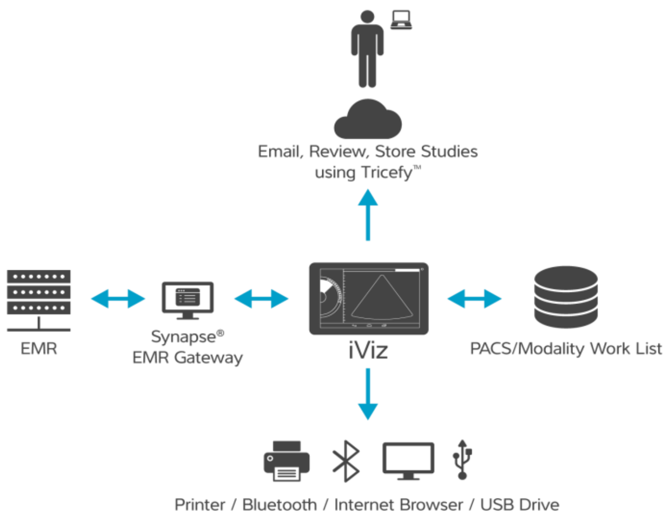


Figure 5. Workflow of mobile ultrasound SonoSite iViz *(https://www.sonosite.com/ products/sonosite-iviz)*

In case patient can not move on his foot, but the X-ray image is needed for the doctor. It is possible to use mobile X-ray device like Siemens Mobilett XP in (Figure 6). These devices are designed for clinical use in: intensive care units, cardiac care units, neonatal intensive care units, operating rooms, emrgency rooms. [20]

Figure 6. Siemens Mobilett XP mobile X-Ray device.

The same device is used in Tartu University Hospital for the same purposes. The digital image is stored in the embedded pc. Mobile X-ray device has Windows operating system, wired and WiFi adapter. It is possible to send the image via WiFi to PACS system, but the wired connection is used for the security reasons. [12]

1.5 Bluetooth

The technology got its name from King Harald Blätand (bluetooth), Denmark. He is known for his achievements. In the X century he united Denmark and Norway under Christianity. Ericsson made the first research of a wireless technology to link mobile phones and accessories in 1994. Then, Ericsson formed the Bluetooth Special Interest Group (Bluetooth SIG) so the other companies could use and promote the standard. It is known, that these companies were: Ericsson, IBM, Intel, Nokia, Toshiba. Later other companies were included in Bluetooth SIG: 3Com, Microsoft, Motorola, Agere. Nowadays, Bluetooth SIG has more than 2000 members, who are interested in developing, promoting and improving the Bluetooth standard. [21]

In 199X the IEEE 802.15 Working GROUP for Wireless Personal Area Networks (WPAN) was formed to develop standards for short range wireless PANs. Bluetooth is a communication network within a small area connection, where all devices are owned by one person or a family, organisation. Devices in Personal Area Network may include portable and mobile devices, personal computers PCs, cell phones and others. It is known, that the standard IEEE 802.15.1 as Bluetooth was approved in 2002. [3]

Bluetooth operates in the 2,4 GHz range and include low power consumption and low cost. Bluetooth can be divided into two types: (1) The original standard specified a Basic Rate (BR) system, and (2) the current version 4.0 of the standard (2011y), which indicates support for a Low Energy System. The BR system in bluetooth supports data rates up to 721,2 kbps, newer standards support up to 2,1 Mbps. High speed operations can be supported up to 24 Mbps using an 802.11 waveform. [4]

Also, bluetooth connections can be defined as point to point or point to multipoint. For point-to-point connections, the physical channel is shared between 2 devices. For point-to-multipoint connections, the physical channel is shared between 2 and more devices.[4]

Bruce Hopkins and Ranjith Antony, in their book «Bluetooth for Java», tell us that a personal area network can be a *piconet* or a *scatternet*. A Bluetooth *piconet* has a single master and up to seven slaves (Figure 7). The master device is the one that initiates the connection. The device, that accepts the connection becomes the slave. These roles are not concrete. If the piconet exists between laptop and phone, the device can be master or slave. [21]

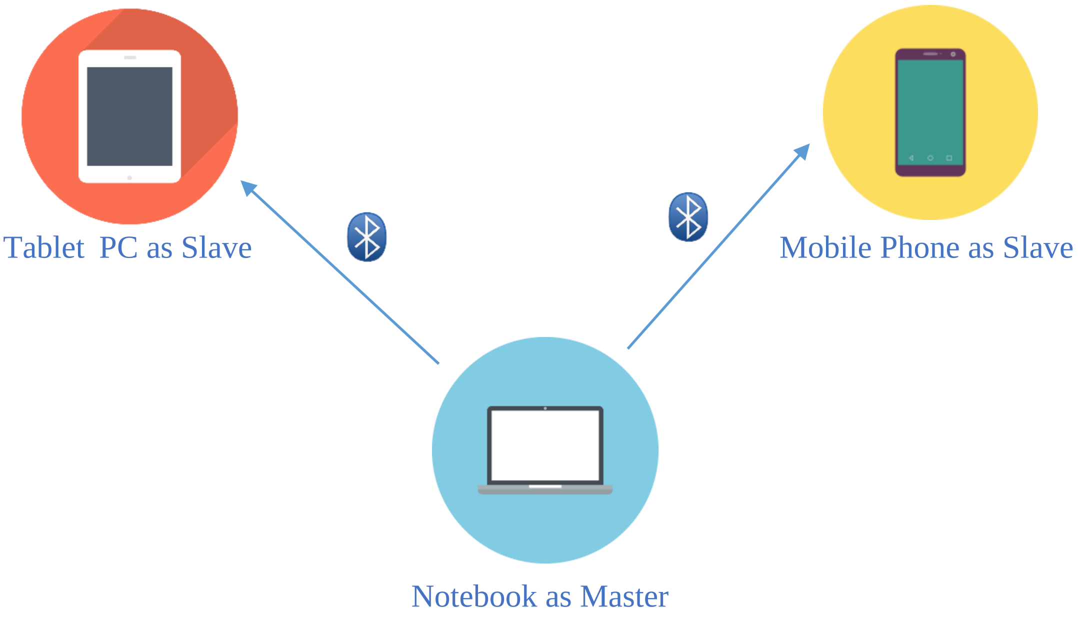


Figure 7. Piconet – the Slaves may connect to the Master *(Figure was reconstructed and updated for new devices from* [21]*)*

If a Bluetooth device, as a slave in piconet connection, is multipoint capable, then a new Bluetooth device can create a piconet with that slave. Then, this wireless personal area network will be called *scatternet* in (Figure 8*)*. [21]

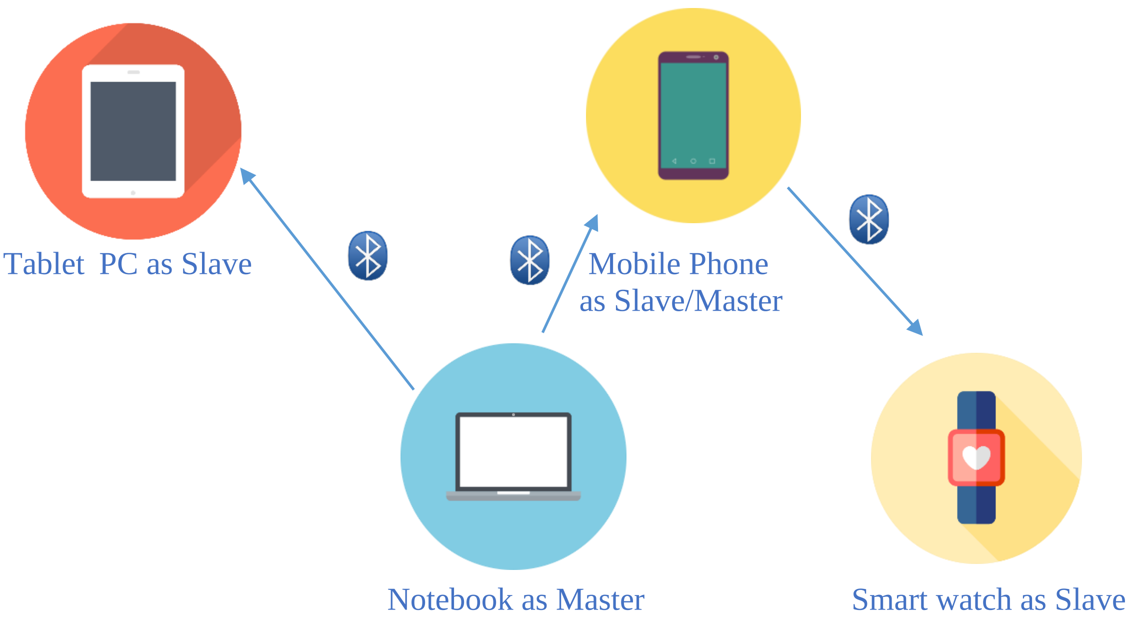


Figure 8. Scatternet- 1 Slave from one piconet is a master in another piconet *(Figure was reconstructed and updated for new devices from* [21]*)*

According to IEEE standards, the Bluetooth devices can communicate in the range from 1 to 100 meters.

A real example of using Bluetooth devices in everyday life as bio signals measuring and storing for a personal healthy lifestyle monitoring can be shown in (Figure 9*)*. As mobile phone has an access to different applications and different networks, it is possible to use scales and mobile phone to control the weight using Bluetooth. Also, when a person makes sport, Bluetooth headset for music, an application on mobile phone for tracking a sport activity and smart watch for tracking activity and check heart rate, can be utilized. It is possible to check how much steps were made during a day, how effective was the training.

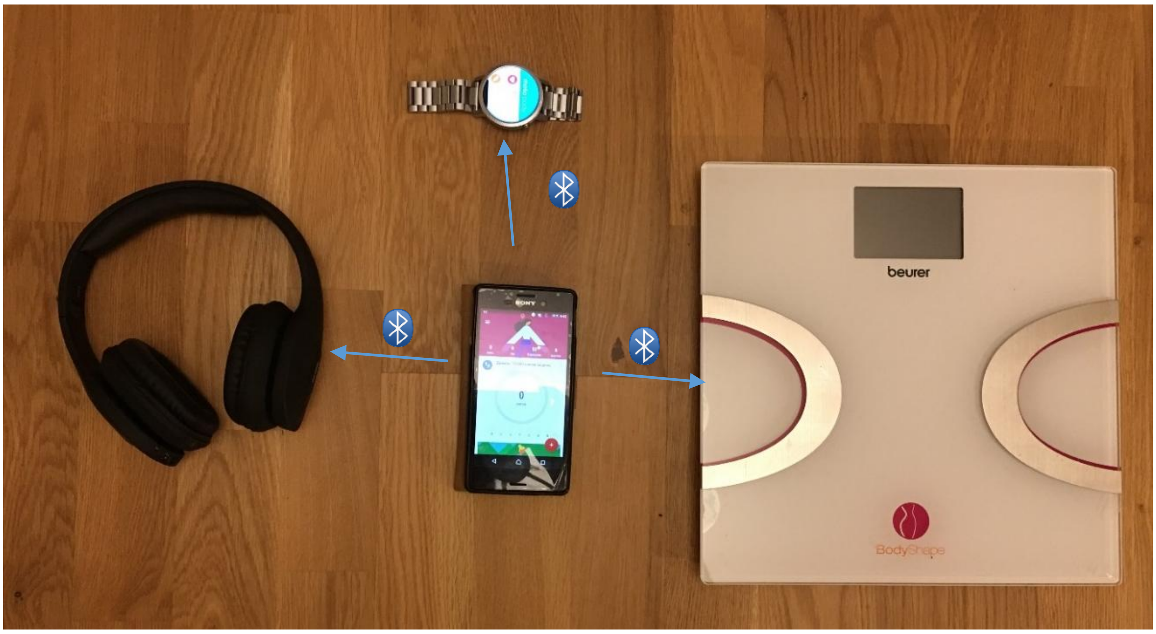


Figure 9. Personal usage of Bluetooth network for monitoring healthy lifestyle.

On the other hand, the Bluetooth has its disadvantages, like connection loss in 1 meter, as an example from real life, smart watch and mobile phone. Also, this connection reduces battery life of the devices.

1.5.1 Bluetooth v 4.2

Nowadays, actual Bluetooth protocol specification is Bluetooth version 4.2, which was introduced in December 2014. It has updated Low Energy protocol. [22]

Bluetooth v4.2 supports about 1 Mbps and possible to use in range of 50 m outdoor and up to 10 m indoor. [23]

Bluetooth v4.2 is possible to find in mobile device like Iphone 6s.

1.5.2 Bluetooth v5.0

Bluetooth SIG has introduced the newest specification of Bluetooth Low Energy v5.0 in December 2016. [24]

Bluetooth v5.0 has new features: increased range for low energy home coverage up to four times of v4.2, increased bandwidth up to two times of v4.2. [24]

Bluetooth v5.0 supports bandwidth about 2 Mbps and supports range about 200 m outdoor and 40 m indoor. [23]

It is a latest standard of Bluetooth and it means that there are not so many devices that has a new hardware. New protocol is used in Samsung Galaxy S8, which was introduced in March 2017. Also, it is used in Iphone 8 and Iphone X, that were introduced in September 2017.

1.5.3 Bluetooth network usage in healthcare

A lot of people have a chronic disease like diabetes. It is a very serious health problem as the diabetic person must live a healthy lifestyle, monitor his blood glucose level and have a food diary.

Nurses and doctors in Tallinn Children`s Hospital check patient`s blood glucose level and a food diary for 2 weeks and put that information to special software. They teach a patient how to live with the disease, how to eat, how to calculate the food energy and how to make insulin injections. Nurses copy the information from the insulin pumps or glucometers. At the hospital is possible to buy different glucometers with Bluetooth connection like: *MyStar Plus* glucometer from Sanofi (Figure 10) and *CareSens N Premier* from I-Sens (Figure 11).

MyStar Plus is a blood glucose monitor system, that is possible to connect to mobile phone via Bluetooth and save information on the Android or IOS application. Mobile application can store and show blood glucose, insulin and carb data. [25]

CareSens N Premier is a medical device for blood glucose monitoring, that is possible to connect to mobile phone or tablet via Bluetooth and save the information on the Android or IOS application. [26]

Figure 10. MyStar blood glucose monitor and mobile application

Figure 11. CareSens N blood glucose monitor.

There is another medical device, which is possible to use in a family doctor cabinet. The device is called *Cube-S* from Eurolyser (Figure 12). It is a small point-of-care analyser. The device can deliver results in minutes, rather than days from a blood droplet. *Cube-S* can connected to PC via USB or to android based Tablet via Bluetooth. Good solution for ehealth. [27]

Figure 12. Cube-S small size laboratory.

Cube –S is a pocket size laboratory. „*The CUBE-S is of particular interest to internists, cardiologists, diabetologists and gynaecologists who want test results in a matter of minutes, not days. This instrument allows the physician to offer a patient an immediate diagnosis during a single visit and it facilitates the immediate and precise management of ongoing therapies.“* [28]

Shimmer Sensing company made an interesting sensor device which is possible to use for healthcare solutions and teaching materials. It has also Bluetooth connection to different devices.

1.5.3.1 Shimmer Sensor

The Shimmer technology was originally established in 2006 under INTEL licence. But the company named «Shimmer Sensing» was founded in 2008 with the aim to develop wearable sensors and software solutions. [31]

From the Shimmers`s main web page it is possible to find out, that Shimmer created a very small, slim wearable wireless sensor hardware which is called «Shimmer3». It has 24MHz MSP430 CPU, 2Gb SD card memory, and plastic case. The Integrated Li-ion battery management. It has small form factor and light weight, low power consumption. There is also integrated motion processor for on-board 3D orientation calculation. One wearable sensor hardware has integrated accelerometer, gyroscope, magnetometer, and altimeter, each with selectable range (Figure 13*)*. The dimensions of this sensor are: 51mm x 34mm x 14mm. Shimmer3 is designed for wearable and remote sensing applications. Usually, Shimmer3 is used in:

- Human Health Monitoring
- Daily Living Activities
- Connected Health Solutions
- Sports Science

Figure 13. Shimmer3 wearable sensor
(*http://www.shimmersensing.com/assets/images/content/product_images/930/imu_sensor-shimmer3-front-and-side-view__small.jpg*)

According to the company information [31] "*Shimmer's wearable sensor platform and equipment allows for simple and effective biophysical and kinematic data capture in real-time for a wide range of application areas*". Shimmer's wireless sensor technology helps to collect high quality scientifically reliable biosignals for helping **researchers** and **academics** in their scientific and developing work.

1.6 Network security in healthcare

For software based control of therapies and patient information, which is stored in the medical system wireless internet connection and simple internet connection is necessary. This makes medical devices vulnerable to cyber-attacks. [29]

Hackers can receive access to a hospital computer, a hospital network, expensive medical device to deliver a virus or malicious software. As an example, hacker can send a virus via email that could infect nurse`s computer. The hospital antivirus protection system can immediately delete the virus, but the medical devices are not so nicely defended. A virus from nurses`s computer may infect devices like: radiological machines, blood gas analysers and outdated devices, which work under older operating systems like Windows 2000 or Windows XP. [29]

There are some easy rules to prevent that problems:

- Build a defendable network environment in hospital. Medical devices, which are in hospital network are should have static ip
- Make a whitelist of applications and devices
- Implement secure password (14 symbols), do not use standard password from the box for the devices
- Do not use medical network for anything else like social networks or news. [29]

1.7 Advantages and disadvantages of wireless networks

There are a lot of wireless technnologies that are possible to use in healthcare. They have own advantages like cost, data rate transmition and disadvantages such as cost, distance of use, connection loss, battery life decreasing.

The wireless technology standards can be divided into three main groups based on geographic range: Wireless Personal Area Networks (WPAN), Wireless Local Area networks (WLAN), Wireless Metropolitan Area Networks (WMAN). For example, WPANs work up to 10 metres, WLANs are discoverable from hundreds of meters up to a few kilometer. WMANs are discoverable up to hundred kilometers (Figure 14*)*. [4]

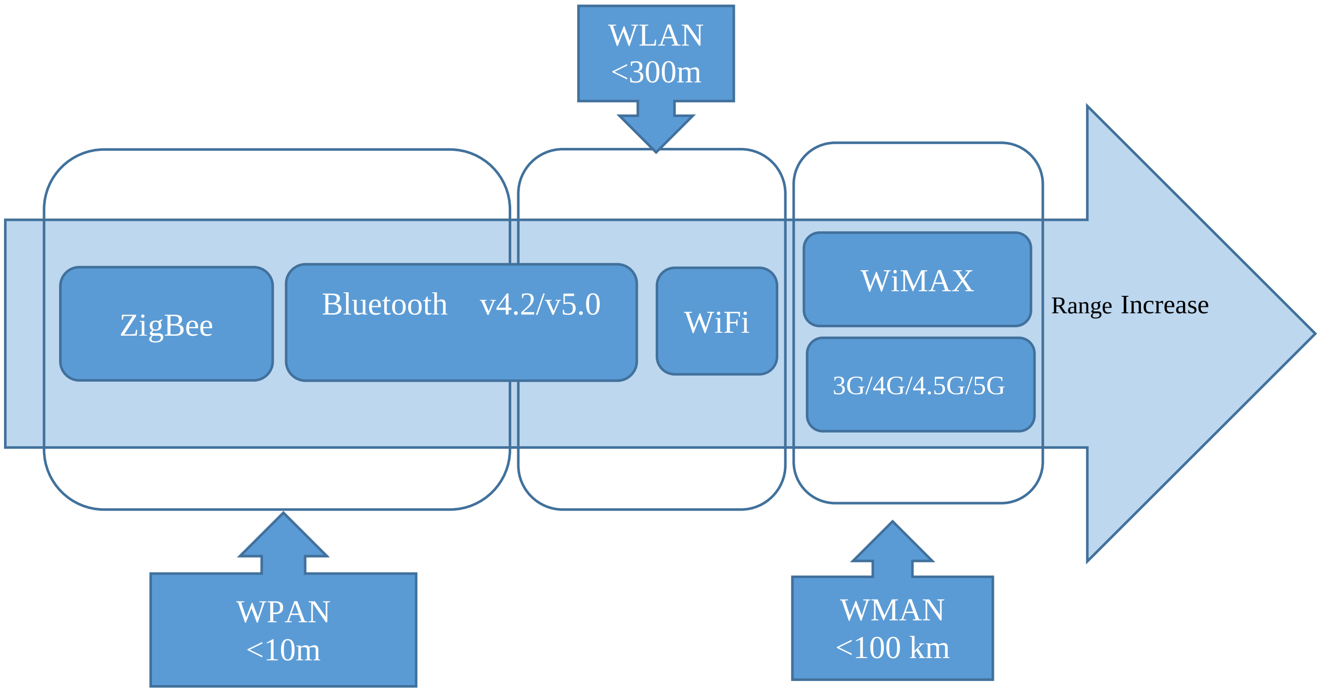


Figure 14. Wireless Network Technologies. Reproduced from [4] and was updated according recent network standards in November 2017.

The wireless network technologies are different and sometimes it is hard to find out what technology is possible to use in own project in healthcare. A comprehensive and comparative table the existing network technologies are given in (Appendix 1, Table 1*)* with some advantages and disadvantages of the networks included. In addition, author thinks, that this table will help to understand what kind of technology is possible to choose and use in special projects in healthcare.

Nowadays, smart watches and other wearable electronics are very popular. Biosignals collected from sensors can be transmitted from a device to phone, using for example WiFi network. According to the android developer specifications link *https://developer.android.com* it is possible to receive access to the device sensors programmatically and call the specific procedures for receiving biological signals like heart rate or step counts and write specific software that sends the data to our server or Database, which is located in our network. On the other hand, if we want to send data from the medical device of company like General Electric or Siemens, we need to use company`s device and software which is rather expensive.

2 Aim of the work

The aim of the thesis was to create a teaching material for students in the form of a manual for a laboratory work as a teaching material, that explains principles of wireless network technologies in healthcare. The primary students will be those, who are going to take a course of «*Electromagnetic Fields and Waves in Biomedical Engineering*» in Tallinn University of Technology.

The main subgoals of the new laboratory work are:

- give a short overview about the wireless networks in healthcare
- familiriaze with the principles of work of the Shimmer ECG sensor, from Shimmer Sensor Company
- Understand, how to receive biomedical signals from sensor using different software and Bluetooth wireless network
- Understand, how to calibrate the sensor
- Set-up a network connection
- Perform biosignal measurments over the wireless network.

3 Materials and methods.

Different possibilities of wireless networks are available for use in healthcare. For example, 3G/4G,4,5G/5G, WiFi and WiMAX. Healthcare specialists may receive access to patient information anywhere and at any time using healthcare network and systems. Other networks like Bluetooth, ZigBee with wireless sensors give a great possibility for data transmission for medical applications.

The sensor from Shimmer Sensing company will be used in this work as a hardware and it will be connected to a PC and a mobile phone via Bluetooth network for capturing a biosignal in realtime.

3.1 Shimmer`s information and hardware.

3.1.1 Shimmer`s main software: ConsensysBasic and ConsensysPro.

Shimmer developed not only hardware solution as different sensors, but an interesting software solutions for all platforms for different devices like: mobile phone or tablet, PC. The Shimmer sensor can communicate to PC or tablet via Bluetooth wireless network or store data on SD card. Specific software provided by Shimmer is needed for usage. [31]

A flagship advanced software is called *Consensys*. There are two versions of the software: free and paid version. Free is called *ConsensysBasic* and professional is called *ConsensysPRO*. The differences are huge. Pro version of the software cost 199.00 EUR per year for one PC, but the Basic software is possible to use for free. Secondly, ConsensysPro can configure and communicate to multiple (up to 7) shimmer sensors simultaneously, but the ConsesysBasic can only configure and communicate to one sensor. [31] Both versions of the software can

- manage,
- communicate to the sensors,
- update sensor firmware,

- save data to Shimmer sensor,
- save data to PC in different formats like: txt, dat, mat and csv for further analysis,
- stream signals to ConsesysBasic software in real-time, while the data is saving.

In spite of ConsesysBasic is free software, it is possible to stream in real-time and save to file huge amount of signals from person, wearing the Shimmer3 sensor, easily and fast without need of developing a huge software. The simpliest signal streaming from sensor to the ConsensysBasic software via Bluetooth connection could be found (Figure 15).

The software is possible to download from the Shimmer company webpage. ConsensysBasic version 1.4.0 software was tested on Windows 10 Enterprise x64 bit version and Windows 7 x32 bit version.

Figure 15. Simple real-time data stream from Shimmer3 to ConsensysBasic on PC via Bluetooth.

3.1.2 Shimmer`s software: ShimmerCapture android.

According to developers from Shimmer company the shimmer3 sensor is possible to pair via Bluetooth not only with PC. They have developed an application, which is called «ShimmerCapture » for mobile phone or tablet. This software is available for android devices in Google Play Market for free. [32] «*Shimmer Capture is an Android application that can connect a Shimmer device, plot the data received by the sensors and save it in a CSV (Character Separated Values) file*».

It is possible to find only advantages of this solution provided by Shimmer company, because the developers go in time with modern technologies. Person can easily download a software, connect a device via Bluetooth and see the biosignals in realtime, then save it to CSV file, which is possible to send via 4G or WiFi for analysis. The software was tested on Sony Xperia M4 Aqua mobile phone under Android Marshmallow 6.0 operating system (Figure 16).

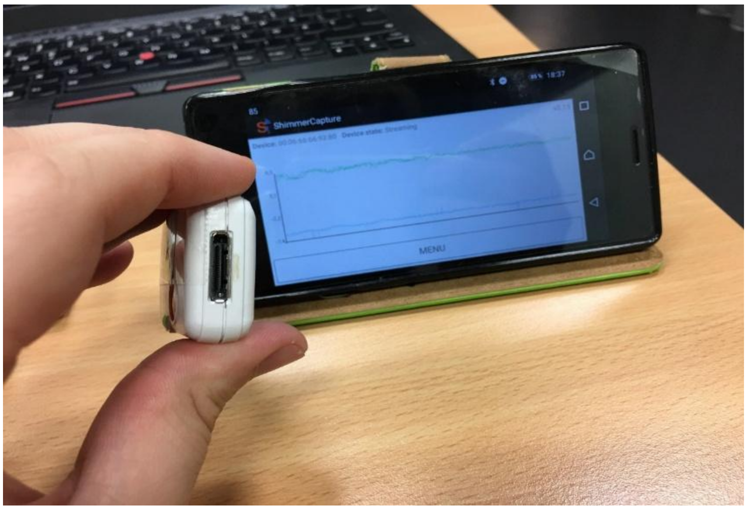


Figure 16. Streaming biosignals from Shimmer3 sensor to android mobile app ShimmerCapture via Bluetooth in real-time.

3.1.3 Shimmer`s software: ShimmerCapture for PC.

It is possible to find additional software from Shimmer web page [33], which is possible to use for free with a PC that uses Linux operating system or Windows operating system. The name of the software is ShimmerCapture. It was written in C# language. And provide same functions as android mobile version, which was discussed earlier:

- Connect the Shimmer3 sensor via Bluetooth
- Stream signals in real-time
- Save data to a CSV file on PC.

The software was tested on notebook with Windows 10 Enterprise x64 bit version. The software works correctly: easy connection via bluetooth to sensor, stream biosignals to software in real-time and possible to save data to PC. Screenshot of the working programm in (Figure 17*)*.

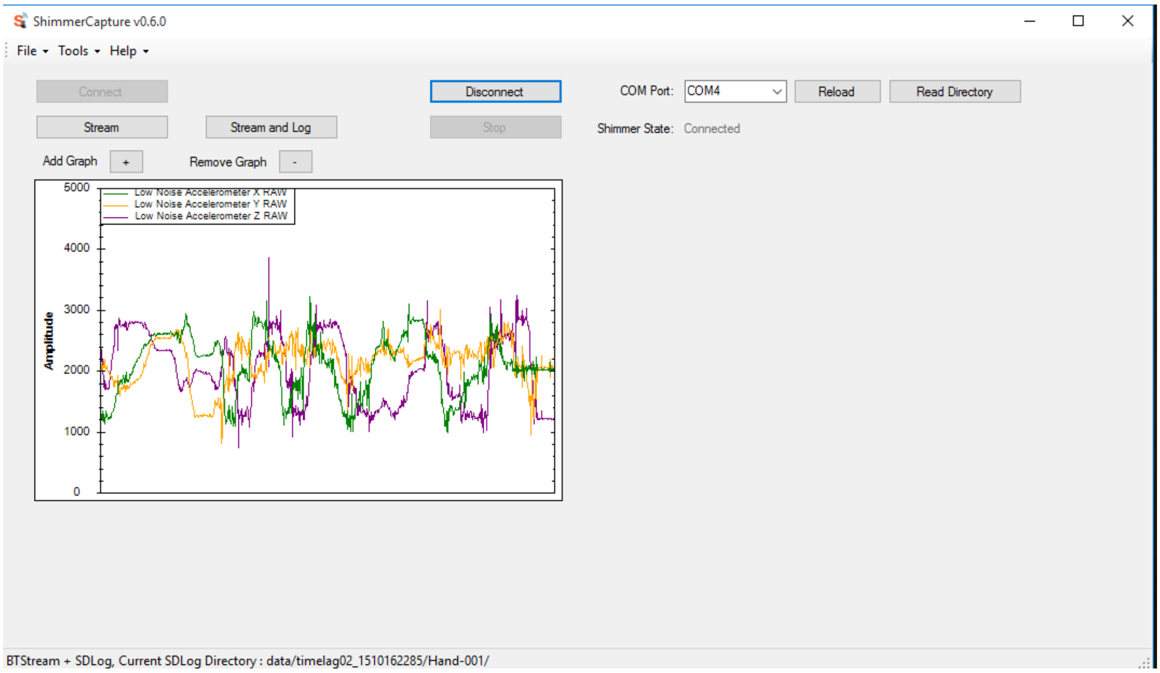


Figure 17. ShimmerCapture for PC, streaming signals from sensor in real-time.

3.1.4 Shimmer`s software: Matlab driver

According to Shimmer company webpage, the shimmer3 sensor can be connected to Matlab software for research. Developers have developed special Matlab driver, which is possible to download from Shimmer company webpage [34]. The main idea of this solution is to stream biosignals from shimmer3 sensor directly to Matlab without using other software solutions. But the developers did not tell us that we need to have a Matlab installed on our PC.

This solution was tested in notebook with windows 10 Enterprise x64 bit version, with Matlab R2014b installed. The result was good enough, like ShimmerCapture for android and ShimmerCaprure for PC. In Matlab sytem the main working directory was changed to Shimmer Matlab Driver folder. The example function «plotandwriteexample» was used to receive results. Then, different input parameters were used to start the function: the number of Bluetooth port connected with sensor as first parameter, streaming time in seconds as second parameter, and filename.dat as third parameter. In a few seconds the Matlab started to connect to sensor via Bluetooth and plot data to Matlab window in real-time. After 30 seconds, programm stopped and the file with filename.dat was created in PC. The screenshot of working Matlab test solution is possible to see in (Figure 18*)*.

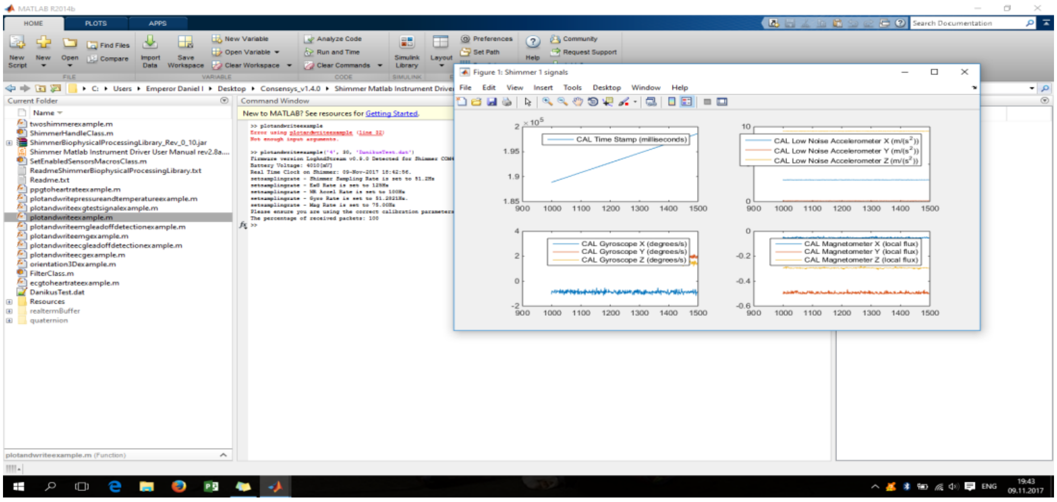


Figure 18. Matlab receives biosignals from Shimmer3 sensor in real-time.

3.1.5 Shimmer`s software: sensor calibration tool

It is known that all measurement instrumentations are calibrated on the factory. When we are using a measurement instrument it is needed to be calibrated for receiving accu rate information of our measurement.

The engineers from Shimmer company have made not only a wearable sensor hardware and great software for streaming and saving biosignals from sensor to file, but they have created an interesting and easy calibration software for Shimmer3 sensors. The software is called «Shimmer 9DOF Calibration», which is possible to find on the company web page and use it for free of charge. Engineers tell us, that «*The Shimmer 9DOF Calibration Application v1.0 provides an automated procedure for calculating the calibration parameters for Shimmer's integrated tri-axial accelerometer, and the 9DoF module's Gyro and Magnetometer sensors. The calibration parameters can be stored to the Shimmer memory and recalled by other applications to provide calibrated sensor data.*». [35]. Furthermore, using this application is possible to check the accuracy and quality of calibrated values.

The Calibration software was tested on notebook with windows 10 Enterprise x64 bit version and Shimmer3 sensor. It works good as written in the manufacturer web page. Also, a screenshot of calibration application is available in (Figure 19*)*.

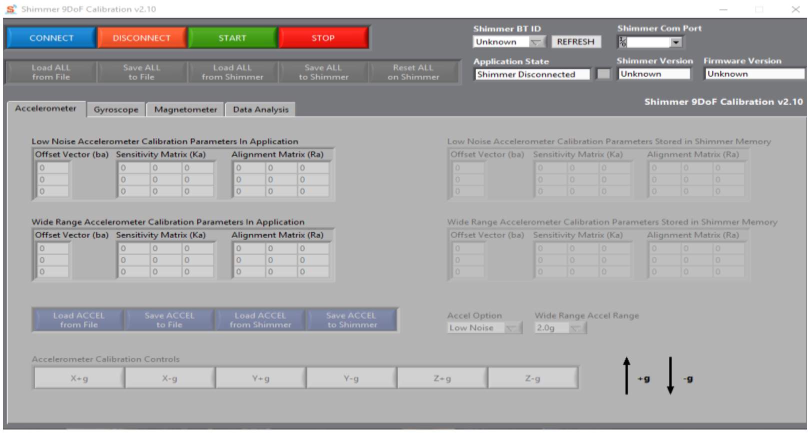


Figure 19. Main window of Shimmer 9DOF Calibration application.

3.1.6 Shimmer`s software: analysis

The real solutions, of using Bluetooth wireless network, from Shimmer company was analyzed. Engineers from the Shimmer company have made a great Shimmer3 wearable sensor hardware for measuring biomedical signals. Also, they have created different nice software solutions for different platforms like: PC linux/windows, Mobile android device, Matlab research software integration and ConsensysBasic/Pro solution.

The main goals of these software solutions are:

- Connect to Shimmer3 sensor via Bluetooth
- Stream biosignals from sensor to the device and make graphical view of the received data
- Save the result in different file formats on device

On the other hand, there are some differences in software solutions ConsensysBasic and ConsesysPro:

- Basic version is free of charge, Pro version prize is 199.00 EUR/year

- Basic version can communicate with 1 sensor online
- Pro version can communicate up to 7 devices simultaneously
- Both versions can manage, plot streamed signals in 1 graph and save data to files.

Furthermore, Shimmer Sensing Company has announced a calibration application for the Shimmer3 sensors for free of charge.

In spite of the fact that a lot of engineers and software developers created great solutions, these solutions have small weaknesses, that makes the preparation for the laboratory work a little harder. During the work different software was tested and the solution comparison was made (Appendix 2, Table 2).

Based on our background research, the final decision was made that since the Matlab has a lot of examples, as freeware it is appropriate to create one new Matlab function as independent solution for the teaching material.

Shimmer3 wearable sensor is a very nice example of a device that will be used in practical teaching material. The software solutions provided by Shimmer company to pair the shimmer3 sensor and pc or mobile are very professional, user friendly and have intuitive interface, which is suitable for students. In addition, the calibration application will be used in laboratory work as a great example of how modern devices are calibrated using software.

3.2 User developed Matlab function as a platform for laboratory work

After the research of different solutions of Shimmer software, it was found that they cannot visualise the magnitude vector of accelerometer and cannot show the heart rate as a number in a real time.

According to Shimmer company, it is possible to use the sample code of their software and it is possible to make changes according to the need.

It was needed to create the single function, that can show the accelerometer magnitude vector, temperature of the sensor, ECG signal and heart rate in a real time. Then, it could save the data, captured from the sensor for the further calculations, in a file.

The structure of the Matlab sample functions was analysed. When the source code was understood and tested, the single function *«GetSignalsFromSensorAndSaveToFile(comPort, captureDuration, fileName1, filename2)»* that contains the signals from ECG sensor, Pressure sensor, Accelerometer sensor was created.

Heart rate calculation from ECG in Matlab needs the *«ShimmerBiophysicalProcessingLibrary_Rev_X_Y.jar»* Java library. It is needed to copy that file in the directory of Matlab: *«C:\Program\Files\MATLAB\R2013b\java\jar»*. Then, it was needed to show 2 paths simultaneously at the beginning of the function:

- addpath('./Resources/') - directory that contains f(x) and where to save file
- javaaddpath('C:\Users\DANIEL\Desktop\ShimmerMatlab\Shimmer Matlab Instrument Driver v2.8\ShimmerBiophysicalProcessingLibrary_Rev_0_10.jar'); - link to the java library location, that contains calculation methods for heart rate calculation.

According to samples, the lowpass-, highpass- and bandstop filters were declared for filtering ECG signal «LL-RA». The same signal is streaming to the plot in a real time and used in heart rate calculation.

It was needed to setup the settings for the java library. The frequency 512 Hz of samples was chosen as a new variable and sent to the java library as a parameter:

fs=512;
ECG2HR = com.shimmerresearch.biophysicalprocessing.ECGtoHRAdaptive(fs);

The new variable «newheartRate» was created. It is a simple number, that we want to receive from java method. Java method has special algorithm, that can calculate the heart rate from input parameters. As an inputs were used: ECG filtered signal and timestamp signal. The variable was put in the console, for real time data analysis. Heart rate, temestamp in ms and filtered ECG LL-RA signal will be saved in file *filename2*.

The accelerometer sensor shows three signals: X, Y and Z. These signals will be saved to the file *filename1* while they are streaming.

According to the book «An Engineer`s guide to Matlab with application from Mechanical, Aerospace, Electrical, and Civil Engineering» [36] :

$$«\textit{Vector } \boldsymbol{a}=a_1\boldsymbol{i} + a_2\boldsymbol{j} + a_3\boldsymbol{k} \tag{1}$$

Its dot product is defined as

$$\boldsymbol{a} \cdot \boldsymbol{a} = a_1^2 + a_2^2 + a_3^2 \tag{2}$$

and its magnitude is obtained from

$$a=\backslash a\backslash=\sqrt{\boldsymbol{a} \cdot \boldsymbol{a}} = \sqrt{a_1^2 + a_2^2 + a_3^2}» \tag{3}$$

Matlab is working with matrixes and vectors and it is needed to calculate and plot every element of 3 signal vectors **X**, **Y**, **Z,** that is why a «.» must be put after each signal variable. The formula (3) will be transformed for using in our function «*GetSignalsFromSensorAndSaveToFile*» will be with «.»:

$$\text{Accelerometer Magnitude vector } \mathbf{A} = \sqrt{(\boldsymbol{X}.^2 + \boldsymbol{Y}.^2 + \boldsymbol{Z}.^2)} \tag{4}$$

The signal vectors **X**, **Y**, **Z** will be captured by our function and saved to file. And each element of the magnitude vector will be calculated with formula (4) during the plotting process in real time.

The function source code with commentaries is available in (Appendix 3).
The screenshot of created working solution is shown on a (Figure 20) below.

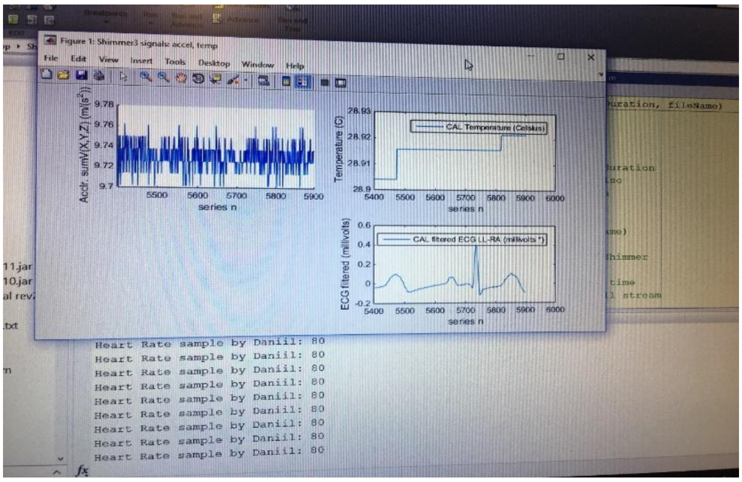


Figure 20. The function «GetSignalsFromSensorAndSaveToFile» is runnung in real time.

3.3 Setting up the laboratory work

The hardware and software, that are needed to be prepared:

- *PC minimum 4Gb Ram, more is preferred*
- *Windows OS 7 or 10*
- *Bluetooth (USB dongle) as a hardware for wireless network*
- *Shimmer3 sensor as a hardware: usb cable, sensor, dock station, calibration stand.* (Figure 21)
- *Java Runtime Environment min 1.8/1.9 or 1.10*
- *Shimmer 9DoF Calibration Tool as a software*
- *Matlab + Shimmer Driver for Matlab as a software with specially created function: «GetSignalsFromSensorAndSaveToFile»*
- *ShimmerCapture for Android as a software as an extra task. (Additional software for those students, who has Android based mobile phone or tablet).*

A laptop with Windows 10 will be used as a test computer for preparation of the teaching material and software testing. Students will use a PC, which is located in Biomedical Engineering Teaching and Research Laboratory, in Tallinn University of Technology, for the laboratory work with Bluetooth wireless network and a medical sensor.

Figure 21. Shimmer Sensor hardware: USB Cable, sensor, dock station, calibration stand.

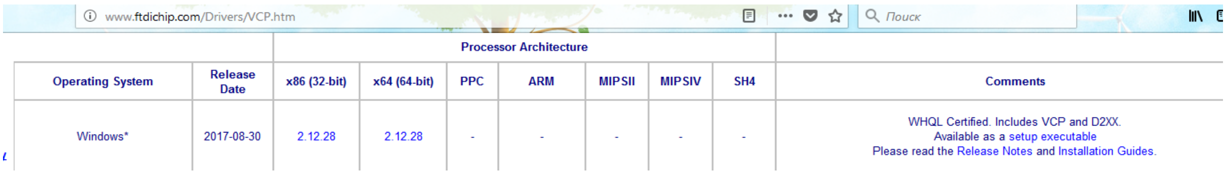
3.3.1 Downloading Java Runtime Environment

Before installing Matlab software, «*JAVA SE 1.8 jre*» or «*JAVA 1.9 SE jre*», or «*JAVA 1.10 SE jre*», needed to be installed from «*ORACLE*» web page: «*http://www.oracle.com/technetwork/java/javase/downloads/jre8-downloads-2133155.html*».

Test laptop has x64 bit Windows OS and PC in a laboratory has x32 bit Windows operating system. The correct version of «*JAVA SE 1.8*» for Windows has been downloaded and installed: for test laptop x64 and PC in a laborratory x86. Java runtime environment will be used by Matlab.

3.3.2 Downloading special drivers for Shimmer platform

Special drivers for connecting PC and sensor device needed to be installed. The PC will see the sensor as a COM port device using that drivers. The recent version could be downloaded from the web page: *«http://www.ftdichip.com/Drivers/VCP.htm»*
(Figure 22)



		Processor Architecture							
Operating System	Release Date	x86 (32-bit)	x64 (64-bit)	PPC	ARM	MIPSII	MIPSIV	SH4	Comments
Windows*	2017-08-30	2.12.28	2.12.28	-	-	-	-	-	WHQL Certified. Includes VCP and D2XX. Available as a setup executable Please read the Release Notes and Installation Guides.

Figure 22. Download the recent drivers for Shimmer hardware.

Open the downloaded file as Administrator and install the drivers.
When installation is finished, switch the Shimmer3 sensor ON (small switch on the corner side of the sensor) and put to the dock station. Then connect the usb cable one side to the dock station and another side to the PC usb. (Figure 23)

Figure 23. Shimmer sensor in dock station, with connected usb cable

3.3.3 Preparing Matlab

Matlab will be used to connect Shimmer3 sensor with the PC, and analyze previous saved data. In Test laptop Matlab version R2014b x64 bit was installed.

To connect Shimmer3 sensor and Matlab, it is needed to download a special **driver** from the official web page: «*https://se.mathworks.com/matlabcentral/fileexchange/43712-shimmer-matlab-instrument-driver*». After a registration, a download link will be available. Then, the driver folder must be copied to Matlab project directory.

Then, it is needed to download and install a special software **Realterm Serial Terminal**. This software will work as a bridge between sensor and Matlab. The link for download is «*https://sourceforge.net/projects/realterm/files/Realterm/2.0.0.57/*»

The PC and sensor have to be connected via Bluetooth, before Matlab will be opened.

- Open Matlab
- Choose a project folder, where the driver is stored
- Run a sample function «*plotandwriteexample('10', 30, 'testdataTEST.dat')*» (Figure 24)

Where the first input is a number of COM port, input 2 is a period of time for display (here is 30s), and input 3 is a name of the file to save data from the sensor to.

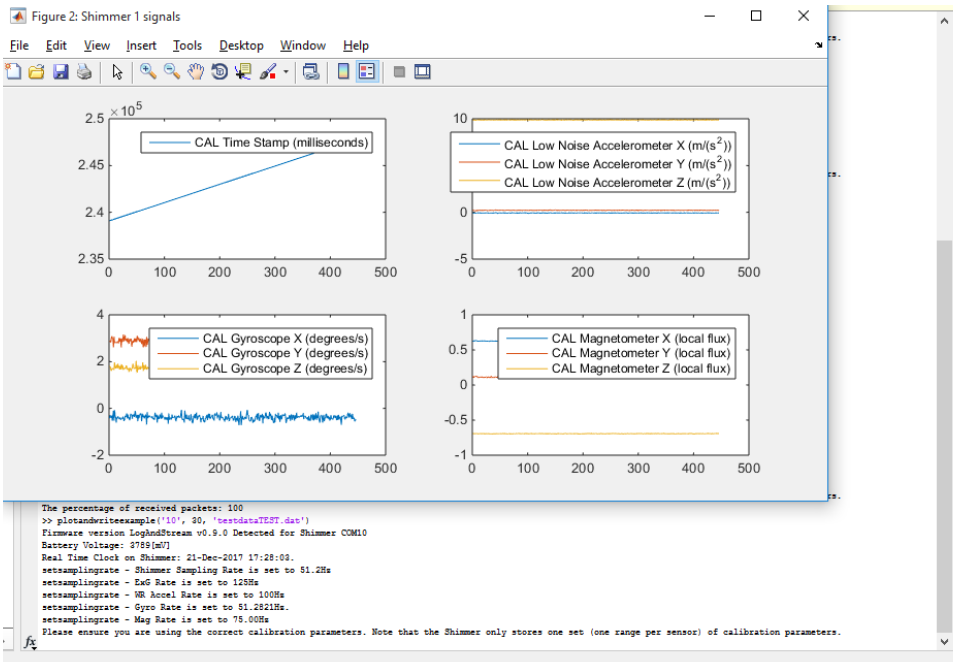


Figure 24. A sample function is running in Matlab

3.3.4 Preparing Shimmer 9DoF Calibration Tool

Shimmer 9Dof calibration tool (Figure 25) is available on official Shimmer web page: «*https://www.shimmersensing.com/products/shimmer-9dof-calibration#download-tab*». Install the software. Then, open the shortcut on the desktop.

Before starting to use the laboratory work, it is needed to prepare Shimmer3 sensor for work. The calibration must be made.

Shimmer3 has 3 sensors integrated, that could be calibrated: **accelerometer, gyroscope** and **magnetometer**.

Shimmer 9DoF calibration tool has 3 different grey tabs for calibration every specific sensor separately for the Shimmer3 device.
Once Shimmer3 device and the software are connected, all three calibration parameters, for every specific sensor, that are stored in the device memory will be shown: (Figure 25)
Application State – shows the status of connection: connected and disconnected.
Dark Blue buttons possible to use only for manipulating with calibration parameters for specific sensor to save/load to/from a file location or device memory.
Data analysis tab shows both calibrated and not calibrated data values, that are streaming from Shimmer device.
Accelerometer Option – enables to choose and option, that will be used analog / low noise accelerometer and digital/wide accelerometer.
Accelerometer Range – before starting a calibration procedure, range could be changed.

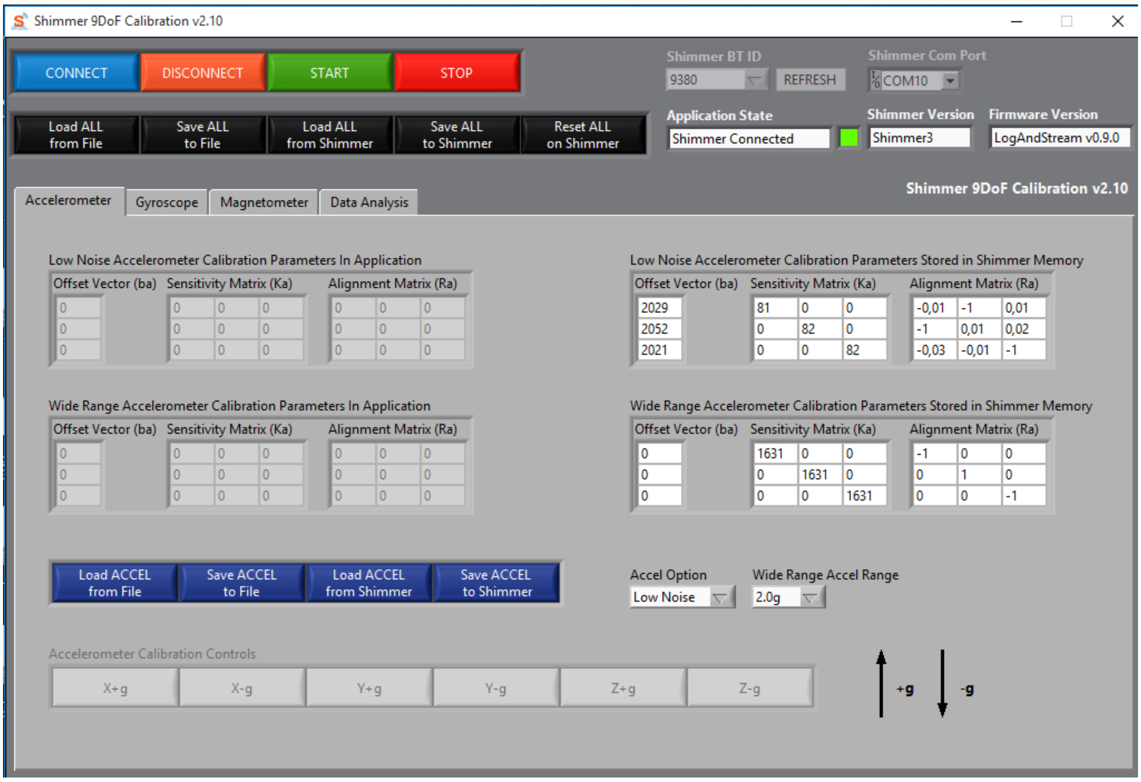


Figure 25. Shimmer 9DoF calibration tool, main window with connected sensor.

«It should be noted that the accuracy of calibration required varies depending on the application of the sensor. Due to the fact the Shimmer is a measurement system and, like all measurement systems it contains a certain amount of noise, the user should not expect to achieve perfect calibration. The user should however try to achieve a level of calibration that meets the needs of their application.-» [36]

The calibrated parameters for accelerometer, gyroscope and magnetometer could be checked in **Data Analysis** tab, only if the new parameters are stored in the memory of the sensor, otherwise default parameters will be displayed on the program window.

Information about the calibration process of the sensors could be found in (Appendix C)

3.3.5 Making control measurements

The hardware and a software were prepared to make some real tests using Matlab with «*GetSignalsFromSensorAndSaveToFile*» function on laptop. As the software installation, testing and development was made on laptop, it is known that Shimmer sensor is connected with a computer. The overall connection scheme will look like (Figure 26).

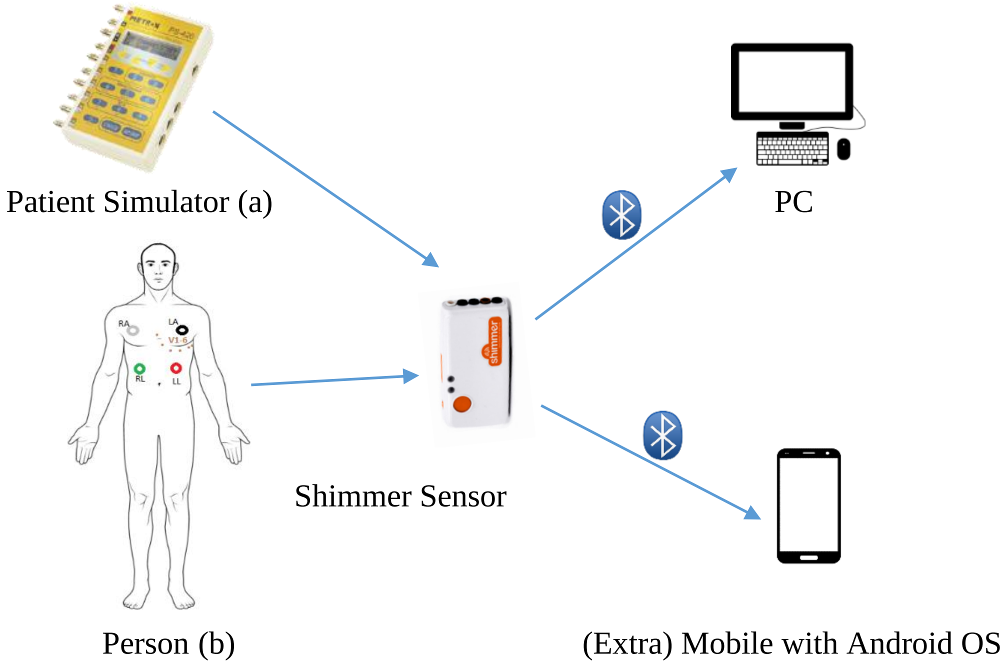


Figure 26. Laboratory work scheme: (a) with patient simulator, (b) with person

Firstly, we need to connect sensor with a patient simulator and run the programe code like 191, which will immitate the patient with ECG signal and heart rate 80bpm (Figure 27*)*.

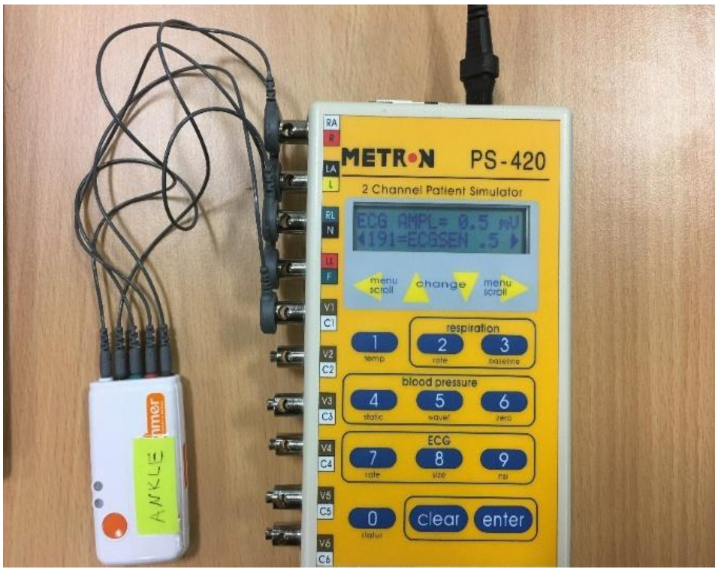


Figure 27. ECG test measurement with Patient Simulator Metron PS-420

Then, we need to run «*GetSignalsFromSensorAndSaveToFile(‘12’,60,’testFile1.dat’, ’testFile2.dat’)*» function in Matlab using input parameters: number of sample ComPort, streaming duration in seconds, file filename1 and file with filename2. It will be better to save files with different names. In the future it will be easier to understand what test measurment was made. As a result, the window with graphs will be seen during 1 minute and the files with measurments will be saved in the working directory (Figure 28*).*

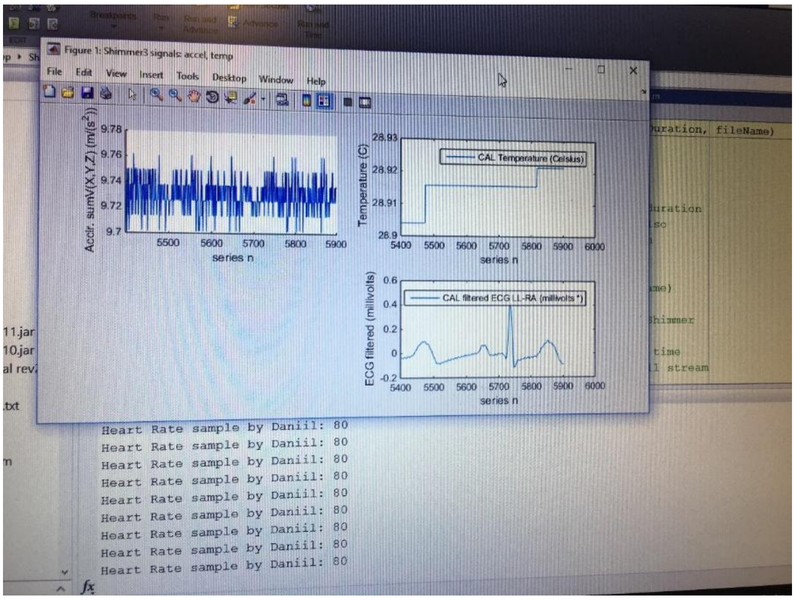


Figure 28. Matlab with a new function for laboratory work.

On the first graph Acclr.SumV(X,Y,Z) is possible to see the real Accelerometer signal, which is represented as Amplitude vector of Accelerometer (X,Y,Z) signals, which is calculated in real time.

On the second Temperature graph, the temperature of the internal pressure sensor could be seen in a real time.

On the third graph ECG (LL-RA), the filtered ECG signal, which was received from the patient simulator, could be seen in a real time.

In the console, the real heart rate, which was calculated from time and ECG signal, could be seen in real time

As we can see, the new function is working with patient monitor. But what about the person? The device has integrated accelerometer. So, it is possible to register different personal activities.

The Shimmer sensor will be connected with a person using ECG wires. 4 measurement sets will be completed with different physical activities like:

- Person is sitting on the chair about 1 minute
- Person is walking about 1 minute
- Person is jumping about 1 minute
- Person is having a rest about 1 minute

3.3.6 Visualisation of the data from the result files

A custom made function was created and opened in Matlab. After importing and analysis of each pair of files, the Workspace is ready for importing other files.

In Matlab menu the command «import data» was pressed and the file was selected for import. Each column from file was saved as Vector with column name in a Workspace window (Figure 29).

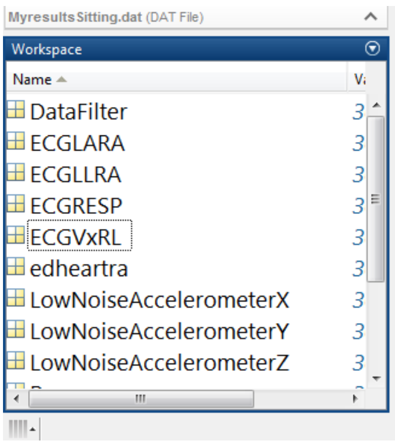


Figure 29. Workspace with data from result files as Vector

It is known, that the magnitude vector of accelerometer was graphically calculated in real time from X, Y, Z signals and it was not saved to file. The magnitude vector of accelerometer as a variable *SumVAccel* could be calculated in Matlab console very easily:

it is needed to use modified formula of finding a magnitude vector **A** in paragraph 4.2. Then, create a command in a console:

fx>> *SumVaccel= sqrt(LowNoiseAccelerometerX.^2 + LowNoiseAccelerometerY.^2+ LowNoiseAccelerometerZ.^2)*

All data was saved into a Workspace of Matlab. We need to show the results of each activity set as a result table. Firstly, we will create a graphical representation of all our signals, that we have received from files.

a) Two variables (Timestamp and ECGLLRA) were chosen from Workspace

b) In Matlab menu the «PLOTS» tab was pressed and «plot» button was pressed (Figure 30)

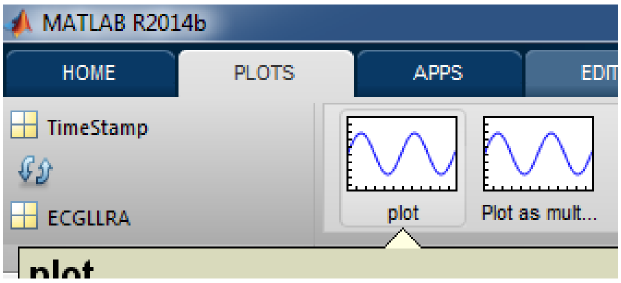


Figure 30. Plotting of 2 variables

The window with figure was created (Figure 31). As a figure is schematic it will be modified.

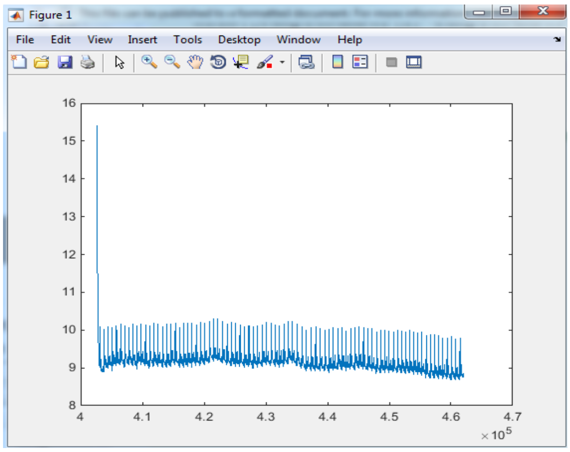


Figure 31. Timestamp and ECGLLRA graphical representation in Matlab.

In figure window, in «View tab» it is needed to put a tick near «plot browser». Firstly, it is needed to put a grid to the figure using «property editor». Secondly, the «property editor» allows us to add the X axis, Y axis and change the range of Y axis. Then, the graph will be copied and will be used as second graph for other signals. As X the *timestamp* will be used and as Y the *SumVAccel* will be taken.

The same manipulations were made for other activities: 2) walking, 3) jumping and 4) rest

3.3.7 Laboratory work tasks

The test measurement sets were a good exercise for testing the software and a hardware solution.

The work tasks for the laboratory work could be:

1. Shimmer sensor and PC connection

2. Shimmer sensor calibration and data saving

   Checking the calibration, using Matlab sample function:
   orientation3Dexample(‘comPort’, captureDurationInSeconds, ‘fileName.dat’)
3. Streaming and saving data, using a new function:

   GetSignalsFromSensorAndSaveToFile(’comPort’,captureDuration,
   ‘fileName1.dat’, ‘fileName2.dat’)

With Patient Simulator: a) as a test.

With student colleague: b) sit, c) walk, d) jump, e) rest.

4 Results

The results of measurement sets in real time were received. The function, that was used as platform for measurement, has saved files in *.dat* format for further graphical reconstruction. Each pair of the file was named like the measurement set:

1. *MyResultsSitting.dat* and *MyResultsSitting1.dat.*
2. *MyResultsWalking.dat* and *MyResultsWalking1.dat.*
3. *MyResultsJumping.dat* and *MyResultsJumping1.dat.*
4. *MyResultsRest.dat* and *MyResultsRest1.dat.*

The measurements for each activity set was made during 1 min, so our files have more than 30000 records with data in each file. The *.dat* file is the same as a text file, it could be opened by different programmes.

4.1 Data analysis of the graphical view

During 1 minute each file has more than 30 000 records and 10 seconds has more than 3500 records as input data needed to fill the table of our results. The figure window in Matlab has the tools, that will help to do the task. It is possible to select the part of 10 second signal and copy the data to an external file (Figure 32).

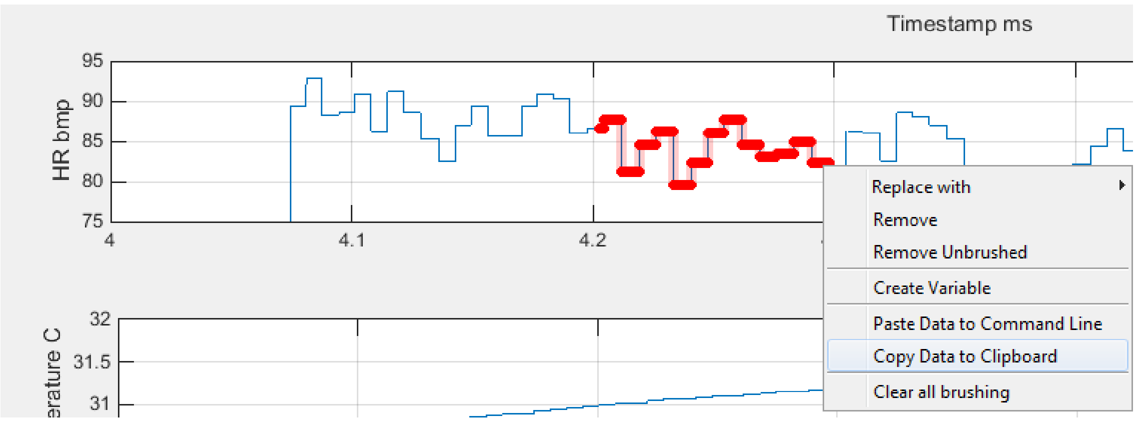


Figure 32. Select the needed signal part and copy to external file.

A new variable with name «*HR10sec*» was created as matrix of signal part in Matlab console. Then, the mean value of the previously created variable was found as a command in console «*Mean(HR10sec)*».

Test measurements, which were made personally and additional data, which was not saved in the result file, was calculated extra. All data of bio signals was received from graphical view as average values for every 10 seconds step and was represented on (Appendix4, Table 3).

Graphical representation of bio signals from a person during different physical activities are given in as follows: A) sitting (Figure 45); B) walking (Figure 46); C) jumping (Figure 47) and D) rest (Figure 48).

A) Person is sitting on the chair for about 1 minute

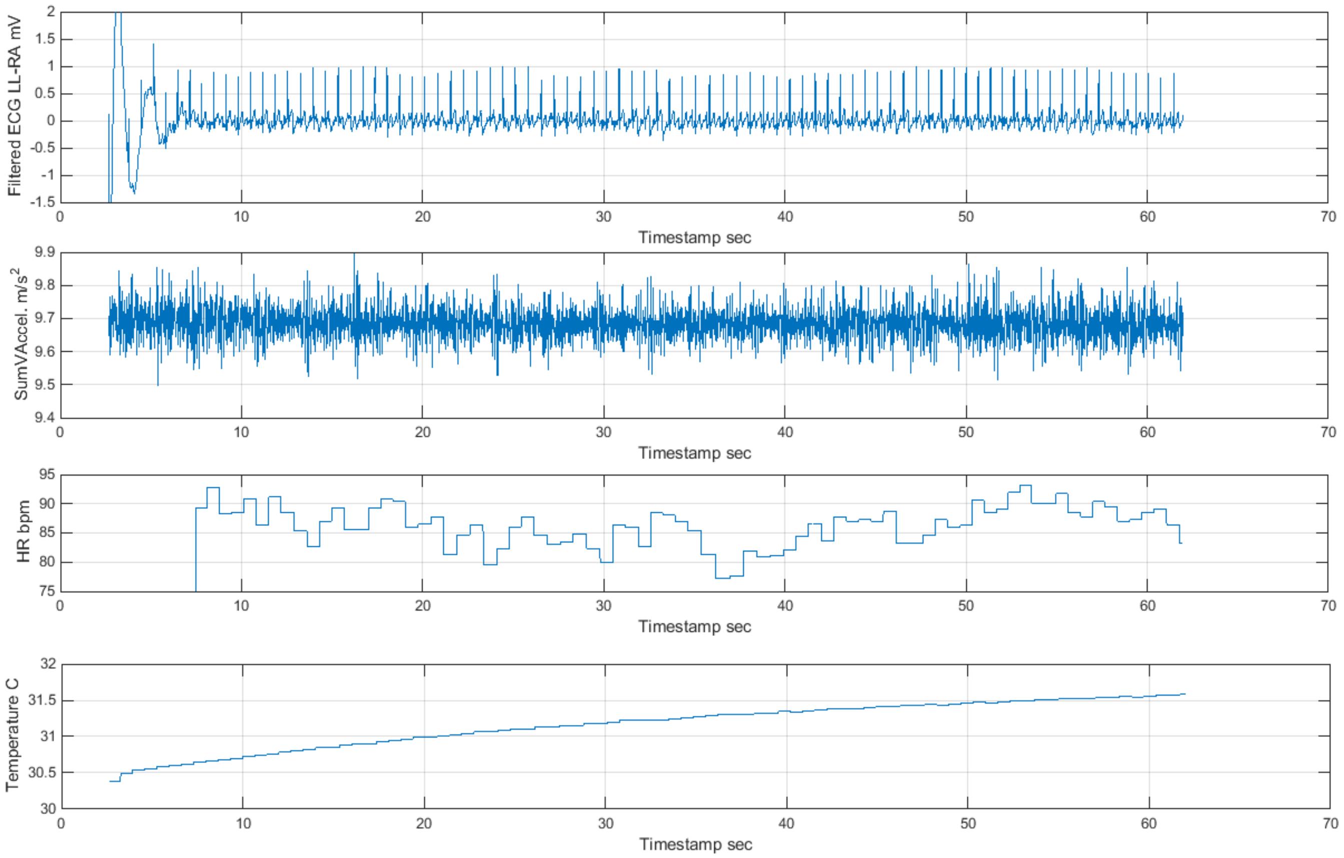


Figure 45. Graphical representation of result files of sitting activity.

B) Person is walking, about 1 minute

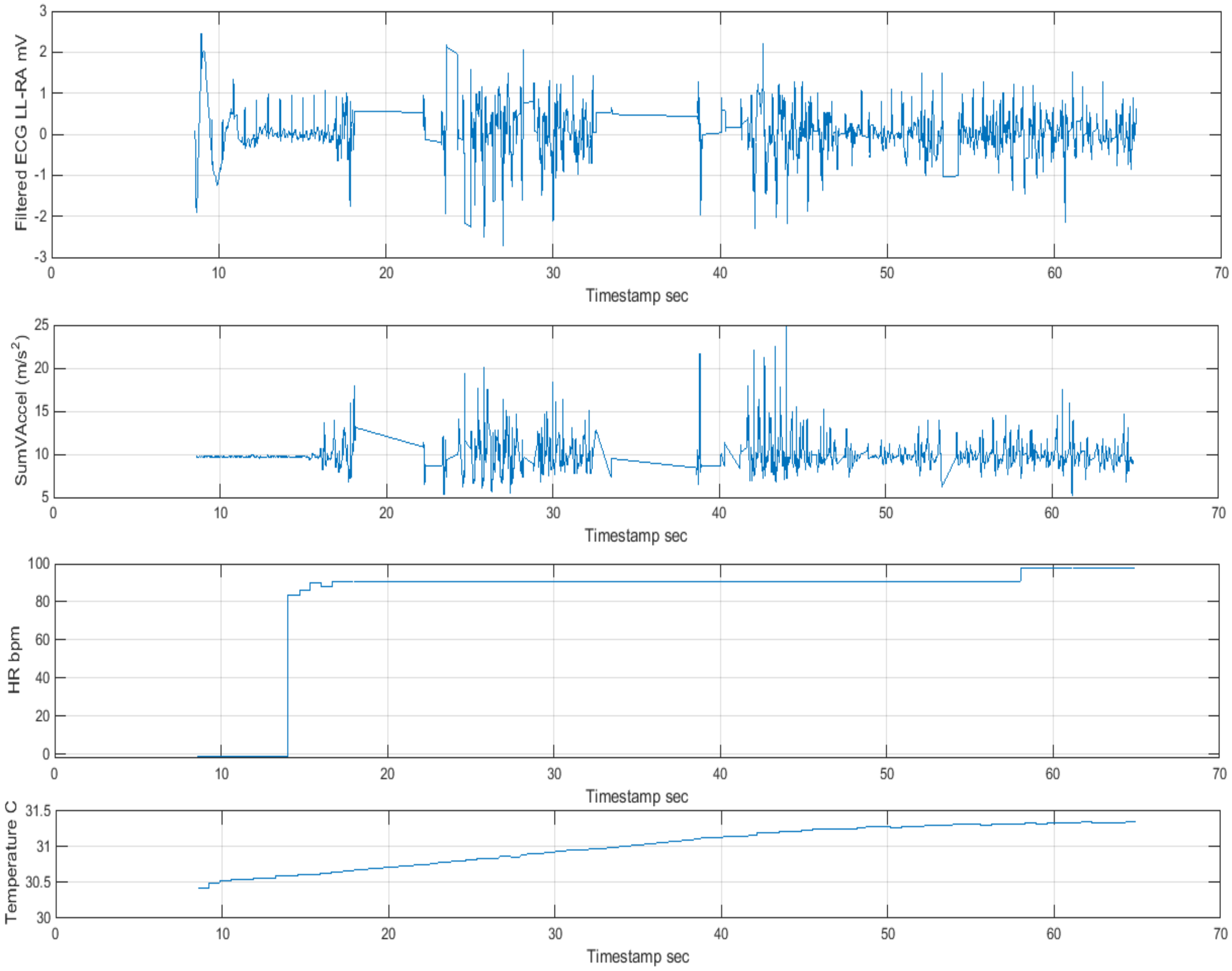


Figure 46. Graphical representation of result files of walking activity.

C) Person is jumping, about 1 minute

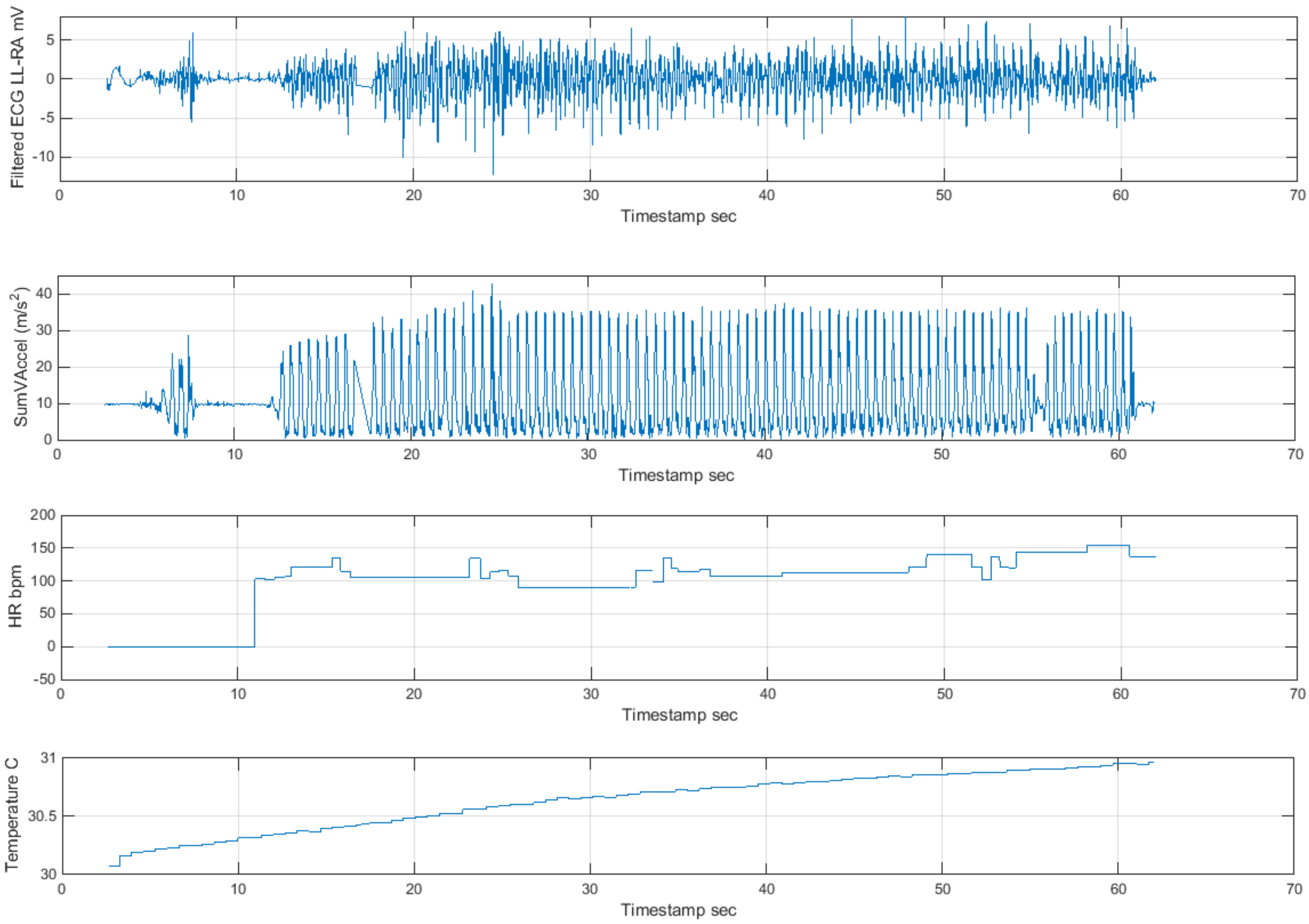


Figure 47. Graphical representation of result files of jumping activity

D) Person is having a rest, about 1 minute

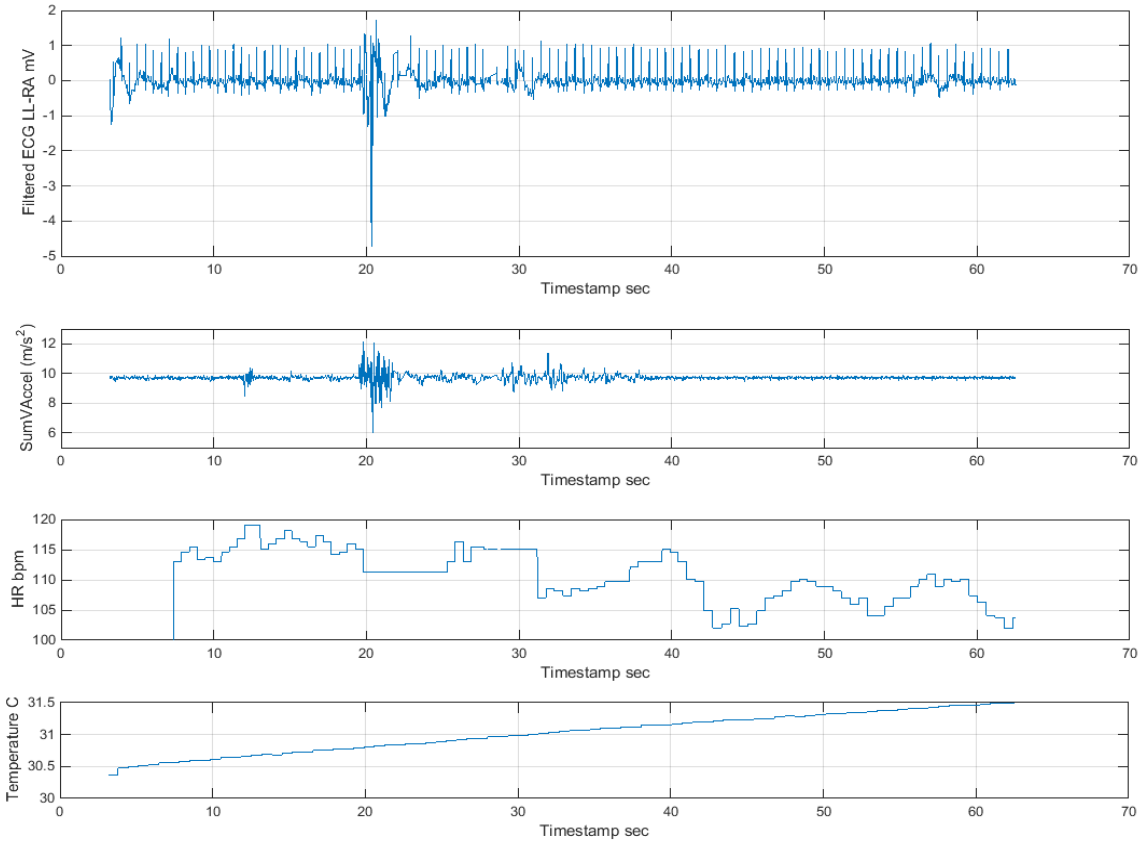


Figure 48. Graphical representation of result files of having a rest

The table from Appendix4 will be used in the laboratory work as a template for measurements.

Based on all measurements and software analyses the laboratory work was created as a main result (Appendix 5).

5 Discussion

Technologies are changing rapidly. The size of medical devices has decreased, but the functionality is wide. Nowadays, a lot of devices in healthcare could be connected to the wireless network. That is why biomedical engineers need to understand the wireless network standards and need to know how to set up the simple network between a medical device and a PC or mobile phone or make a decision of what kind of a network to choose for healthcare organisation.

The main aim of the thesis was to create a laboratory work as a practical exercise for biomedical engineering students.

Firstly, it was needed to analyse the actual wireless networks to understand the difference between networks and find real examples of medical devices or systems, that already used in healthcare in Estonia and other countries. It was found that WiFi, Bluetooth, Cellular networks: 3G/4G/4.5G, WiMAX and ZigBee are widely used in healthcare all over the world and 5G network will be used in a near future. It is important to note, that there are a lot of different medical devices that are using the wireless networks in medical organizations. It is great to realize, that Estonian hospitals are widely using wireless networks with medical devices like mammo bus in Tartu University Hospital; MyStar and CareSens N blood glucose monitors in Tallinn Children`s hospital for checking patient`s blood glucose level for children with diabetes; Family doctors are using Cube-S small size laboratory for express analyses. In spite of that, it is needed to remember about wireless network security, main security advices were given during the work. In addition, all wireless networks have its own advantages and disadvantages, that could be found in (Appendix1, Table1). Also, this table helped to understand what kind of technology is possible to choose and use in special projects in healthcare.

Secondly, the Shimmer sensor was taken as a main medical device, that will be used in a laboratory work. It could be connected to a PC or Tablet, or mobile phone with Android OS using Bluetooth connection. The creators of the device have made software solutions for different operating systems and platforms, which are free of charge (to use). The cost of the paid version of the ConsensysPro software is 199.00 EUR per year. For reaching the goals of the master´s thesis, a new software solution was developed and tested. Created software has more possibilities, than official free of charge versions.

Thirdly, the analysis of the software solutions was made. It was great to realise, that great hardware and software engineers are working together to make good programmes and a hardware in one company. All solutions had its advantages and disadvantages that could be seen in a software comparison table (Appendix2, Table2). Advantages of Shimmer solutions were: Bluetooth connection, plot a signal to graph on real time, free software license except ConsensysPro, save streamed data to file.

On the other hand, it was not possible to just take and use suitable programme and describe it for a laboratory work. Disadvantages of the Shimmer software solutions, were: 1) it was not possible to see a magnitude vector of accelerometer in a real time and 2) the signals from the sensors were visualised in one graphical view. So, it was difficult to realise, what kind of signals are running on the graph, if you try to plot 3-4 signals simultaneously.

The special solution as a main platform for the laboratory need was developed. It is based on Matlab and examples of the Shimmer Company. A single Matlab function *«GetSignalsFromSensorAndSaveToFile(comPort, captureDuration, fileName1, filename2)»* will be used as a software for laboratory work. It can capture different signals, like ECG LL-RA, temperature and accelerometer X, Y, Z, from Shimmer ECG sensor to files. Also it shows these signals in real time, separate graphs and calculates the accelerometer magnitude vector from X, Y, Z on fly. The source code is available (Appendix3).

Test measurements were made with a new solution as 1 minute per activity. It was needed to understand, how it behaves during personal activities, like sitting, walking, jumping and having a rest. Created solution performed as expected. Testing data was saved into two files. During the results analysis, it was found that every result file contains more than 30 000 records of tested activity in numbers from sensor and a person. In order to visualize the results as graphical views and create a table of measurements, it was decided to use Matlab to represent ECG, heart rate, temperature, and a magnitude vector signals for each tested activity. Because of the huge amount of records, it was decided to take an average number of each part of 10 seconds from the graphical views for filling the result table (Appendix 4, Table3). Furthermore, the result table represent information about tested activities.

As it could be seen from the table in Appendix4 and graphical figures (Figures: 45,46,47,48), during different activities person have different ECG signal, magnitude vector of accelerometer and heart rate.

During walking, the quality of ECG signal on the graph is low, that is why the Heart rate signal has almost constant value on the graph (Figure 46). One reason could be, that the Shimmer sensor was not attached correctly, it was hanging on the ECG wires. For the better quality of a signal, the sensor should be fastened with a strap. Therefore, the series of measurements of the walking activity were made with a correct sensor positioning on the body with a strap. In spite of this, the signals of walking activity were very low and the main issue still exists. The magnitude vector of accelerometer, ECG and HR signals are discontinuous during a walking activity as it was shown on (Figure 46). During this activity heart rate grows a little.

The issues related to loss of a Bluetooth wireless signal (as it shows only last received signal values). The result files of each activity were compared. It was found that about 12 000 records were absent in walking activity files, but in other activities were saved about 30 000 records for 1 minute session. Person was walking about 4 m away from PC, but other activities were made about 1m near the PC. The same situation could be found with a mobile phone and smart watches. Sometimes connection is lost, because of the distance, but it is known that Bluetooth can work on 10m distance.

During the jumping activity, the sensor was held behind a hand and a chest. The amplitude vector of accelerometer shows higher and lower values, so it is a very nice example of jumping. As long as person was jumping, the heart rate was increasing (Figure 47).

During a sitting activity the ECG signal was stable and heart rate was changed up and down between 77BPM to 92,5BPM. The amplitude vector of accelerometer shows that person was sitting and breathing.

During the rest activity the person was staying and then sat on the chair. The ECG signal was nice, and heart rate was changed from 118 BPM to 100 BPM. The amplitude vector of accelerometer shows us that the patient was breathing and had a rest.

Nevertheless, the error result of the heart rate (HR), that could be seen on the *Table3* or at the beginning of the new function running as negative number 1 («-1»), was not related to the function or a device. It is caused by a bug of an algorithm in a Java programming language library, that was used as a part of created software solution and «ShimmerBiophysicalProcessingLibrary_Rev_0_10.jar». This library contains Java programming code, presented by sensor manufacturer. The bug was called by a method in an algorythm, that calculates heart rate (HR) using filtered ECG signal and timestamp. Each free solution from the Shimmer Sensing Company has this bug.

According to the results, the developed solution and the Shimmer sensor could be used for training future engineers and for research purposes.

Summary

As a main result of this thesis a laboratory work “Capturing biomedical signals using wireless network” was created (Appendix5). It will be a teaching material for students, who are going to take a course of «*Electromagnetic Fields and Waves*» in Tallinn University of Technology. The goal of the course is to teach the students about the properties and characteristics of electromagnetic fields and waves with relation to biomedical engineering and medical sciences. Created laboratory work will help to future medical engineers to step into the world of medicine, work with real patient`s data, create and analyse data in a real time, to practice a teamwork, to practise a role of a researcher and a patient, learn IT wireless network systems and the basics of programming.

This master`s thesis could be useful as a guiding material for students. Also, the software analysis solutions and created function may be a starting point of a creating other laboratory works or software system for research purposes.

It was a great challenge for the author. The new things were learned, different technologies were tried and the big experience was received.

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Appendix 1 – Wireless network technologies comparison

Table 1. The characteristics and some advantages and disadvantages of wireless network technologies

	Characteristics and comparison of wireless network technologies								
	Bluetooth	Bluetooth 4.2	Bluetooth 5.0	WiFi	Zigbee	3G/4G	4.5G	5G	WiMAX
Data rate	1-3 Mbps	1 Mbps	2 Mbps	1-54 Mbps, up to 150 Mbps	20-250 Kbps	384-1Mbps / 100Mbps	1 Gbps	10 Gbps	up to 70 Mbps
Hardware requirement	Bluetooth adaptor on all devices connected	Bluetooth adaptor on all devices connected	Bluetooth adaptor on all devices connected	WiFi adaptors on all devices of the network	Zigbee adaptors on all devices of the network	Antennas, stations in the city, telecommunication provider like Tele2, Telia, Elisa and devices with 3g or 4g modules like phones	Antennas, stations in the city, telecommunication provider like Tele2, Telia, Elisa and devices with 3g or 4g modules like phones	Antennas, stations in the city, telecommunication provider like Tele2, Telia, Elisa and devices with 3g or 4g modules like phones	Antennas, stations in the city. Devices, with adaptors that can use this network.
Ease of use	Simple, up to 7 devices, easy to connect.	Simple, up to 7 devices, easy to connect.	Simple, up to 7 devices, easy to connect.	Harder, needed to configure access point hardware and software.	According to Zigbee alliance it is easy, but needed to configure Pan coordinator, Coordinator and a device to a network	On the telecommunication level like Tele2, Telia it is hard. On the user level it easy	On the telecommunication level like Tele2, Telia it is hard. On the user level it easy	On the telecommunication level like Tele2, Telia it is hard. On the user level it easy	On telecommunication level like Tele2, Telia it is hard. On the user level is easy
Example devices	Mobile phone, headset, mouse,PC, smartwatch,	Mobile phone, headset, mouse,PC, smartwatch	Mobile phone, headset, mouse,PC, smartwatch	Notebook, PC, smartwatch, Server, sensors.	different sensors for home automation and healthcare	Mobile phones, sensors, medical transport and mobile medical devices	Mobile phones, sensors, medical transport and mobile medical devices	Mobile phones, sensors, medical transport and mobile medical devices	Air stations, antennas in the city, that are capable to work with WIFI
Range	1-10 metres	10m indoor, 50m outdoor	200m indoor, 40m indoor	100 metres	1-10 metres	5-30 km up to 100km	5-30 km up to 100km	5-30 km up to 100km	5-15km/50km
Power Consumption	Low	Lower	the Lowest	High	Low	High	High	Lower than 4G	High
Frequency	2,4 GHz	2,4 GHz	2,4 GHz	2,4 - 5 GHz	2,4GHz, 915 MHz, 868 MHz	in Europe 700, 800, 900, 1800, 2600 MHz in America another	in Europe 700, 800, 900, 1800, 2600 MHz in America another	in Europe 700, 800, 900, 1800, 2600 MHz in America another	2GHz, 66GHz

Appendix 2 – Software type comparison

Table 2 Software type comparison: strengths and weaknesses

Software type comparison		
type of software	Strength	Weakness
ConsensysBasic	1) free version 2) plots signals in real time on graph 3) Save streamed data to file 4) Bluetooth connection with sensor	1) possible to connect only 1 sensor 2)all signals are plotted on 1 graph 3) Not possible to use algorythms for ECG/ heart rate 4) Cannot show a Magnitude vector
ConsensysPro	1) Save streamed data to file 2) plots signals in real time on graph 3) Bluetooth connection with sensor 4) Possible to use integrated	1) price 199EUR/Year 2) all signals are plotted on 1 graph 3) cannot show a Magnitude vector of Accelerometer signal
ShimmerCapture Android	1) free version 2) plots signals in real time on graph 3) Save streamed data to file 4) Bluetooth connection with sensor	1) all signals are plotted on 1 graph 2) Cannot show a Magnitude vector of Accelerometer signal 3) Cannot show heart rate as number
ShimmerCapture Windows/Linux	1) free version 2) plots signals in real time on graph 3) Save streamed data to file 4) Bluetooth connection with sensor 5) Possible to run on PC with Windows or Linux OS	1) all signals are plotted on 1 graph 2) Cannot show a Magnitude vector of Accelerometer signal 3) Cannot show heart rate as number
Matlab Driver with different samples	1) free version 2) plots signals in real time on graph 3) Save streamed data to file 4) Bluetooth connection with sensor 5) ECG and Heart rate graphs	1) cannot show a Magnitude vector of Accelerometer signal in a sample 2) Heart rate as a graph in a sample NB! Possible to make needed modifications.
new Matlab Function "GetSignalsFromSensorAndSaveToFile"	1) free version for Tallinn University of Technology 2) plots signals in real time on different graphs 3) Save streamed data to file 4) ECG graph 5) Magnitude vector of Accelerometer signal as a graph 6) Heart rate as a realtime	1) possible to connect only 1 sensor

Appendix 3 – Function Source code for laboratory work

```
function void = GetSignalsFromSensorAndSaveToFile(comPort, captureDuration,
fileName, filename1)
%
%  28.03.2018 - Daniil Titov 122322YABM. Based on ShimmerMatlab examples from %
%  Shimmer.com
%  2.05.2018 - Update HR, FILTERED ECG to file2
%  plots accelerometer, temperature, ecg signals from the Shimmer
%  paired with COMPORT. The function will stream data for a fixed duration
%  of time. The function also
%  writes the data in a file FILENAME.dat.
%  ALSO shows the heart rate in real time.
%  SYNOPSIS: GetSignalsFromSensorAndSaveToFile('comPort', captureDuration,
%  'fileName.dat')
%
%  INPUT1: comPort - String value defining the COM port number for Shimmer
%
%  INPUT2: captureDuration - Numerical value defining the period of time
%                            (in seconds) for which the function will stream
%                            data from  the Shimmers.
%  INPUT3: fileName - String value defining the name of the file that data
%                     is written to in a comma delimited format.
%  INPUT4: fileName1
%  OUTPUT: filename1.dat, filename2.dat and real-time graph and heart rate in
%           console.
%
%  EXAMPLE: GetSignalsFromSensorAndSaveToFile('7',60,'file1.dat','file2.dat')
%
% NOTE: To use the Java Shimmer Biophysical Processing Library in
% conjunction with the MATLAB:
% Save the ShimmerBiophysicalProcessingLibrary_Rev_X_Y.jar  file to
% C:\Program\Files\MATLAB\R2013b\java\jar (or the equivalent) on your PC and
% add the location of the ShimmerBiophysicalProcessingLibrary_Rev_X_Y.jar file
% to the JAVA dynamic class path:
%
% NOTE: In this example the ECG data is pre-filtered using a second order
% Chebyshev HPF with corner freq 0.5Hz by using FilterClass.m
%


addpath('./Resources/')  % directory that contains f(x) and where to save file
%% import com.shimmerresearch.biophysicalprocessing.*  that is used in java
%% add the path for the library. Daniil Titov 28.03.2018
%% write the correct path to the library.
javaaddpath('C:\Users\DANIEL\Desktop\ShimmerMatlab\Shimmer Matlab Instrument
Driver v2.8\ShimmerBiophysicalProcessingLibrary_Rev_0_10.jar');

% Define shimmer comPort
shimmer = ShimmerHandleClass(comPort);
% assign user friendly macros for setenabledsensors
SensorMacros = SetEnabledSensorsMacrosClass;

% sample rate in [Hz]
fs = 512;

firsttime = true;
```

```
% Note: these constants are only relevant to this script and are not used
% by the ShimmerHandle Class
% Number of samples that will be displayed in the plot at any one time
NO_SAMPLES_IN_PLOT = 500;
% A delay period of time in seconds between data read operations
DELAY_PERIOD = 0.2;
numSamples = 0;

%% filter settings

% mains frequency [Hz]
fm = 50;
% corner frequency highpassfilter [Hz]; Shimmer recommends 0.5Hz for monitoring applications, 0.05Hz for diagnostic settings
fchp = 0.5;
% number of poles (HPF, LPF)
nPoles = 4;
% pass band ripple (%)
pbRipple = 0.5;
% enable (true) or disable (false) highpass filter
HPF = true;
% enable (true) or disable (false) lowpass filter
LPF = true;
% enable (true) or disable (false) bandstop filter
BSF = true;

% highpass filters for ExG channels
if (HPF)
hpfexg1ch1 = FilterClass(FilterClass.HPF,fs,fchp,nPoles,pbRipple);
hpfexg1ch2 = FilterClass(FilterClass.HPF,fs,fchp,nPoles,pbRipple);
hpfexg2ch1 = FilterClass(FilterClass.HPF,fs,fchp,nPoles,pbRipple);
hpfexg2ch2 = FilterClass(FilterClass.HPF,fs,fchp,nPoles,pbRipple);
end
% lowpass filters for ExG channels
if (LPF)
lpfexg1ch1 = FilterClass(FilterClass.LPF,fs,fs/2-1,nPoles,pbRipple);
lpfexg1ch2 = FilterClass(FilterClass.LPF,fs,fs/2-1,nPoles,pbRipple);
lpfexg2ch1 = FilterClass(FilterClass.LPF,fs,fs/2-1,nPoles,pbRipple);
lpfexg2ch2 = FilterClass(FilterClass.LPF,fs,fs/2-1,nPoles,pbRipple);
end
% bandstop filters for ExG channels;
% cornerfrequencies at +1Hz and -1Hz from mains frequency
if (BSF)
bsfexg1ch1 = FilterClass(FilterClass.LPF,fs,[fm-1,fm+1],nPoles,pbRipple);
bsfexg1ch2 = FilterClass(FilterClass.LPF,fs,[fm-1,fm+1],nPoles,pbRipple);
bsfexg2ch1 = FilterClass(FilterClass.LPF,fs,[fm-1,fm+1],nPoles,pbRipple);
bsfexg2ch2 = FilterClass(FilterClass.LPF,fs,[fm-1,fm+1],nPoles,pbRipple);
end
%% ECG2HR settings
% method that is located in java library, for heart rate calculation
ECG2HR = com.shimmerresearch.biophysicalprocessing.ECGtoHRAdaptive(fs);
%%
% TRUE if the shimmer connects
if (shimmer.connect)
% define settings for shimmer
```

```
% set the shimmer sampling rate
shimmer.setsamplingrate(fs);
% Select internal expansion board 'ECG'+Calibration
shimmer.setinternalboard('ECG');
shimmer.setinternalboard('9DOF');
% Disable other sensors
shimmer.disableallsensors;
% Enable needed sensors for our f(x), 1 is true as activated
shimmer.setenabledsensors(SensorMacros.ECG,1,SensorMacros.ACCEL,1,SensorMacros.P
RESSURE,1);
shimmer.setaccelrange(0);
% TRUE if the shimmer starts streaming
if (shimmer.start)

plotData = [];
timeStamp = [];
filteredplotData = [];
h.figure1=figure('Name','TTÜ Shimmer3 signals: accel, temp, ecg');
set(h.figure1, 'Position',[100, 500, 800, 400] );
% reset to 0
elapsedTime = 0;
% start timer
tic;

while (elapsedTime < captureDuration)
 % pause for this period of time on each iteration to allow data to arrive in
the buffer
 pause(DELAY_PERIOD);
 % Read the latest data from shimmer data buffer, signalFormatArray defines the
format of the data and signalUnitArray the unit
 [newData,signalNameArray,signalFormatArray,signalUnitArray] =
shimmer.getdata('c');
 if (firsttime==true && isempty(newData)~=1)
    firsttime =
writeHeadersToFile(fileName,signalNameArray,signalFormatArray,signalUnitArray);
 end

 % TRUE if new data has arrived
 if ~isempty(newData)
    % get signal indices
    chIndex(1) = find(ismember(signalNameArray, 'Time Stamp'));
    %here is defined signal from ECG sensor
    chIndex(2) = find(ismember(signalNameArray, 'ECG LL-RA'));
    %here is defined signal from Accelerometer sensor
    chIndex(3) = find(ismember(signalNameArray, 'Low Noise Accelerometer X'));
    chIndex(4) = find(ismember(signalNameArray, 'Low Noise Accelerometer Y'));
    chIndex(5) = find(ismember(signalNameArray, 'Low Noise Accelerometer Z'));
    %here is defined signal from Pressure sensor, but we use only temperature
signal
    chIndex(6) = find(ismember(signalNameArray, 'Temperature'));

    ECGData = newData(:,chIndex);
    ECGDataHeartrate=newData(:,chIndex(2));
    ECGDataFiltered = ECGDataHeartrate;
    % filter with high pass filter
    if (HPF)
        ECGDataFiltered = hpfexg1ch1.filterData(ECGDataFiltered);
    end
    % filter with low pass filter
```

```
    if (LPF)
        ECGDataFiltered = lpfexg1ch1.filterData(ECGDataFiltered);
    end
    % filter with band stop filter
    if (BSF)
        ECGDataFiltered = bsfexg1ch1.filterData(ECGDataFiltered);
    end
    % compute Heart Rate from ECG data, calling from java method
    newheartRate = ECG2HR.ecgToHrConversion(ECGDataFiltered(:,1),
newData(:,chIndex(1)));
    % output heart rate in console
    fprintf('Heart Rate sample by Daniil: %f \n',newheartRate);

fid=fopen(filename1,'at'); % output to file2 2.05.2018
fprintf(fid, ['TimeStamp2' ' ' 'ECGSIG' ' ' 'HR' '\n']);
fprintf(fid, '%f %f %f  \n', [newData(:,chIndex(1)) ECGDataFiltered(:,1) newheartRate
]');
fclose(fid);
    % Update the plotDataBuffer with the new data
    plotData = [plotData; newData];
    filteredplotData = [filteredplotData; ECGDataFiltered];
    numPlotSamples = size(plotData,1);
    numSamples = numSamples + size(newData,1);
    % get timestamps
    timeStampNew = newData(:,1);
    timeStamp = [timeStamp; timeStampNew];
    if numSamples > NO_SAMPLES_IN_PLOT
       plotData = plotData(numPlotSamples-NO_SAMPLES_IN_PLOT+1:end,:);
       filteredplotData = filteredplotData(numPlotSamples-
NO_SAMPLES_IN_PLOT+1:end,:);
    end
    sampleNumber = max(numSamples-NO_SAMPLES_IN_PLOT+1,1):numSamples;
    % Save data to file
    dlmwrite(fileName, newData, '-append', 'delimiter', '\t','precision',16);

    set(0,'CurrentFigure',h.figure1);
%Sum Vector graph of X,Y,Z, signals from accelerometer sensor in real-time
%formula from "An Engineers`s guide to Matlab with application from Mechanical ,
%Aerospace , Electrical, and civil engineering SECOND EDITION" p275 Daniil Titov
22.03.2018
    subplot(2,2,1);
    signalIndex3 = chIndex(3);
    signalIndex4 = chIndex(4);
    signalIndex5 = chIndex(5);
    hold on;
    plot(sampleNumber,
sqrt(plotData(:,signalIndex3).^2+plotData(:,signalIndex4).^2+plotData(:,signalIn
dex5).^2) );
    xlim([sampleNumber(1); sampleNumber(end)]);
    ylim('auto')
    xlabel('series n');
    ylim('auto'), ylabel('Acclr. sumV(X,Y,Z) (m/(s^2))');
    % Create subplot for Temperature signal from pressure sensor
    subplot(2,2,2);
    signalIndex6 = chIndex(6);
    plot(sampleNumber, plotData(:,signalIndex6));
    legend([signalFormatArray{signalIndex6} ' ' signalNameArray{signalIndex6} '
(' signalUnitArray{signalIndex6} ')']);
    xlim([sampleNumber(1) sampleNumber(end)]);
```

```
    xlabel('series n');
    ylabel('Temperature (C)');

    % Create subplot for LL-RA signal from ECG sensor
    subplot(2,2,4);
    signalIndex2 = chIndex(2);
    % Plot the filtered ecg for channel 2 of SENSOR_EXG1
    plot(sampleNumber,filteredplotData(:,1));
    legendName1=[signalFormatArray{signalIndex2} ' ' 'filtered' ' '
signalNameArray{signalIndex2} ' (' signalUnitArray{signalIndex2} ')'];
    % Add legend to plot
    legend(legendName1);
    xlim([sampleNumber(1) sampleNumber(end)]);
    xlabel('series n');
    ylim('auto'), ylabel('ECG filtered (millivolts)');

end
   % stop timer and add to elapsed time
   elapsedTime = elapsedTime + toc;
   % start timer
   tic;
end
   % stop timer
   elapsedTime = elapsedTime + toc;
   % stop data streaming
   shimmer.stop;
end
   % disconnect from sensor
   shimmer.disconnect;
end
```

Appendix 4 – Personal measurement results in table

Table 3. Personal measurement results using laboratory function in Matlab

Measurement Results				
Acitivity	time (s)	heart rate (bpm)	Sensor t (C)	SumVAccel (m/s^2)
Sit on a chair	0	-1	30.6	9.6853
	10	88	30.9	9.6926
	20	84	31.1	9.6873
	30	83	31.3	9.6836
	40	86	31.4	9.6849
	50	90	31.5	9.6834
	60	87	31.6	9.6804
Walking	0	-1	30.4	9.7073
	10	91	30.5	9.7773
	20	91	30.8	9.7024
	30	91	31.0	9.7164
	40	91	31.2	9.9302
	50	98	31.3	9.8683
	60	98	31.3	9.8189
Jumping	0	-1	30.2	9.9144
	10	112	30.4	10.2005
	20	102	30.6	11.5337
	30	107	30.7	11.1376
	40	116	30.8	11.1007
	50	139	30.9	11.3835
	60	140	30.9	10.8320
Rest	0	-1	30.4	9.7047
	10	117	30.8	9.7108
	20	113	30.9	9.7124
	30	110	31.1	9.7319
	40	107	31.2	9.7117
	50	108	31.4	9.7153
	60	104	31.5	9.7135

Appendix 5 – Laboratory work

«Capturing biomedical signals using wireless network»

TALLINN UNIVERSITY OF TECHNOLOGY
Faculty of Information Technology
Department of Health Technologies

Student:	Date:
Group:	Defence date:
Work nr:	Supervisor:
	Supervisor`s signature:
«Capturing biomedical signals using wireless network»	
Objective: Setup wireless connection, Sensor calibration, Read biosignals from sensor, Capture the signal with different software	Equipment needed: PC, Shimmer3 ECG sensor, calibration stand, Shimmer 9DoF calibration tool, usb cabel, ECG wires, Bluetooth network, 2-Channel Patient Simulator Metron PS-420, Matlab software Extra: phone with Android OS.

Scheme

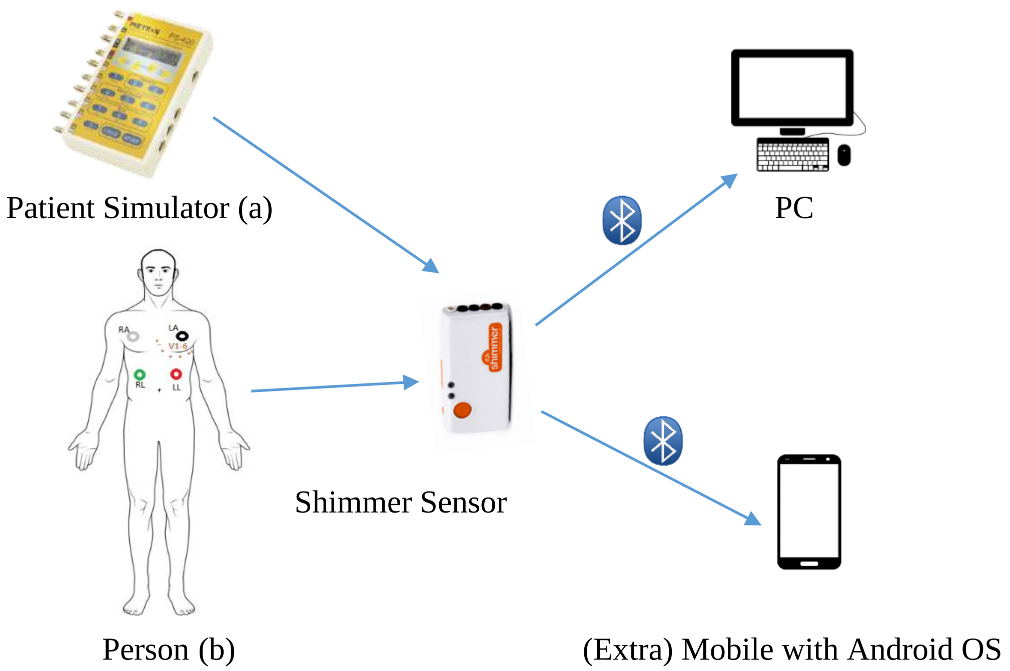

Figure 1. Laboratory work scheme: (a) with patient simulator, (b) with person

1 Purpose

Get acquainted with principle of operation of the Shimmer3 ECG sensor. Get to know how to receive biomedical signals from the sensor using different software and wireless network. Get to know how to calibrate the sensor.

2 Theoretical foundations

The technology got its name from King Harald Blätand (bluetooth), Denmark. He is known for his achievements. In the X century he united Denmark and Norway under Christianity. . [Bluetooth for Java, Bruce Hopkins & Ranjith Antony, 2003, p 11-12]

Bluetooth operates in the 2,4 GHz range and include low power consumption and low cost. Bluetooth can be divided into two types: (1) The original standard specified a Basic Rate (BR) system, and (2) the current version 4.0 of the standard (2011y), which indicates support for a Low Energy System. The BR system in bluetooth supports data rates up to 721,2 kbps, newer standards support up to 2,1 Mbps. High speed operations can be supported up to 24 Mbps using an 802.11 waveform. [Wireless Networking, Burbank, Andrusenko, Everett, Kasch, 2013, p. 51-52]

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Also, bluetooth connections can be defined as point to point or point to multipoint. For point-to-point connections, the physical channel is shared between 2 devices. For point-to-multipoint connections, the physical channel is shared between 2 and more devices.

Bruce Hopkins and Ranjith Antony, in their book «Bluetooth for Java», tell us that a personal area network can be a *piconet* or a *scatternet*. A Bluetooth *piconet* has a single master and up to seven slaves (Figure 2). The master device is the one that initiates the connection. The device, that accepts the connection becomes the slave. These roles are not concrete. If the piconet exists between laptop and phone, the device can be master or slave.

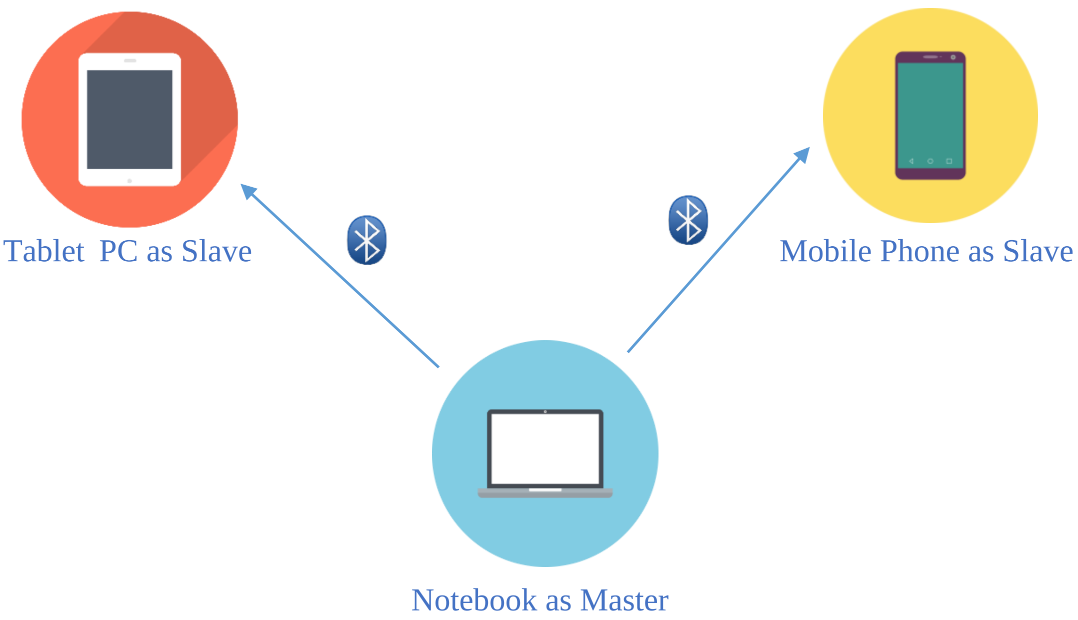


Figure 2. Piconet – the Slaves may connect to the Master

If a Bluetooth device, as a slave in piconet connection, is multipoint capable, then a new Bluetooth device can create a piconet with that slave. Then, this wireless personal area network will be called *scatternet* in (Figure 3).

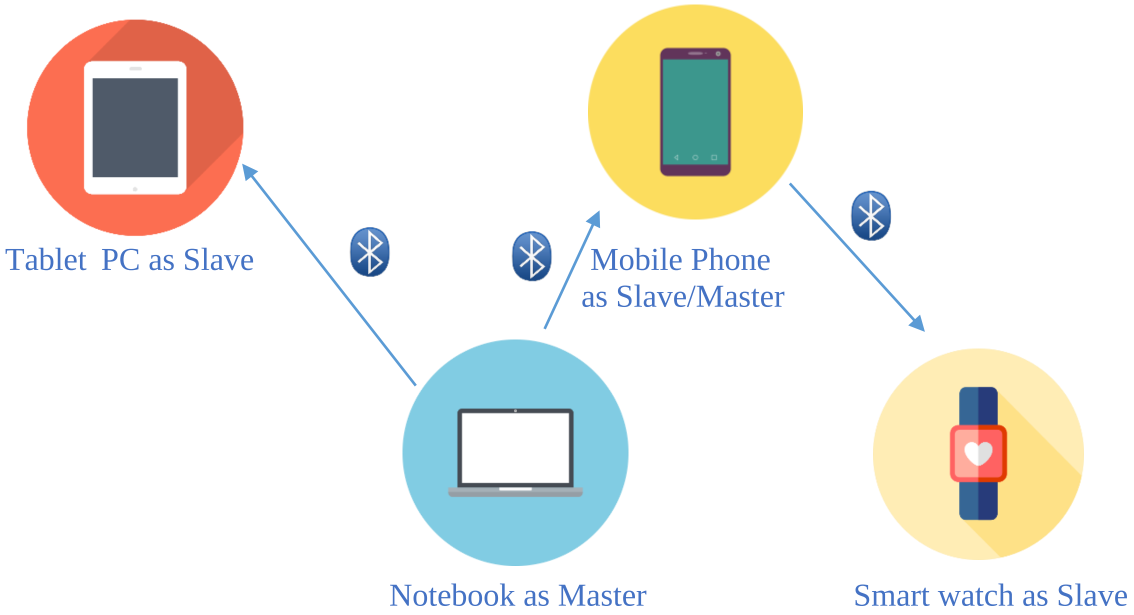


Figure 3. Scatternet- 1 Slave from one piconet is a master in another piconet

According to IEEE standards, the Bluetooth devices can communicate in the range from 1 to 100 meters.

3 Possible questions for protection

1) What does the calibration mean? Why it is needed?
2) Describe the Bluetooth wireless network.
3) Is the wireless connection secure for using with patient`s data?
4) What kind of wireless networks do you know? Are they suitable for using in healthcare?
5) What does the accelerometer mean?
6) Why the Patient Simulator device was used? In what situations it could be used elsewhere?
7) What will the ECG signal (LL-RA) look like on the graph, if 1 wire will be disconnected? Give an example.
8) Person is making different physical activities (standing, running, etc.) Does the heart rate change? Describe why.

9) How heart rate is connected with ECG?

10) How will the sensor work, if we connect it to PC or phone? Will the measurement results be the same?

4 Used tools

For the laboratory work is needed: PC, Shimmer3 ECG sensor. Shimmer calibration stand, Shimmer dock, Matlab and Shimmer 9DoF calibration tool, Bluetooth network and 2-Channel Patient Simulator Metron PS-420.

For the extra exercise is possible to use Shimmer Capture software for android device and mobile phone (with Android operating system). *Not obligatory*!

5 Work Task

0) Connect Shimmer sensor to PC (PC and sensor connection. Appendix A*)*
1) Shimmer sensor calibration and data saving (Calibration manual. Appendix C)
2) Read calibrated data (Is the sensor calibrated correctly?)

   9DoF calibration tool
3) Stream and save Shimmer sensor`s calibrated data:

   Function: GetSignalsFromSensorAndSaveToFile('comPort', captureDuration, 'fileName.dat','filename1.dat')

   With Patient Simulator: a) test

   With student colleague: b) sit ; c) walk ; d) jump and e) rest
4) Calculation of saved file (Accelerometer vector magnitude)

   Could be found using a formula:

   $$\text{Magnitude vector } \mathbf{A} = \sqrt{(X.^2 + Y.^2 + Z.^2\,)} \qquad (1)$$
5) ECG processing (lead 2 positive). Heart Rate calculation from file or from the software.
6) Extra exercise: connect the sensor with mobile phone (if you have an Android OS). (Mobile phone and sensor connection. Appendix B)

6 Measurement

ECG connectors have different colours and are used for capturing different signals according to their placement: LA(black)- left arm, RA(white)- right arm, LL(red)-left leg, RL(green)- right leg, Vx(1,2,3,4,5,6) (brown)–on the chest.

Shimmer sensor must be connected to a PC via Bluetooth and a Patient Simulator Metron PS-420 using 5 leads. (Figure 4)

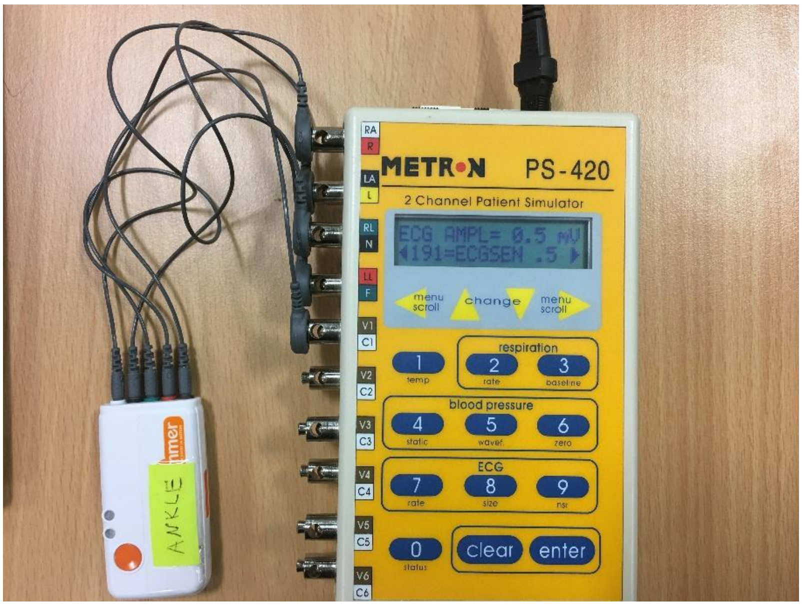


Figure 4. ECG test measurement with Patient Simulator Metron PS-420

On the Patient Simulator device choose ECG simulating signal using code «191» or similar signal from sigal card of the device. Run the function in Matlab, which was described in part 7.5(3) with duration time 1 minute. It will be a test measurment.

When the test measurement will be completed, check the file created and look at the data saved. Then it is needed to connect the sensor to a real «patient». Ask a colleague, to assist you in a measurement process. Shimmer sensor needed to be connected correctly on the chest (Figures 5,6).

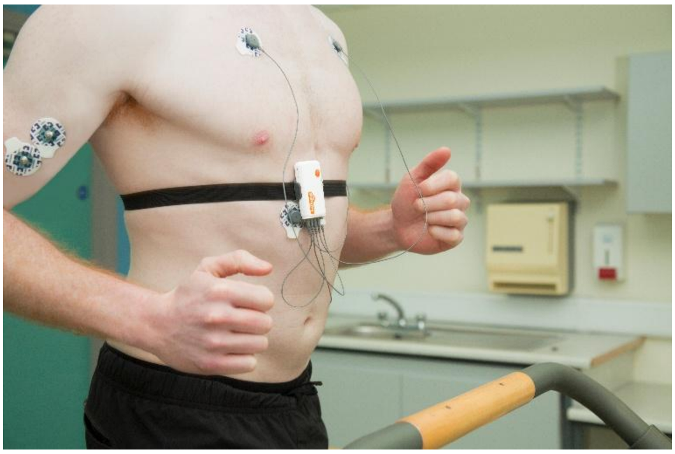


Figure 5. Shimmer ECG sensor connection on student.

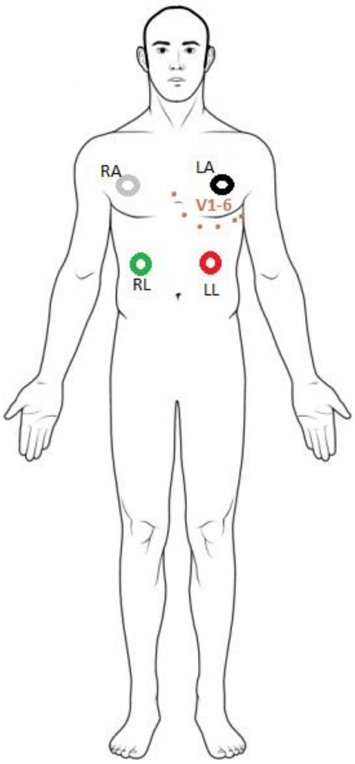


Figure 6. Shimmer ECG sensor connection on a patient schematic

When the leads have been connected, it is needed to run the function in Matlab, which was described in part 3. It is needed to make 4 measurements in 4 different states. Every measurement will last 1 minute. For the further calculations save all calculated files to your directory.

7 Measurment results

1) As a result, it is needed to prepare and fill in the table *Table(1)* for all 4 physical activities: sit, walk, jump, rest.

2) Create Accelerometer Amplitude Vector **A** figure from time dependency (ms) for each state.

3) Create ECG (LL-RA)(millivolts) and time dependency figures for each state.

4) Create Heart rate and time dependency figures for each state.

5) Create Temperature and time dependency figures for each state.

Table 1. Measurement result protocol template

Measurement Protocol				
Acitivity	time (s)	heart rate (bpm)	Sensor t (C)	SumVAccel m/s^2
Sit on a chair	0			
	10			
	20			
	30			
	40			
	50			
	60			
Walking	0			
	10			
	20			
	30			
	40			
	50			
	60			
Jumping	0			
	10			
	20			
	30			
	40			
	50			
	60			
Rest	0			
	10			
	20			
	30			
	40			
	50			
	60			

8 Report

The report should include: front page, connection scheme, result table and figures. Figures should be numbered with legends and below should be written clarifying text. All steps of the work have to be documented in the report. The conclusion has to be written.

9 Advices

a) Name your files according to measurement set, like (jumping.dat, jumping1.dat)

b) Use Matlab to create Graphical views from result files.

For filling a result table for a report, use mean values of each 10 seconds period of measurement set. The figure window in Matlab has great tools, that will help you. The part of 10 second signal could be selected and the data have to be copied to an external file in Excel or in a new matrix variable in Matlab. (Figure 7).

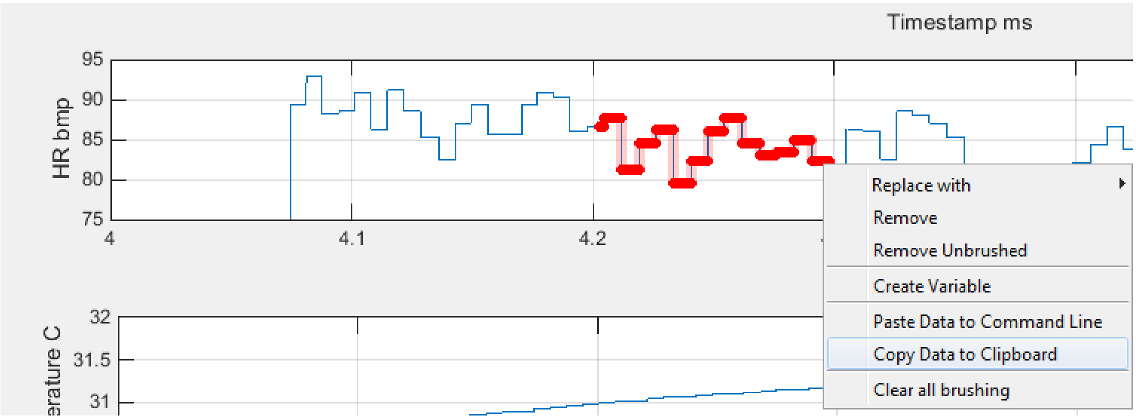
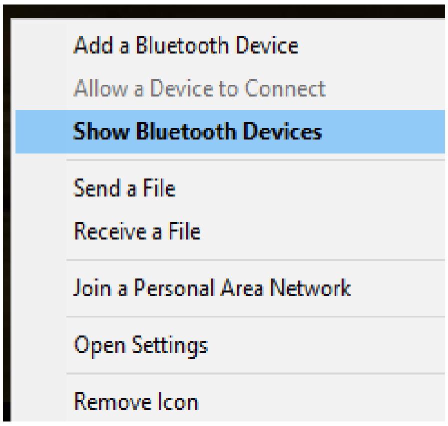


Figure 7. Select the needed signal part and copy to external file.

c) Finding a mean value of a signal part could be done, if you create a new variable in Matlab in console, like «*HRpart1=[HR values of this part]*», then use *mean()* function in Matlab like this « *mean(HRpart1)*».

Appendix A: PC and Sensor connection

- Make sure, that the sensor is ON and led indicator is showing the light signal.
- Find the Bluetooth logo in bottom right corner of the PC display, and make a click
- Choose «Show Bluetooth Devices» (Figure 8)
- Find the Shimmer3 sensor and press «Pair»
- As a security password type «1234» and press next (Figure 9)
- Wait for the connection establishing for 2-3 seconds.
- The sensor is connected to the PC



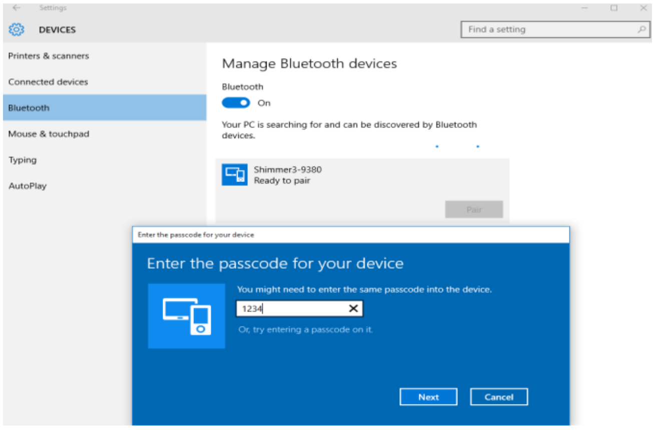


Figure 8. Bluetooth menu **Figure 9.** Security code

Find the Shimmer3 sensor COM port in the PC: start/pc/properties/Device Manager/Ports COM & LPT (Figure 10) This number will be needed in calibration and Matlab connection.

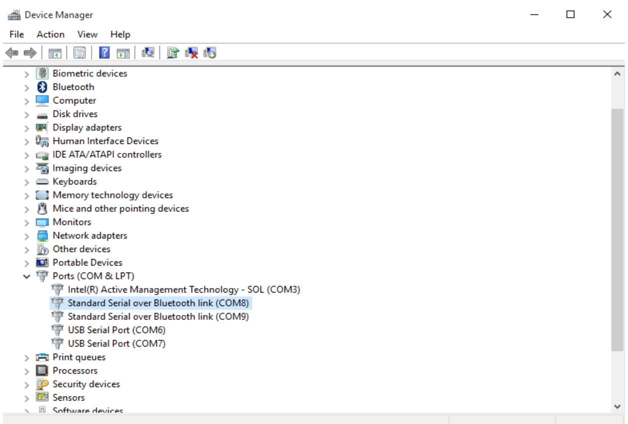


Figure 10. Sample port found

Appendix B: Mobile phone with Android and Sensor connection

The shimmer3 sensor is possible to pair via Bluetooth with Tablet or Mobile phone device, which works under Android OS. Find the application, which is called «ShimmerCapture », in Play Market. Then, download it to your device for free. The link for download looks like this:

[*WWW: https://play.google.com/store/apps/details?id=com.shimmersensing.shimmerconnect&hl=en*]

Appendix C: Shimmer sensors calibration

A) Accelerometer calibration

Before accelerometer calibration start, make sure the Bluetooth connection has been established.

- In upper right corner, choose your Device: connection COM port.
- Push the blue button «CONNECT»: calibration application will be connected with the sensor.
- Put the Shimmer3 sensor to calibration stand like it is shown on *(*Figure 11*)*. Because of the rounded shape of the sensor, it is not possible to make device calibration without stand. Otherwise, the calibration will not be correct. [*Shimmer Company, «Shimmer 9Dof Calibration user manual rev2.10a», 2017 p.7]*
- Push the green button «START» for data streaming from the sensor
- Choose the (X,Y,Z) coordinate system *(*Figure 12*)*
- Put the Shimmer3 sensor to the start position *(*Figure 11*)* [36]

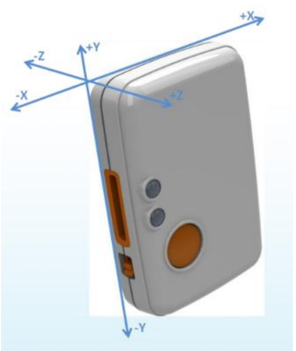


Figure 12. Coordinate system

Figure 11. Calibration Start position.

- Position 1: Place the Shimmer3 sensor, with the stand, on the table surface as **X+ axis is pointing upwards** like gravity vector (**g+ vertical up**.). Then, press «**X+g**» button. Wait some seconds for matrix calculation. *(*Figure 13*)*

Figure 13. Position 1.

Figure 14. Position 2.

Figure 15. Position 3.

- Position 2: Place the Shimmer 3 sensor on the table surface as **X- axis is pointing away from gravity vector** (**g- vertical down**). Then, press «**X-g**» button. Wait some seconds for matrix calculation. (Figure 14)
- Position 3: Place the Shimmer3 sensor, with the stand, on the table surface as **Y+ axis is pointing upwards** like gravity vector (**g+ vertical up**.). Then, press «**Y+g**» button. Wait some seconds for matrix calculation. (Figure 15)

Figure 16. Position 4

Figure 17. Position 5

Figure 18. Position 6

- Position 4: Place the Shimmer 3 sensor on the table surface as **Y- axis is pointing away from gravity vector** (**g- vertical down**). Then, press «**Y-g**» button. Wait some seconds for matrix calculation. (Figure 16)

- Position 5: Place the Shimmer3 sensor, with the stand, on the table surface as **Z+ axis is pointing upwards** like gravity vector (**g+ vertical up**.). Then, press «**Z+g**» button. Wait some seconds for matrix calculation. (Figure 17)

- Position 6: Place the Shimmer 3 sensor on the table surface as **Z- axis is pointing away from gravity vector** (**g- vertical down**). Then, press «**Z-g**» button. Wait some seconds for matrix calculation. (Figure 18)

Press red button «STOP» telling the sensor to stop streaming.
Once the calibration has been completed the accelerometer offset vector (ba), the sensitivity matrix (Ka) and axis alignment matrix(Ra) will be updated on the calibration screen. [36]

If something is going wrong and the calculated data is not displaying correctly or some element has a «NAN» value. It is needed to repeat the calibration. [36]

After a success calibration, the calculated data could be saved to PC or to the sensor directly. Use the dark blue buttons «SAVE ACCEL TO FILE» or «SAVE ACCEL TO SHIMMER». The new calibrated parameters possible to reuse in the future. [36]