CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Electrical Engineering

Department of Cybernetics

Daily activity monitoring using a device with accelerometers

Master's Thesis

Study Programme: Biomedical Engineering and Informatics

Branch of study: Biomedical Engineering

Thesis advisor: Ing. Jaromír Doležal Ph.D.

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Prague

Czech Technical University in Prague
Faculty of Electrical Engineering

Department of Cybernetics

DIPLOMA THESIS ASSIGNMENT

Student: Bc. Barbora F a r k a š o v á

Study programme: Biomedical Engineering and Informatics

Specialisation: Biomedical Engineering

Title of Diploma Thesis: Daily Activity Monitoring Using a Device with Accelerometers

Guidelines:

1. Perform literature and existing device research with respect to various wearable device positioning.
2. Propose suitable solutions of measuring wearable device positioning.
3. Design suitable experiments and an experimental protocol to verify individual solutions of measuring wearable device positioning.
4. Assemble measuring board, conduct experiments for selected variants and analyze measured data.
5. Compare achieved results and interpret individual solutions of measuring wearable device positioning usability.

Bibliography/Sources:

[1] BRAVO, J., CHEN, L., NUGENT, C., PECCHIA, L.: Ambient Assisted Living and Daily Activities: 6th International Work-Conference, IWAAL 2014, Belfast, UK, December 2-5, 2014, Proceedings. New York: Springer International Publishing, 2014. ISBN 978-3-319-13104-7.
[2] FREEDLAND, K., JENNINGS, J.R., LLABRE, M.M., MANUCK, S.B., STEPTOE, A., SUSMAN, E.J.: Handbook of Behavioral Medicine: Methods and Applications. New York: Springer International Publishing, 2010. ISBN 978-0-387-09487-8.
[3] GUTMAN, G., SIXSMITH, A.: Technologies for Active Aging. New York: Springer International Publishing, 2013. ISBN 978-1-4419-8347-3.
[4] LAAKE, Petter, Haakon Breien BENESTAD a Bjørn Reino OLSEN: Research methodology in the medical and biological sciences. Boston: Elsevier/AP, c2007. ISBN 978-0-12-373874-5.
[5] LUQUE, A., NIHTIANOV, S.: Smart Sensors and MEMS: Intelligent Devices and Microsystems for Industrial Applications. Cambridge: Woodhead Publishing Limited, 2014. ISBN 978-0-85709-502-2.

Diploma Thesis Supervisor: Ing. Jaromír Doležal, Ph.D.

Valid until: the end of the summer semester of academic year 2015/2016

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Dean

Prague, February 25, 2015

České vysoké učení technické v Praze
Fakulta elektrotechnická

Katedra kybernetiky

ZADÁNÍ DIPLOMOVÉ PRÁCE

Student: Bc. Barbora F a r k a š o v á

Studijní program: Biomedicínské inženýrství a informatika (magisterský)

Obor: Biomedicínské inženýrství

Název tématu: Monitorování denní aktivity pomocí zařízení s akcelerometry

Pokyny pro vypracování:

1. Proveďte rešerši literatury a existujících zařízení se zaměřením na různé umístění nositelného zařízení.
2. Navrhněte vhodné varianty umístění nositelného měřicího zařízení.
3. Navrhněte vhodné typy experimentu a experimentální protokol pro ověření užitečnosti jednotlivých variant umístění nositelného měřicího zařízení.
4. Sestavte měřící přípravek, proveďte experimenty pro vybrané varianty a analyzujte naměřená data.
5. Srovnejte dosažené výsledky a vyhodnoťte vhodnost jednotlivých variant řešení.

Seznam odborné literatury:

[1] BRAVO, J., CHEN, L., NUGENT, C., PECCHIA, L.: Ambient Assisted Living and Daily Activities: 6th International Work-Conference, IWAAL 2014, Belfast, UK, December 2-5, 2014, Proceedings. New York: Springer International Publishing, 2014. ISBN 978-3-319-13104-7.
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[5] LUQUE, A., NIHTIANOV, S.: Smart Sensors and MEMS: Intelligent Devices and Microsystems for Industrial Applications. Cambridge: Woodhead Publishing Limited, 2014. ISBN 978-0-85709-502-2.

Vedoucí diplomové práce: Ing. Jaromír Doležal, Ph.D.

Platnost zadání: do konce letního semestru 2015/2016

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prof. Ing. Pavel Ripka, CSc.
děkan

V Praze dne 25. 2. 2015

STATUTORY DECLARATION

I declare that I have developed and written the enclosed Master Thesis completely by myself, and I quoted all sources in accordance to Methodological guideline of adherence to ethical principles in the preparation of university theses.

In Prague ....

Signature of author

PROHLÁŠENÍ AUTORA PRÁCE

Prohlašuji, že jsem předloženou práci vypracovala samostatně a že jsem uvedla veškeré použité informační zdroje v souladu s Metodickým pokynem o dodržování etických principů při přípravě vysokoškolských závěrečných prací.

V Praze dne ....

Podpis autora práce

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TABLE OF CONTENTS

ANOTATION

The main goal of this thesis Daily activity monitoring using a device with accelerometers is to choose the best variant of wearable device positioning for senior’s daily activities monitoring. Population is aging and considering this fact we can expect lot of changes in approach of the worldwide health system. It is of the utmost importance that seniors could remain at home as long as possible otherwise the healthcare will be costly. Thus the technical solution that will be able to monitor daily activities of seniors is needed.

The very wearable device with accelerometer was constructed. Assembling of measuring board is described. Principal components are Motion Processing Unit MPU-6050 and Bluetooth HC-06, both for Arduino platform. Experiments and experimental protocols to verify individual solutions of measuring wearable device positioning were designed. The three main exercises were Chair, Bed and Gait. Each of them contains two or more experimental protocols which are described in detail.

A tool in Matlab supporting evaluation according the developed methodology was designed. This tool helps with assessing of particular phases and markers in a given type of experiment. This method is subjective because of a hand-operated marking. Multiple-criteria decision analysis was used for evaluation.

First of all the experimental measuring with healthy participant was performed. Second part of experimental measuring was verification of experimental measuring with another healthy participant. The evaluation of the best position of a wearable device was done by the developed methodology.

Then the practical measuring with three seniors was performed. Seniors’ movement was different considering the experimental measuring when participants were strictly directed by experimental protocols.

The most interesting part of the measuring was analysis of the blind record for the final evaluation of suitability of the chosen wearable device positioning. The participant was freely moving in his own home environment. After the measurement was done it was evaluated without a knowledge of what exactly participant was doing during that time. Every movements and their phases were detectable in a signal of the blind record. Evaluation of the blind measuring was as successful. According to all these results the wearable device positioning on an arm is the best choice for daily activities monitoring.

ANOTACE

Hlavním cílem této diplomové práce Monitorování denní aktivity pomocí zařízení s akcelerometry je výběr nejlepší varianty umístění takového zařízení. Populace stárne a vzhledem k tomuto faktu můžeme očekávat různé změny ve světovém zdravotnickém systému. Velký důraz je kladen na seniory a jejich co nejdelší pobyt v jejich domácím prostředí. V opačném případě by zdravotní péče jako taková byla nákladnější. Vyvstává potřeba technického řešení, které by bylo schopno monitorovat denní aktivitu seniorů.

Bylo zkonstruováno zařízení s akcelerometrem a také vytvořena jeho dokumentace. Hlavními součástkami jsou Motion Processing Unit MPU-6050 a Bluetooth HC-06. Byly vytvořeny experimenty a experimentální protokoly k verifikaci individuálních umístění zařízení. Třemi hlavními experimenty jsou experimenty se židlí, s postelí a při chůzi. Každý z těchto experimentů obsahuje dva či více experimentálních protokolů, které jsou detailně popsány.

Zpracování dat v Matlabu a metodologie vyhodnocení užitečnosti signálu byla založena na vytvořených funkcích, které umožňují získat naměřená data ze senzoru MPU-6050 a dále provést jejich předzpracování.

Metodologie pro vyhodnocení signálů je založena na nástroji, který byl vytvořen v Matlabu. Tento nástroj pomáhá se zhodnocením určitých fází a značek pro specifický typ experimentu. Tato metoda je subjektivní díky ručnímu označování těchto fází. Pro vyhodnocení výsledků byla použita vícekriteriální analýza kombinovaná s váženou lineární funkcí.

Všechna data byla analyzována. Nejprve bylo provedeno experimentální měření se zdravým účastníkem. Druhou částí experimentálního měření bylo měření verifikační s dalším zdravým jedincem. Tyto výsledky byly porovnány s ohledem na vhodnost umístění zařízení.

Po obou těchto měřeních bylo vybráno nejvhodnější umístění zařízení pomocí vytvořené metodologie. Rozsah výsledných hodnot pro každý experiment byl přepočítán a normalizován. Následně byl určen součet výsledků pro každé umístění a poté tyto výsledky porovnány. Na základě provedeného experimentálního měření bylo jako nejvhodnější umístění vybráno umístění zařízení na paži jedince.

Poté bylo provedeno praktické měření. V jeho první části byli pozorováni a měřeni senioři během tří hlavních experimentů, přičemž nebyli obeznámeni s předchozím experimentálním měřením. Pohyb seniorů byl odlišný od experimentálního měření, které bylo striktně řízeno experimentálními protokoly. Nicméně hlavní značky a fáze pohybů byly dobře či částečně detekovatelné.

Nejzajímavější částí měření byla analýza slepého záznamu pro konečné zhodnocení vhodnosti vybraného umístění zařízení, kdy se první zdravý účastník volně pohyboval ve svém domácím prostředí. Po skončení měření byl výsledek analyzován bez znalosti, které úkony účastník během záznamu prováděl. Každý pohyb a jeho fáze byla ve slepém signálu detekovatelná a takovéto měření může být tedy označeno jako úspěšné. Vzhledem ke všem těmto dosaženým výsledkům se umístění zařízení na paži jedince jeví jako nejvhodnější pro monitorování jeho denní aktivity.

KEYWORDS

Accelerometers, aging, daily activity, fall, gait, monitoring

KLÍČOVÁ SLOVA

Akcelerometry, stárnutí, denní aktivita, pád, chůze, monitorování

1 INTRODUCTION

One of the main theme for United Nations Department of Economic and Social Affairs, Population Division (UN DESA PD), is monitoring of the global population aging. It is now a well-established fact. [38]

Following this worldwide situation a need of a new approach to world healthcare system arises. At present, it is quite clear that if we want to limit the costs of health and long-term care, we have to make better use of modern technology [47] namely for prediction. The analysis of social service [48][49][50] suggests that it is also important to take into account more technical and expert and aspects.

The institutional care comes to be costly so there is a need that seniors could remain at home as long as possible. They can freely move in their own home environment which could be equipped with some system for monitoring. So their home could become to be an intelligent building by usage of telemedicine. Such systems could be helpful to prediction of dangerous states or for individual analysis of senior's behavior.

This thesis focuses to daily activities monitoring by device with accelerometer. Experimental protocols based on initial behavior analysis during the senior's daily routine will be designed. The experimental and verification measuring will be provided with two healthy participants without any history of orthopedic injury or conditions likely to affect their nature movement. For practical measuring three seniors were chosen.

Through measuring of movements the most suitable wearable device positioning will be selected as the best placement of sensor for daily activities monitoring.

2 THEORETICAL PART

The idea of such a device which could be easily worn during all daily activities is based on a future needs of rapidly aging society. The first chapter of a theoretical part 2.1.1 discusses a population aging, its expectations and impact on the world economy. Assistive technologies are on the increase in present and this situation brings opportunities in their exploitation. The second chapter 2.1.2 presents assistive technologies which could be used for instrumented assessments of physical functioning that are feasible for home monitoring as a much debated topic. Chapters 2.1.3 and 2.1.4 describe possible technical solutions of daily monitoring for old people and who actually these eligible patients could be.

At first place it is necessary to perform literature and existing device research with respect to various wearable device positioning. Both for commercial devices which have been already placed on the market 2.1.4.1 and also for existing projects 2.1.4.2.

Since the device has to use accelerometers the knowledge about its working principle (2.2.2) is required. For a study a motion processing unit MPU-6050 was chosen. This unit combines a 3-axis gyroscope and a 3-axis accelerometer. So a principle of gyroscope is explained in a chapter 2.2.1.

2.1 LITERATURE REVIEW

There were mentioned some of interesting topics in an introduction chapter and on the following pages they will be discussed more deeply. The first part investigates population aging problem (2.1.1) which leads to the discussion about opportunities in an exploitation of assistive technologies (2.1.2) and possible technical solution for old people daily monitoring (2.1.4) and who actually these eligible patients are (2.1.3).

The main goal of this theoretical part of literature review is to become familiar with commercial devices which have been already placed on the market (2.1.4.1) but also with existing projects (2.1.4.2). The most important there are the synoptic tables (TABLE 2), (TABLE 3) and a charts (PIC. 1) and (PIC. 13) referring to a positioning of sensors which have been used.

2.1.1 POPULATION AGING

According to the World Health Statistics 2014 [01] [12] people everywhere are living longer.

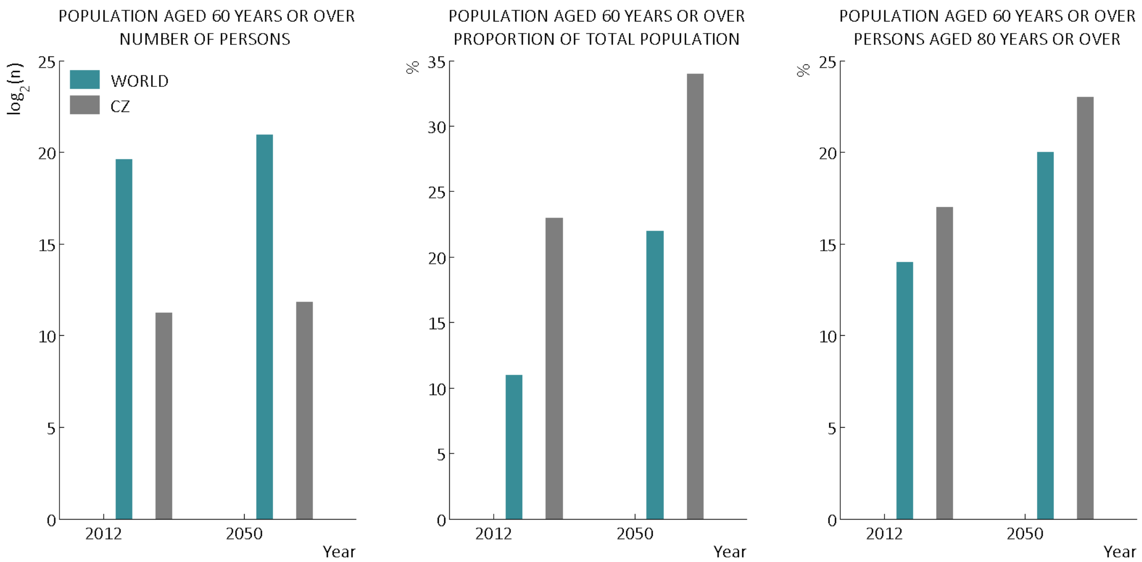


FIGURE 1: POPULATION AGED 60 YEARS OR OVER

In 2050 older persons will outnumber the population of children (0-14 years) for the first time in human history. One out of every nine persons in the world is aged 60 years or over. By 2050, one out of every five persons is projected to be in that age group. The older population is itself ageing. Currently, the oldest old population (aged 80 years or over) accounts for 14 percent of the population aged 60 years or over. The oldest old is the fastest growing age segment of the older population. By 2050, 20 percent of the older population will be aged 80 years or over [13] as shown in FIGURE 1.

The number of centenarians is growing even faster and is projected to increase tenfold from approximately 343,000 in 2012 to 3.2 million by 2050. The majority of older persons are women. In 2012 there are 84 men per 100 women among older persons, and only 61 men for every 100 women among the oldest old.[13]

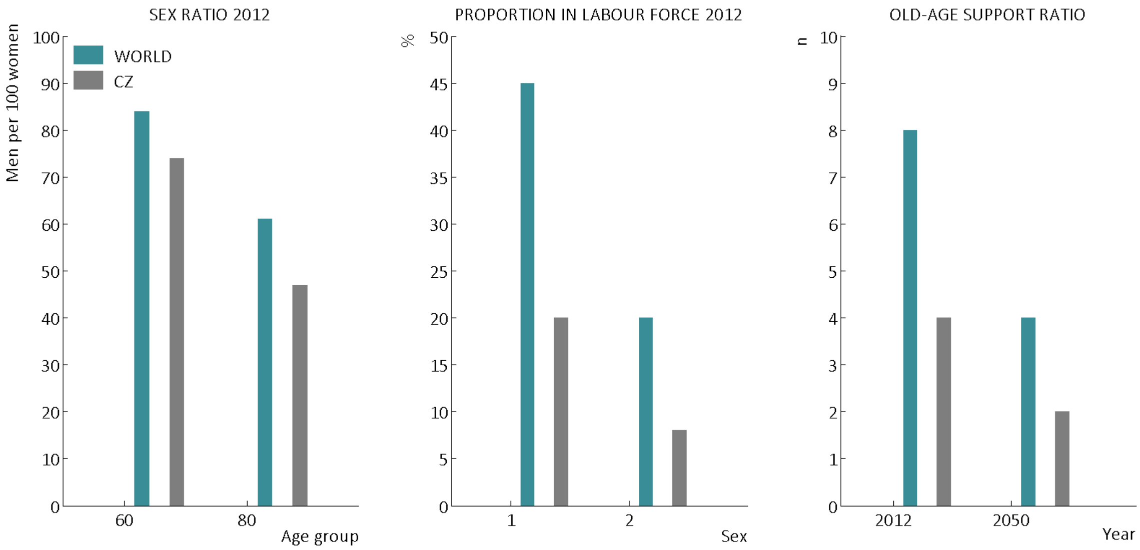


FIGURE 2: POPULATION AGED 60 YEARS OR OVER - PROSPECTIVE LABOUR FORCE

The old-age support ratio (dependency of older persons on potential workers) fell from 12 to 8 working-age persons for each older person between 1950 and 2012, and is projected to further decrease to 4 by 2050. [13] All is shown in FIGURE 2.

Considering this fact we can expect lot of changes in approach of the worldwide health system. Population is aging. That entails also the economic structure alteration. There will not be enough space for seniors and insufficiency of a staff in a long-term institutional care. This approach comes to be costly.

It is of the utmost importance that persons aged 65+ could remain at home as long as possible. It is not only due to decreasing tendency of a hospital or old people's home staff but also for their own good and possibility to stay with their families. Thus the technical solution that will be able to individualization according to the patient has to be developed. And such a device would enable them to stay at home with their families a longer.

2.1.2 OPPORTUNITIES IN AN EXPLOITATION OF ASSISTIVE TECHNOLOGIES

Assistive technology is one of many opportunities that are necessary to reduce the disabling influence of many environments. Technology is a ubiquitous part of our everyday lives, which for the most part, makes our daily tasks simpler to do. [35]

For an early diagnosis several different clinical tests exist, such as the Timed Get-up-and-go, the Berg Balance Scale, and the Tinetti Balance Scale. Those tests can be used to predict the risk of falling. Falls are a major problem. Factors that augment the risk of falling are muscular weakness [27], previous fall [28] and balance problems, visual, vestibular, or proprioceptive problems [29].

But unfortunately those tests are not able to identify progressive changes in fall risk. However, these measures have never been integrated into a home-based test. [30]

More recently, gait has been used as a biometric trait for identification purposes. [31] The hypotheses related to gait analysis are generally very restrictive: fixed camera, gait at a constant velocity, a frontoparallel approach in relation to the camera, all of the subjects visible, constant luminosity, absence of distractions, and so forth.

It has to be said that instrumented assessments of physical functioning that are feasible for home monitoring have not been adequately resolved and it is a much debated topic.

In these days lot of devices have been invented which are used for a real time position reporting (GPS location, fall detection, entering/leaving geo-fences reporting) and also for an emergency call by SOS button. The indoor navigation systems are slowly becoming commonplace. But there is still a gap in the global market. We already know how to prevent to a fall, how to detect a fall but what we really want to determine, is how to predict fall or early diagnose a disease just by an observation of potential patient in his own home environment. And this is an opportunity in an exploitation of assistive technologies to use small and lowcost sensors to get and process data which would have been leading us to a novel results about the patient's daily activities in his own environment.

2.1.3 ELIGIBLE PATIENTS FOR MONITORING

Such as was already mentioned in an opening of the thesis device potentially usefulness is high in case of using it for seniors. For example Alzheimer disease (2.1.3.1) is the most common type of dementia but still the right diagnostic (2.1.3.2) of this disorder is weak and comes usually when a person suffers from advanced stage of the disease.

2.1.3.1 ALZHEIMER DISEASE

Alzheimer's disease is the most common cause of dementia. It is a physical progressive disease that affects the brain. During the course of the disease, proteins build up in the brain to form structures called plaques and tangles. This leads to the loss of connections between nerve cells, and eventually to their death and loss of brain tissue. [32]

There are some common symptoms of Alzheimer's disease. In particular, they may have difficulty recalling recent events and learning new information. These symptoms occur because the early damage in Alzheimer's is usually to a part of the brain called the hippocampus, which has a central role in day-to-day memory. Memory for life events that happened a long time ago is often unaffected in the early stages of the disease. [32]

TABLE 1: SYMPTOMS OF ALZHEIMER'S DISEASE

	THE PERSON MAY:
1	Lose items (keys, glasses) around the house
2	Struggle to find the right word in a conversation or forget someone's name
3	Forget about recent conversations or events
4	Get lost in a familiar place or on a familiar journey
5	Forget appointments or anniversaries
6	Problems judging distance or seeing objects in three dimensions (parking the car become much harder, problems with gait and navigating stairs)
7	Concentrating, planning or organizing – difficulties making decisions, solving problems or carrying out a sequence of tasks (cooking a meal)
8	Orientation – becoming confused or losing track of the day or date

As Alzheimer's progresses, problems with memory loss, communication, reasoning and orientation become more severe. Some people start to have delusions or hallucinations.

In the later stages of Alzheimer's disease someone may become much less aware of what is happening around them. They may have difficulties eating or walking without help, and become increasingly frail. Eventually, the person will need help with all their daily activities. On average, people with Alzheimer's disease live for eight to ten years after the first symptoms. [32]

An early diagnosis has many benefits: it provides an explanation for the person's symptoms; it gives access to treatment, advice and support; and it allows them to prepare for the future and plan ahead. There is no single test for Alzheimer's disease but there is a standard procedure:

- The doctor will first need to rule out conditions such as infections, vitamin and thyroid deficiencies (from a blood test), depression and side effects of medication.
- The doctor will also talk to the person, and where possible someone who knows them well, about their medical history and how their symptoms are affecting their life. Then the doctor may ask the person to do some tests of mental abilities.
- The doctor can generally refer the person to a specialist. This could be an old-age psychiatrist, a geriatrician, a neurologist, or a general adult psychiatrist.
- The person may undergo a brain scan, which can show whether certain changes have taken place in the brain. The most widely used are CT (computerized tomography) and MRI (magnetic resonance imaging).

DSM-IV Criteria for the Diagnosis of Alzheimer's Disease is placed in the attachment.

There is currently no cure for Alzheimer's disease, but there is a lot that can be done to enable someone to live well with the condition. This will involve drug and non-drug care, support and activities. There are drug treatments for Alzheimer's disease that can temporarily alleviate some symptoms or slow down their progression in some people. The drug may help with memory problems, improve concentration and motivation, and help with aspects of daily living such as cooking, shopping or hobbies. [32]

2.1.3.2 OBSERVING OF SYMPTOMS

Nevertheless some of symptoms are possible to observe earlier if we are not indifferent to them. There are placed many of a senior's family members' video confessions who was diagnosed with Alzheimer disease.

In most cases those family members try to retrospectively determine in which part of a life their close senior was while went through specific stage of Alzheimer disease. Family members go through their family photos and movies or share their stories with their elderly. For example in the video [34] is seen difference in speech whether a walk.

After consideration of the possibility of such observations so far undiagnosed seniors a motion of a patient appear to be the most significant. Not only that changes in their walking are able to be detectable, it is also possible to observe their movement related with behavior.

Symptoms such as forgetting personal things or their swapping on strange places are often downplayed. Such a movement is already possible describe by logic. Puzzled crossing the room at their own home, longer downtime in walk or direct localization of personal belongings such as keys, cell phone, and so on.

2.1.4 TECHNICAL SOLUTION FOR DAILY MONITORING

Pursuant to the conclusion of chapter 2.1.1 the technical solution that will be able to individualization according to the patient has to be designed. Such a system allows patients to prolong autonomy in their own home without the need for supervision

For patients with neurodegenerative diseases for daily activity monitoring it is most viable system including wearable device with accelerometers and data processing. The question is where to optimally place this wearable device considering the type of activity in a home environment.

With respect to various wearable device positioning the literature and existing device research was performed.

2.1.4.1 COMMERCIAL PRODUCTS

A great majority of falls in ageing people result from a combination of factors. The aging process itself is one of these factors. Other contributing factors include chronic health problems (diseases of heart, problems in eyes, poor vision, muscle weakness, dementia, arthritis etc.), physical and functional impairments (lower extremity weakness, balance disorders), medications and alcohol abuse, and hazards and obstacles in the home (poor lighting, lack of bathroom safety equipment, loose carpets). [23] Currently, an automated method for accurately recording falls is not available.

On the market there are lot of various devices but ultimately are all very similar. Six existing devices were selected for comparison their functions, usability, construction, price and positioning. Data collation is shown in a synoptic table (TABLE 2) and in a chart below. (PIC. 1)

POSITIONING OF COMMERCIAL PRODUCTS

ARM

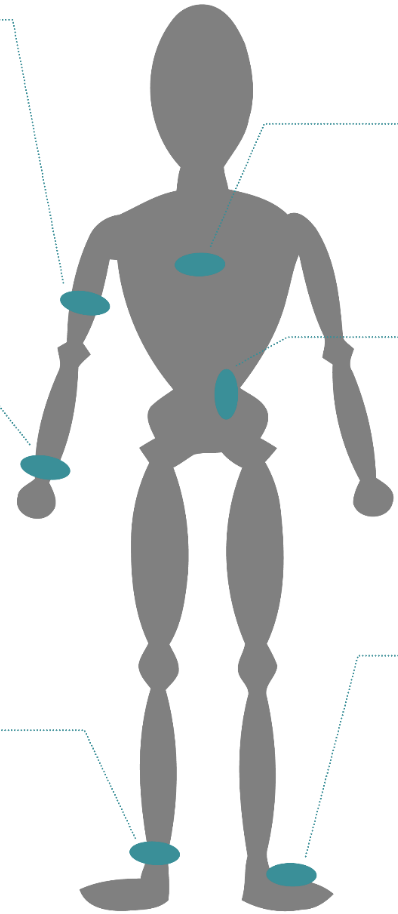
ENDOMONDO SPORTS TRACKER
FADE: FALL DETECTOR
FALL DETECTOR
MAN DOWN APP
NIKE+
RUNTASTIC PRO
SPORTS TRACKER
THE CAREBEACON MEDICAL ALERT

WRIST

LAIPAC S911 BRACELET - LAIPAC TECHNOLOGY, INC.
FITBIT FLEX - FITBIT, INC.
FIT SMART - ADIDAS GROUP
SMART RUN - ADIDAS GROUP
NIKE+ FUELBAND SE - NIKE, INC.
FORERUNNER 220 - GARMIN CZECH, S.R.O.
IHEALTH EDGE AM3S - IHEALTH LAB INC.

ANKLE

APDM MOVEMENT MONITORS
- SAPPHIRE
- EMERALD
- OPAL



NECK

LAIPAC S911 LOLA - LAIPAC TECHNOLOGY, INC.
PERSONAL INSPECT - CLEVERTECH, S.R.O.
DIRECTLIFE - PHILIPS

BELT

FITBIT ONE - FITBIT, INC.
DIRECTLIFE - PHILIPS

SHOE

SPEED_CELL - ADIDAS GROUP

PIC. 1: POSITIONING OF COMMERCIAL PRODUCTS

LAIPAC S911 BRACELET - LAIPAC TECHNOLOGY, INC.

This is a wearable device with positioning on a wrist. (PIC. 2) Among those bracelets apparatuses is this one most voluminous and heaviest. On the other side it disposes of more functions and usability than another of this type which are nowadays mostly called fitness bracelets. It is used for a real time position reporting (GPS location, fall detection, entering/leaving geo-fences reporting) and also for an emergency call by SOS button. [15]

PIC. 2: LAIPAC S911 BRACELET [PIC01]

FITBIT FLEX - FITBIT, INC.

Unlike previous technical solution of Laipac Technology, Inc., this one is 5x smaller and 13x lighter. Compare (PIC. 2) and (PIC. 3). But unfortunately it does not allow anything than data recording from its accelerometer inside. There is no possibility to a real time position reporting by GPS or Bluetooth communication for this device. [14]

PIC. 3: FITBIT FLEX [PIC03]

FITBIT ONE - FITBIT, INC.

Other solution of Fitbit, Inc. is Fitbit One. (PIC. 4) This is not a bracelet anymore. This is a clip-based device that tracks steps, distance, calories burned, floors climbed and sleep. [14]

Thus all functions are the same as for Fitbit Flex but because of the silicone clip this one is wearable in a pocket or on a belt. [14]

PIC. 4: FITBIT ONE [PIC04]

LAIPAC S911 LOLA - LAIPAC TECHNOLOGY, INC.

Laipac Technology, Inc. also developed device wearable on a neck. (PIC. 5) This is an ultra-small pendant GPS Location device with 2 way voice and real-time tracking. It has G sensor for man-down alert and geo-fencing capability. [15]

PIC. 5: LAIPAC S911 LOLA [PIC02]

PIC. 6: PERSONAL INSPECT [PIC05]

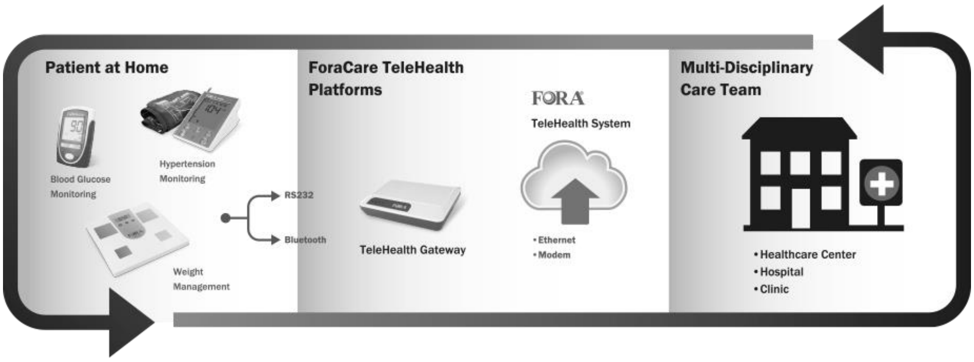
PERSONAL INSPECT - CLEVERTECH, S.R.O.

Similar to s911 Lola is a Czech product Personal Inspect which was developed in cooperation with CTU FBMI. This device is one of a kind on the national market. Unlike previous technical solution of Laipac Technology, Inc., this one is 4x greater and 1.5x heavier. Compare (PIC. 6) and (PIC. 5). It's also interesting that price of this solution is about 33 US$ more expensive than s911 Lola though there is no functions such as entering/leaving geo-fences reporting or data recording. [52]

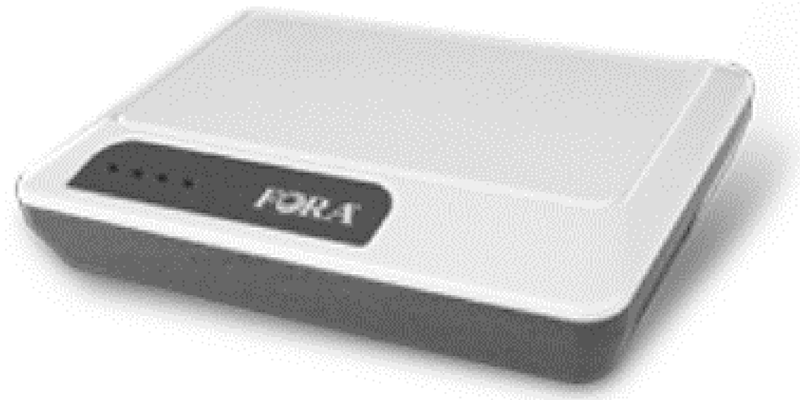
TELEHEALTH GATEWAY GW9014 - FORA CARE, INC.

This technical apparatus (PIC. 8) developed by Fora Care, Inc. differs from all previous devices by its primary function. It works as data receiver and transmitter which helps to manage the data easily and remotely.

By using this product data can be monitored and analyzed effectively through the connection to the server [16] as can be seen in the PIC. 7. Bluetooth (GW9014B)/RS232 (GW9014A)/Ethernet/Dial-Up is used here.



PIC. 7: FORA CARE SOLUTION [PIC06]



PIC. 8: TELEHEALTH GATEWAY GW9014 [PIC06]

TABLE 2: COMPARISON OF SELECTED EXISTING TECHNICAL SOLUTIONS

ID	PRODUCT NAME	MANUFACTURER	PROPORTIONS	WEIGHT	PRICE	POSITIONING	DATA COMMUNICATION/TRANSMISSION
1	Laipac s911 Bracelet	Laipac Technology, Inc.	5.0 x 4.4 x 1.5 cm	110.0 g	223.53 US$	Wrist	GSM/GPRS Quad-band 850/900/1800/1900MHz
2	Laipac s911 Lola	Laipac Technology, Inc.	5.4 x 4.0 x 1.6 cm	44.3 g	156.94 US$	Neck	GSM/SMS/GPRS/2 Way Voice
3	TeleHealth Gateway GW9014	Fora Care, Inc.	17.0 x 12.0 x 3.0 cm	221.8 g	159.99 US$	-	Bluetooth (GW9014B)/Ethernet/Dial-Up
					99.99 US$	-	RS232 (GW9014A)/Ethernet/Dial-Up
4	Fitbit Flex	Fitbit, Inc.	20.8 x 1.5 x 1.0 cm	8.5 g	99 US$	Wrist	Bluetooth 4.0
5	Fitbit One	Fitbit, Inc.	4.8 x 1.9 x 0.9 cm	9.0 g	99 US$	Belt	Bluetooth 4.0
6	Personal Inspect	CleverTech, s.r.o	8.4 x 0.5 x 0.2 cm	65.0 g	190.38 US$	Neck	GSM Quad-band 850/900/1800/1900MHz

TABLE 3: TECHNICAL SPECIFICATION OF SELECTED EXISTING DEVICES

ID	PRODUCT NAME	FUNCTIONS							
		GPS LOCATION	FALL DETECTION	REAL TIME POSITION REPORTING	ENTERING/LEAVING GEO-FENCES REPORTING	DATA RECORDING	CONFIGURATION	SOS BUTTON	STATUS INDICATION
1	Laipac s911 Bracelet	o	o	o	o	o	o	o	o
2	Laipac s911 Lola	o	o	o	o	o	-	o	o
3	TeleHealth Gateway GW9014	-	-	-	-	-	o	-	o
4	Fitbit Flex	-	-	-	-	o	-	-	o
5	Fitbit One	-	-	-	-	o	-	-	o
6	Personal Inspect	o	o	o	-	-	-	o	o

ID	PRODUCT NAME	HARDWARE									
		MICROPHONE	SPEAKER	VIBRATIONS	BATTERY	POWER	GYROSCOPE	ACCELEROMETER	DISPLAY	USB PORT	MEMORY
1	Laipac s911 Bracelet	o	o	-	o	o	-	o	o	o	o
2	Laipac s911 Lola	o	o	o	o	-	-	o	-	-	o
3	TeleHealth Gateway GW9014	-	-	-	o	o	-	-	-	-	-
4	Fitbit Flex	-	-	o	o	o	o	o	-	o	o
5	Fitbit One	-	-	o	o	o	o	o	o	o	o
6	Personal Inspect	o	o	-	o	o	-	o	-	-	-

2.1.4.2 EXISTING PROJECTS RESEARCH

In these days the lot of companies, laboratories or universities are trying to design and develop a new technology for seniors monitoring. The devices should allow detection and possibly prediction of dangerous states of the client such as for example falls. List of such projects is shown below.

Existing research projects aim to provide a thematic network focusing on the issue of promoting healthy, independent living for older adults (e.g. FARSEEING [17]) and focusing on falls prevention (e.g. ProFouND [18]).

WEARABLE SENSOR-BASED IN-HOME ASSESSMENT OF GAIT, BALANCE, AND PHYSICAL ACTIVITY FOR DISCRIMINATION OF FRAILTY STATUS

This project comes with an idea to discriminate frailty status and to discrimination between frailty levels. Wearable sensors were used [19] such as 3-axis accelerometer in mid-chest pocket for 48 hrs. [20]

Temporal-spatial gait parameters (speed, stride length, stride time, double support, and variability of stride velocity) and physical activity (percentage of walking, standing, sitting, and lying; mean duration and variability of single walking, standing, sitting, and lying bouts) were measured. Gait speed, hip sway, and steps/day were the most sensitive parameters for the identification of prefrailty. Stride length and double support were the most sensitive gait parameters for discriminating between three frailty levels. [19]

DETECTING HUMAN FALLS WITH 3-AXIS ACCELEROMETER AND DEPTH SENSOR

Mr. Kepski and Mr. Kwolek presented a novel approach to fall detection applying Kinect sensor [21] to achieve reliable fall detection in larger areas. High sensitivity and specificity can be obtained using dense depth images acquired by a ceiling mounted Kinect and executing the proposed algorithms for lying pose detection and motion analysis. [21]

CHOICE STEPPING REACTION TIME TEST USING EXERGAME TECHNOLOGY FOR FALL RISK ASSESSMENT IN OLDER PEOPLE

Stepping is a common task to avoid a fall and stepping reaction time has been associated with recurrent falls in older people. [22]

Spatial and temporal measurements of the lower and upper body were derived from a low-cost and portable 3D-depth sensor Microsoft Kinect and 3D-accelerometer. Fallers had a slower stepping reaction and a slower reaction of their upper compared to non-fallers. It took fallers significantly longer than non- fallers to recover their balance after initiating the step. Researcher were able to identify significant differences between performances by fallers and non-fallers. [22]

FATE - FALL DETECTOR FOR THE ELDERLY PROJECT

The solution focused on improving the elder's quality of life by an accurate detection of falls in ageing people, both at home and outdoors. This is done by implementing an accurate, portable and usable a highly sensitive fall detector (PIC. 9) incorporating accelerometers that runs an algorithm to detect falls, and a telecommunications layer based in wireless technologies. [23]

PIC. 9: FATE - FALL DETECTOR FOR ELDERLY PROJECT [PIC07]

It consists of an indoors telecommunications network based in ZigBee, a central computer (with or without Internet connection) and a mobile phone communicated with the central computer and the fall sensor via Bluetooth. All incidents and measures will be stored in the server, so that they can be used as a monitoring data for the carers/doctors thus improving subject fall prevention and treatment. [23]

Secondary element is a bed presence sensor to dismiss false fall positives that tend to happen if the person lies in the bed in a sudden way while wearing the fall detector. To control the time the person spends in bed and also to detect falls from the bed. [23]

WISEL - WIRELESS INSOLE FOR INDEPENDENT & SAFE ELDERLY LIVING

The main goal of WIISEL is to develop a flexible research tool to collect and analyze gait data from real users and correlate parameters related with the risk of falls from the elderly population. The potential utility is enabling the early identification of functional mobility decline in performance (i.e. assessment of motor fluctuations and disease progression) and enabling fall detection in the home setting. [24]

PIC. 10: WISEL TECHNICAL SOLUTION [PIC08]

The WIISEL tool will consist of a combination of a flexible software platform together with wearable insole device collecting data related with gait. Risk of falls will be assessed based on multiple gait parameters and gait pattern recognition. Thanks to a wireless system and several sensors embedded into the insole, the data captured by the movement of the foot are sent first to a mobile device and later to a server, so that the evolution of a patient can be monitored remotely in terms of gait, fall risk, activity and mobility. (PIC. 10) [24]

PIC. 11: WISEL INSOLES PROTOTYPES [PIC08]

The main progress of the work till May 2013 was that the final design maximizes battery duration, comfort and usability. [24]

During the period since May 2013 till November 2013 first insoles prototypes (PIC. 11) have been developed, which include 14 sensors in each insole, a combined 3-axis accelerometer and 3-axis gyroscope to monitor the chosen spatial and temporal parameters as fall risk indicators. As for the data analysis, the feasibility of the pattern recognition algorithm has been confirmed and a data analysis and prediction framework has been designed and developed. [24]

And today’s situation is really interesting for a market because the WIISEL insole system was successfully tested by elderly in Ireland and Israel. [24]

A STUDY OF POSITION INDEPENDENT ALGORITHMS FOR PHONE-BASED GAIT FREQUENCY DETECTION

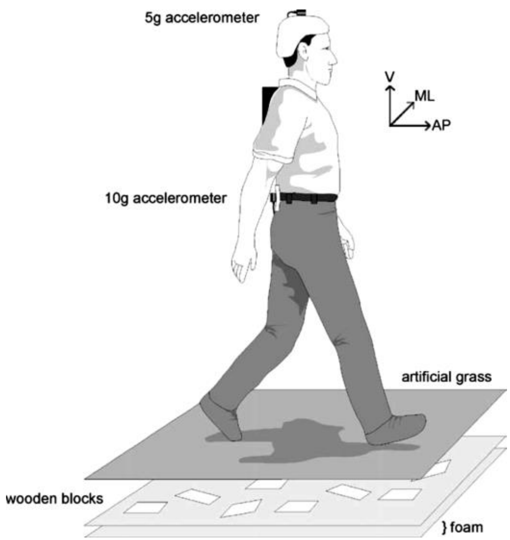
The main issue with smartphone-based gait frequency estimation algorithms is how to adjust for variations in orientation and location of the phone on the human body. Researchers use sensor data collected from volunteers walking with a smartphone exploiting kinematic sensors and test two different methods of extracting step frequency: time domain peak counting and spectral analysis. [25]

This study suggests a hybrid approach where both time-domain and spectral approaches be used together to complement each other's shortcomings. [25]

ACCELERATION PATTERNS OF THE HEAD AND PELVIS WHEN WALKING ON LEVEL AND IRREGULAR SURFACES

The aim of this study was to evaluate acceleration patterns at the head and pelvis while subjects walked on a level and an irregular walking surface, to develop an understanding of how the postural control system responds to challenging walking conditions. Linear accelerations of the body were measured along three orthogonal axes using two tri-axial piezo-resistant accelerometers. [44]

The head accelerometer was mounted on the top of a lightweight foam bicycle helmet. The pelvis accelerometer was affixed to a plate firmly strapped onto the subject with a belt at the level of the sacrum. (PIC. 12) The accelerometers were connected to a light-weight laptop computer via a data acquisition card interface and both were housed in a small backpack. The entire apparatus weighed 2.5 kg.



PIC. 12: WALKING ON IRREGULAR SURFACE [PIC09]

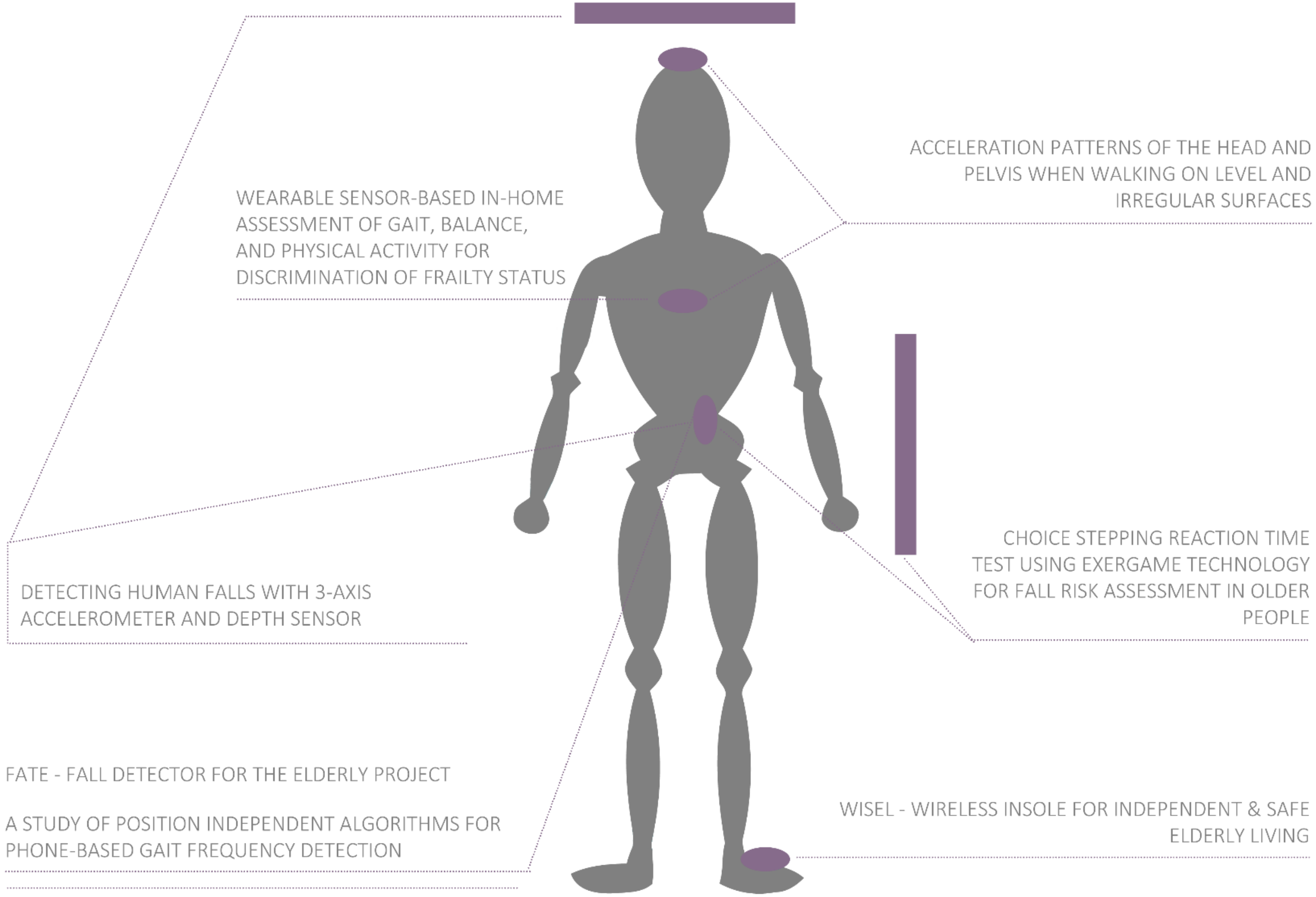
The shoe sole hardness [45] and heel height [46] influence balance performance and footwear also influences walking speed. To control for this potential confounding influence, all subjects were provided with standard Oxford-style lace-up shoes with a suede upper and nitrile rubber sole. [44]

A 20 m long walkway consisted of 5 mm-pile artificial grass underlain with two layers of 20 mm-thick soft foam rubber and 20 mm thick wooden blocks of varying sizes and shapes in an arbitrary manner was constructed to provide a partially yielding, irregular walking surface. Head and pelvis accelerations were sampled at 200 Hz. [44]

The following variables were then calculated. Walking velocity (m/s), cadence (steps/min), average step length (cm), walk ratio, acceleration root mean square (RMS), acceleration amplitude variability and harmonic ratio. [44]

When walking on the irregular surface, significantly greater accelerations were evident at the pelvis in all three directions. [44]

POSITIONING OF DEVICES IN PROJECTS



PIC. 13: POSITIONING OF PROJECTS

2.2 GYROSCOPE AND ACCELEROMETER

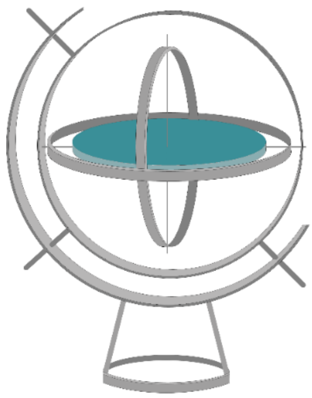
The most important for a practical part of the thesis is a knowledge of gyroscope and accelerometer principles. Gyroscope detects a rotational motion, more precisely steady rotational motion and is specified in the chapter 2.2.1. On the other side, an accelerometer measures a value of deflection of an internal MEMS structure such a result of acceleration and its principle is explained in the chapter 2.2.2. The overview about MEMS technology comes below in the chapter 2.2.3.

2.2.1 GYROSCOPE

Gyroscope is a device for measuring orientation. It uses the principle of preserving angular momentum.

Gyroscopes exist on several operating principles such as the mechanic, electronic, microchip-packaged MEMS gyroscope devices found in consumer electronic devices, solid-state ring lasers, fiber optic gyroscopes, and the extremely sensitive quantum gyroscope. [39] Mechanical gyroscope (PIC. 14) typically comprise a spinning wheel or disc in which the axle is free to assume any orientation. [40]

Within mechanical devices a conventional gyroscope is a mechanism comprising a rotor journaled to spin about one axis the journals of the rotor being mounted in an inner gimbal which is journaled for oscillation in and outer gimbal for a total of two gimbals. [41] Specific application of gyroscopes include inertial navigation systems for their precision, i.e. telescopes, ballistic missiles, flying vehicles and in tunnel mining. [42]



PIC. 14: MECHANICAL MODEL OF GYROSCOPE

Gimbals allow rotation about two crossed axes. The gimbals linkage is likely the older of the two having roots in China and Tibet. There is much evidence that the invention appeared in China and/or Tibet as artifacts have been found with gimbals dating to around 500 CE. This mechanism was likely part of a universal kinematic language in several parts of the world and may not have a unique inventor but the most speculated is Leonardo da Vinci. [43]

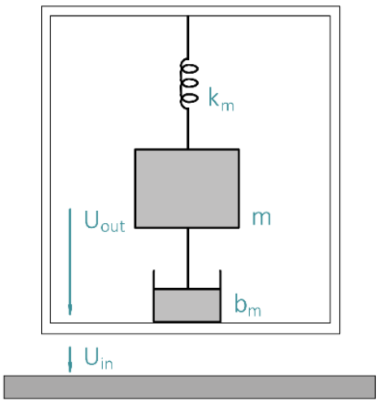
The outer gimbal is mounted so as to pivot about an axis in its own plane determined by the support. The inner gimbal is mounted in the gyroscope frame so as to pivot about an axis in its own plane that is always perpendicular to the pivotal axis of the gyroscope frame. The axle of the spinning wheel defines the spin axis.

2.2.2 ACCELEROMETER

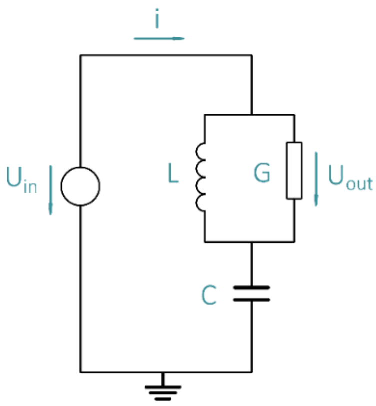
Accelerometers are used for acceleration measuring, vibrations and mechanical impacts (pulse load). Acceleration is defined as the first derivation of velocity and the second derivation of movement in time (2.1)

$$a = \frac{\mathrm{d}v}{\mathrm{d}t} = \frac{\mathrm{d}^2 x}{\mathrm{d}t^2} \tag{2.1}$$

Principle of the most of accelerometers is that a measuring mass element m which is in many cases called seismic or test element is driven in the system mass-spring-damping. (PIC. 15). [05]



PIC. 15: THE BASIC PRINCIPLE OF MECHANICAL ACCELEROMETER



PIC. 16: THE BASIC PRINCIPLE OF ACCELEROMETER IN ELECTRICAL DOMAIN

The accelerometer is the system in which the stress force $-m\,\mathrm{d}^2 x_{\mathrm{IN}}/\mathrm{d}t^2$ works in a damped harmonic oscillator circuit (PIC. 16) whose oscillations could be described by the

$$m\frac{\mathrm{d}^2 x_{\mathrm{OUT}}}{\mathrm{d}t^2} + b_m \frac{\mathrm{d}x_{\mathrm{OUT}}}{\mathrm{d}t} + k_m x = -m\frac{\mathrm{d}^2 x_{\mathrm{IN}}}{\mathrm{d}t^2} \tag{2.2}$$

equation (2.2). where b is a damping coefficient, k_{m} the mechanical elastic stiffness of the spring along the x direction and x_{out} is a relative shift of seismic mass towards to a fixed frame. When an acceleration conditions are constant than the shift x_{out} is directly proportional to an input acceleration $\mathrm{d}^2 x_{\mathrm{in}}/\mathrm{d}t^2$,it could be said that

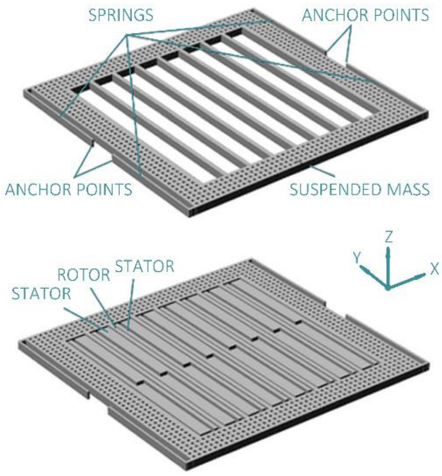
$$x_{\mathrm{OUT}} = \frac{m}{k_m}\frac{\mathrm{d}^2 x_{\mathrm{IN}}}{\mathrm{d}t^2} \tag{2.3}$$

In electrical domain (PIC. 16) a voltage is equal to a velocity and a transfer function could be formulated in a form (2.4) where Z_{LG} is a complex impedance of parallel combination of an inductance-conductivity and X_{C} expresses a capacitance. Majority of accelerometers works on a principle of transfer a test element to electrical signal. [05]

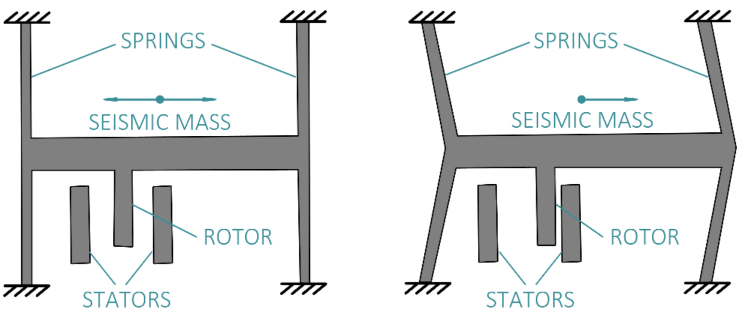
$$\frac{U_{\mathrm{OUT}}}{U_{\mathrm{IN}}} = \frac{Z_{\mathrm{LG}}}{X_{\mathrm{C}}+Z_{\mathrm{LG}}} \tag{2.4}$$

2.2.3 MEMS ACCELEROMETERS

PIC. 17 presents the schematic of uniaxial MEMS accelerometer with capacitive readout. The device comprises a seismic mass, constrained to move only in the x direction by a set of springs anchored to the substrate. A set of capacitive parallel-plate differential cells is used to sense the displacements of the seismic mass. Each capacitive cell comprises a moving part - rotor and two electrodes fixed to substrate – stators. With an acceleration occurs a movement against a steady state. (PIC. 18) [05]



PIC. 17: SCHEMATIC ILLUSTRATION OF A UNIAXIAL MEMES ACCELEROMETER



PIC. 18: PRINCIPLE OF A MEMS ACCELEROMETER: ACCELERATION CHANGE

MEMS technologies allow realization a parallel connection of dozens till hundred such differential capacitors. [05]

3 PRACTICAL PART

This chapter describes the practical part. The measuring board assembling will be presented here in 3.1. The documentation for assembling of this measuring board is a part of this chapter, as well as detailed information about main components. These are Motion Processing Unit MPU-6050 (3.1.2) and Bluetooth Modul HC-06 (3.1.3). For a practical usability for the wearable device, the measuring board was covered with a black plastic box and fixed to a black armband.

Solutions of measuring wearable device positioning will be presented in the chapter 3.2. Following the literature review the best positions for device were selected. The final set of placements contains caudal head arm, trunk, wrist, thigh, hip, knee and ankle. In subheads of this chapter the pros and cons of projected use of sensors will be presented.

In the chapter 3.3 experiments and an experimental protocol to verify individual solutions of measuring wearable device positioning are explained. The three main exercises are Chair, Bed and Gait. Each of them contains two or more experimental protocols, which will be presented in this chapter.

Data preprocessing in Matlab and the methodology of a signal evaluation usability could be find in chapters 3.4 and 3.5.

3.1 MEASURING BOARD

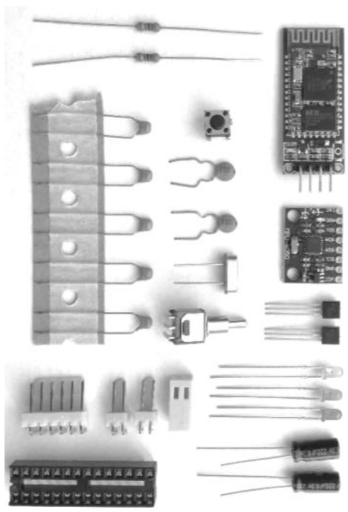
For experiments to verify individual solutions of measuring wearable device positioning the very device had to be constructed. Requirements for the device were accuracy, wearability, size and weight. Actually its size was something for discussion because this device is only for laboratory purpose so the minimalism was not the main aim. Assembling of measuring board is described in a chapter 3.1.1. Principal components are Motion processing unit MPU-6050 (3.1.2) and Bluetooth Modul HC-06 (3.1.3) both from Arduino. The documentation of a measuring board was done and it will be presented below.

3.1.1 ASSEMBLING OF A MEASURING BOARD

The measuring board was made based on a design provided by Ing. Petr Novák, PhD. For this thesis the board had to be made independently. First of all the components which are shown in TABLE 4 and PIC. 19 were bought in a shop and online. For realization the universal drilled PCB (printed circuit board) was chosen.

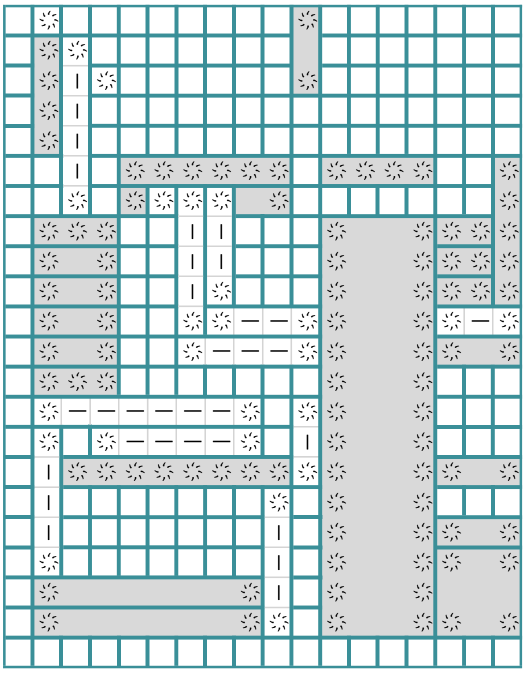
TABLE 4: SET OF MAIN COMPONENTS

QUANTITY	COMPONENT
2	HT7533-1
2	RRA 4X4k7
1	ARD-87 Arduino Bluetooth RF Modul HC-06 (SLAVE)
1	MPU 6050
1	AT mega 328
1	LED 5MM BLIK GREEN 20/30° LED 517GD-F
1	LED 5MM BLIK RED 20/30°
1	LED 5MM BLIK YELLOW 32/60° L-56BYD
2	CK 22p/50V NPO RM5,08 5%
5	CK 100n/63V Y5V RM5,08 20%
2	RM 4k7 0207 0,6W 1%
2	CE 220u/6,3V JAM-SK 5x11 RM2 BULK

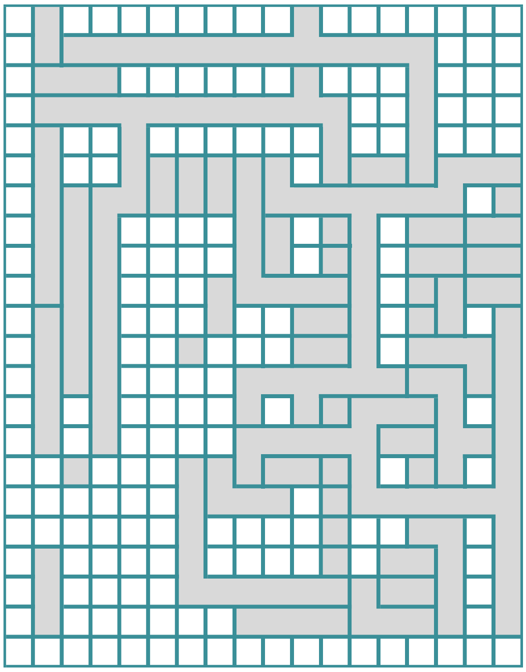


PIC. 19: COMPONENTS FOR ASSEMBLING OF MEASURING BOARD

Subsequently the draft of connections was drawn (PIC. 22) and a wiring was designed on a graph paper. The PCB was fitted with all components (PIC. 21) and soldered as the PIC. 20 shows.

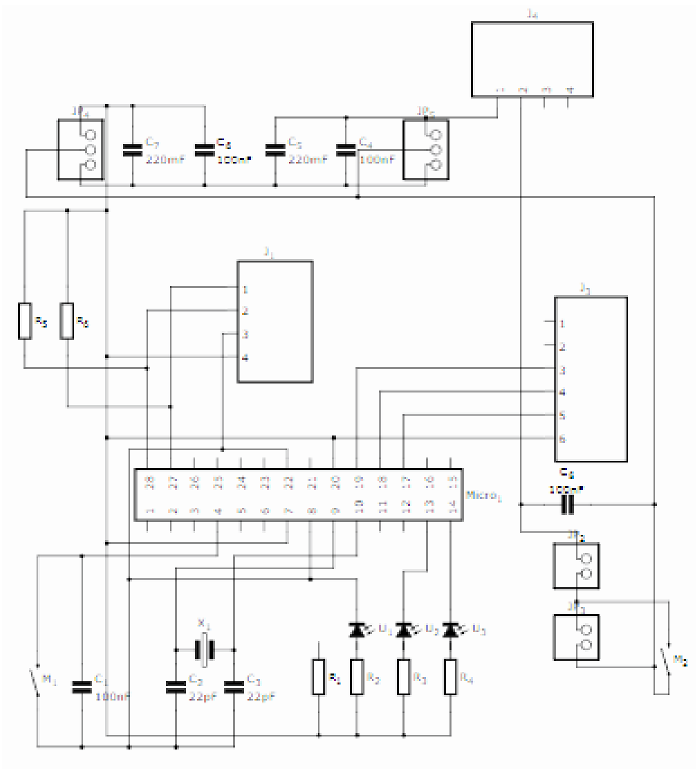


PIC. 21: PCB FITTED WITH ALL COMPONENTS



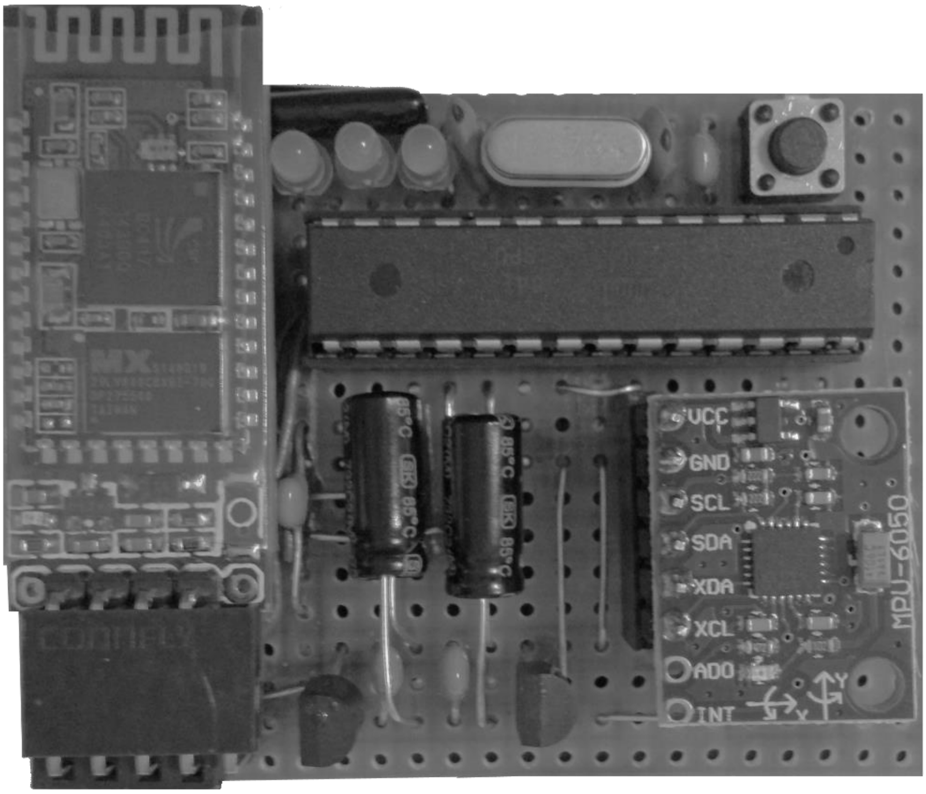
PIC. 20: PCB SOLDERED

The measuring board is primarily powered by 4 AA batteries but there is a connector for an adapter too. For measuring of acceleration the motion processing unit MPU-6050 was selected and its functions are described in the next chapter 3.1.2. For data transmission the Arduino Bluetooth Modul HC-06 (TABLE 4) (PIC. 19) was used.



PIC. 22: DRAFT OF CONNECTIONS

For a user friendly data access the Sensors Base Application was used [51]. This application allows to add and edit patient's cards. After a successfully set, the measuring start or stop simply by pressing a button. Then the record is paired with selected patient and the data are obtained in two separated files. These files are then loaded to Matlab (Matrix Laboratory) (3.4).



PIC. 23: MEASURING BOARD

For a practical usability the measuring board (PIC. 23) was covered with a black plastic box and fixed to a black armband (PIC. 24). The armband is equipped with a velcro fastener.

PIC. 24: MEASURING WEARABLE DEVICE

3.1.2 MOTION PROCESSING UNIT MPU-6050

The MPU Device provides integrated 6-axis motion processor solution that eliminates the package-level gyroscope and accelerometer cross-axis misalignment associated with discrete solutions. The device combines a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die together with an onboard Digital Motion Processor (DMP) capable of processing complex 9-axis sensor fusion algorithms using the field-proven and proprietary MotionFusion engine. [37]

For precision tracking of both fast and slow motions, the MPU-6050 features a user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps). The parts also have a user-programmable accelerometer full-scale range of ±2g, ±4g, ±8g, and ±16g. [37]

3.1.3 BLUETOOTH MODUL HC-06

This module permits any microcontroller with a standard RS232 serial port to communicate with a PC or a Smartphone equipped with a Bluetooth Master module. Its main specifications are: [36]

- Bluetooth number: JY-MCU-HC-06, surface mount with
- Integrated antenna
- Operating Voltage: 5 volt, reduced to 3.3 volts, @ 8 ma.
- Default baud rate: 9600 bps.
- Default pin: 1234
- Default name: BlueBolt.
- Class: 2, with up to 10 meter coverage.

3.2 SOLUTIONS OF MEASURING WEARABLE DEVICE POSITIONING

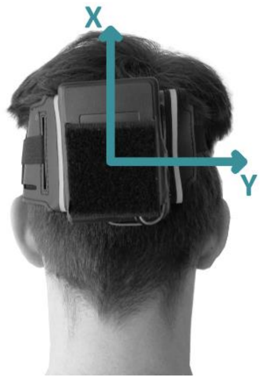
Following the literature review the best positions for device placement are trunk, hip and a shoe. But the approach in these projects is not similar to this thesis so another possible positions have to be examined.

The final set of placements contains caudal head, arm, trunk, wrist, thigh, hip, knee and ankle. In subheads below the pros and cons of projected use of sensors placed on a various body parts are presented. These thoughts are clearly structured into the TABLE 5. These are thoughts that will be examined and evaluated by experimental measuring. (4.1)

TABLE 5: PROJECTED USE OF SENSORS PLACED ON VARIOUS BODY PARTS (O PROS, - CONS)

POSITION	FALL DETECTION	CADENCE MONITORING	BALANCE MONITORING	SITTING UP/DOWN ON A BED	SITTING UP/DOWN ON A CHAIR
HEAD	O	-	O	O	O
ARM	O	-	-	-	O
TRUNK	O	-	O	O	O
WRIST	-	-	-	-	-
HIP	O	-	O	-	O
THIGH	O	O	O	-	O
KNEE	-	O	-	-	-
ANKLE	-	O	-	-	-

3.2.1 SENSOR PLACED ON A HEAD



PIC. 25: SENSOR PLACED ON A HEAD

The greatest use of a sensor placed on a head (PIC. 25) is for balance examination. It should be helpful for fall detection because of its height place. But there is not a center of gravity on a head so this position has a weakness. With this position is possible to measure a person who is sitting/getting up on/of a bed. With the sensor on a head it is not a potentiality to measure steps parameters.

3.2.2 SENSOR PLACED ON AN ARM

PIC. 26: SENSOR PLACED ON AN ARM

This position is not determined for a precise measuring of fractional movements of participants due to its interferences caused by arm movement when walking. On the other side a sensor placed on an arm (PIC. 26) should be used for a long-term measuring such as walking, running or riding a bike. This solution is highly used by commercial sport-testers which probably have a high sampling rate but they don't use all samples in the end. This positioning is also well applicable for a fall detection for its high place.

3.2.3 SENSOR PLACED ON A TRUNK LIKE A BRACELET

PIC. 27: SENSOR PLACED ON A TRUNK

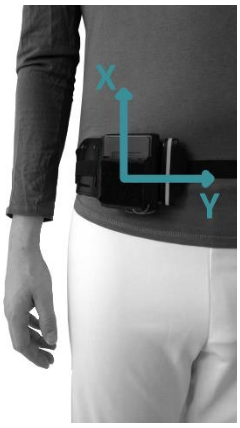
Sensor which is placed on a trunk like a bracelet is one of the best positions on upper body. The sensor is closer to a center of gravity then a head but the bracelet movement causes inaccuracies. The better way is a fixed bracelet (PIC. 27) when movements are suppressed. This placement is useable for a fall detection, sitting up/down on a bed measurement, sitting up/down on a chair measurement, long-term measuring, but the walking and cadence (stride length) measuring should be problematic.

3.2.4 SENSOR PLACED ON A WRIST LIKE A WATCH

PIC. 28: SENSOR PLACED ON A WRIST

With a sensor placed on a wrist like a watch (PIC. 28) is the same problem like with a sensor placed on an arm. There are also interferences caused by arm movement when walking. Moreover interferences on a wrist are even more apparent. Such a sensor should be used for a long-term monitoring (walking, running, or simply to outdoor/indoor participant detection).

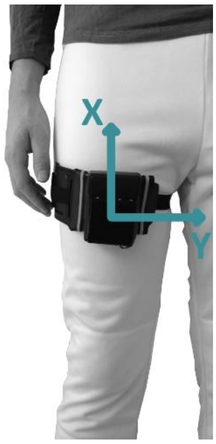
3.2.5 SENSOR PLACED ON A HIP ON A BELT



PIC. 29: SENSOR PLACED ON A BELT

Sensor placed on the level of a center of gravity such as on the belt (PIC. 29) is the good way to obtain precise data of balance, walk and falls. Unfortunately the cadence is not measureable by such a sensor principally with a participating of an older person who doesn't perform the rocking motion of a hip. This is a movement which could be possible to observe on a cyclogram of hip's and knee's angles changing when walking.

3.2.6 SENSOR PLACED ON A THIGH



PIC. 30: SENSOR PLACED ON A THIGH

Sensor which is placed on an upper thigh (PIC. 30) should be very useful. There is an assumption that it could be able to monitor either fall detection, cadence, balance or sitting up/down on a chair because of its position near to a center of body gravity but also on a leg so the walk could be measured as well. The heel strike marker in a signal from a sensor could be detected but due to its low amplitude it will be not as apparent as in a signal from a sensor placed on an outer knee.

3.2.7 SENSOR PLACED ON AN OUTER KNEE

Sensor which is placed on an outer knee (PIC. 31) helps to monitor everything about a participant's gait. Measuring of angles of a knee in time gives us a clear vision about a gait velocity, acceleration and cadence so the sensor based on accelerometer is predestinated for gait monitoring. On the other side such a sensor is not determined for fall detection considering its quite low position.

PIC. 31: SENSOR PLACED ON AN OUTER KNEE

3.2.8 SENSOR PLACED AROUND AN ANKLE

With a sensor placed around an ankle (PIC. 32) is the same problem like with a sensor placed on an outer knee with a fall detection, balance or sitting up/down on a chair. But for the cadence monitoring it could be the best way.

PIC. 32: SENSOR PLACED AROUND AN ANKLE

3.3 EXPERIMENTS TO VERIFY MEASURING WEARABLE DEVICE POSITIONING

The series of observations and measurements were performed to compare and verify individual solutions of measuring wearable device positioning. The participants were studied in their own home environments. First of all the short exercises were rehearsed with the participant and then measured with the device on the specific parts of their body. Selected parts were caudal head, arm, trunk, wrist, hip, knee and ankle.

For measuring the short exercises the set of experimental protocols was created and their procedure is described below (TABLE 6). About 2 sec extra steady was measured between each phase of an exercise for a following data processing and recognizing phases among themselves.

TABLE 6: EXPERIMENTAL PROTOCOLS

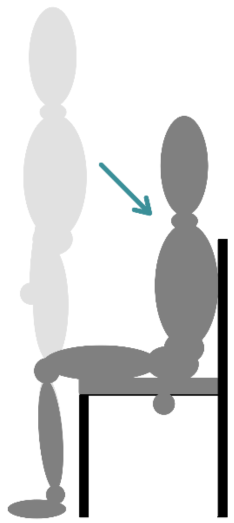
EXERCISE	EXERCISE TYPE	EXPERIMENTAL PROTOCOL
CHAIR	SIT DOWN	The subject stands still above a chair and after a while sits down on a chair
	STAND UP	The subject sits still on a chair and after a while stands up above a chair
BED	LIE DOWN	The subject stands still above a bed and after a while sits on a bed, puts down his feet on the bed and lies down on the bed
	GET UP	The subject lies still on a bed on his back and after a while sits up on a bed, puts down his feet on the floor and stands up above the bed
GAIT	SLOW WALK	The subject stands still and after a while walks slow straight 5 m and stops
	SLOW WALK WITH A TURN	The subject stands still and after a while walks slow straight 5 m, turns on a place and walks slow back again
	NORMAL WALK	The subject stands still and after a while walks straight 5 m and stops
	NORMAL WALK WITH A TURN	The subject stands still and after a while walks straight 5 m, turns on a place and walks back again
	SWIFT WALK	The subject stands still and after a while walks swift straight 5 m and stops
	SWIFT WALK WITH A TURN	The subject stands still and after a while walks swift straight 5 m, turns on a place and walks swift back again
	WALK UPSTAIRS	The subject stands still and after a while walks up 12 stairs and stops
	WALK DOWNSTAIRS	The subject stands still and after a while walks down 12 stairs and stops

3.3.1 EXPERIMENTS WITH A CHAIR

These experiments should simulate the most perform activity from all seniors' daily activities. From such as experiments it is possible to obtain data about senior's motion during sitting down (3.3.1.1) or standing up (3.3.1.2). It's possible to find very markers in a measured signal corresponding to phase of a movement.

3.3.1.1 CHAIR – SIT DOWN

Although the sitting down (PIC. 33) sounds like a quite simple motion it could be divided into few phases. These phases could be detected in a signal dependently on sensor positioning on a participant's body and its rotation in space. Following markers will be used in evaluation of measured signals. (4)



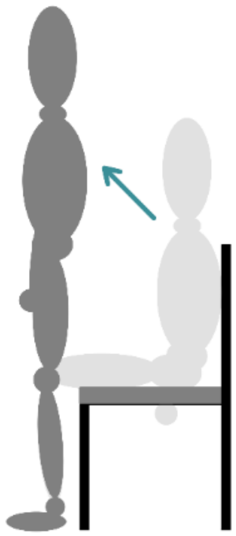
PIC. 33: CHAIR - SIT DOWN

B	BEGINNING	Beginning of a movement which is easily detectable in a signal by sudden change of an acceleration amplitude
T	TILT	Tilt of a trunk is causing the braking, in signal could be seen as a stopping of an acceleration amplitude changing and its contiguous record which is steady in amplitude
D	DECELERATION	Deceleration of a movement is a next marker which could be detectable by a recurrence of change of an acceleration
S	SHAKE	Shake of a body following after a seating is a quick change of an acceleration in both directions, it could be seen as a peak with a small amplitude
E	END	End of a movement which is easily detectable in a signal by sudden change of an acceleration amplitude

3.3.1.2 CHAIR – STAND UP

Like a previous exercise when participant is sitting down the stand-up exercise (PIC. 34) could be divided into few phases too. In fact these are the same markers thus beginning of a movement (B), tilt of a trunk (T), deceleration (D), shake of a body (S) and end of a movement (E). Markers are detectable in a signal in a same sequence as in the exercise Chair – Sit down.

But this movement could be more interesting in signal processing of records where seniors were measured. These graphs could contain abnormalities such as supporting oneself or tilting on a side and others. The velocity of standing up could be also calculated.



PIC. 34: CHAIR - STAND UP

3.3.2 EXPERIMENTS WITH A BED

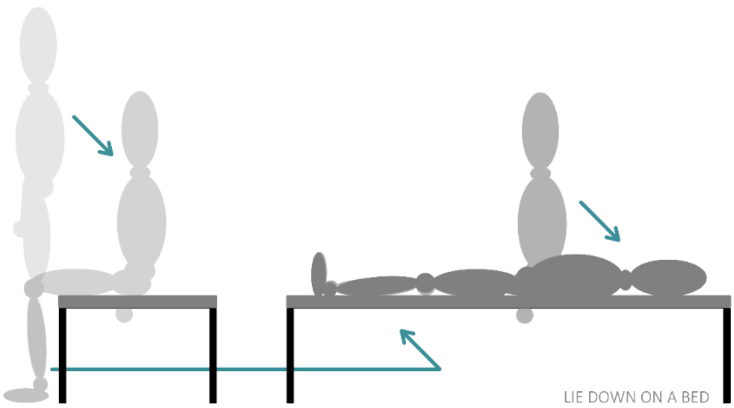
Experiments performed on a bed are mostly important for the time which participant spends by doing the specific phases. From such as experiments is possible to obtain data about senior's motion during lying down on a bed (3.3.2.1) or getting up of a bed (3.3.2.2). It's possible to find very markers in a measured signal which correspond to phase of a movement.

3.3.2.1 BED – LIE DOWN

This exercise contains three phases in total (PIC. 35). First part is when participant is sitting down on an edge of a bed, then he is lifting his legs and putting them on a bed whereas his body is rotating and in the end of this movement he is lying on a bed. Every phase has few markers moreover. The first phase was described in a chapter 3.3.1.1.

STB	SIT DOWN (BEGINNING)	Beginning of a movement (sitting down on the edge of a bed) which is easily detectable in a signal by sudden change of an acceleration amplitude

T	TILT	Tilt of a trunk is causing the braking, in signal could be seen as a stopping of an acceleration amplitude changing and its contiguous record which is steady in amplitude
D	DECELERATION	Deceleration of a movement is a next marker which could be detectable by a recurrence of change of an acceleration
S	SHAKE	Shake of body following after a seating is a quick change of an acceleration in both directions, it could be seen as a peak with a small amplitude
STE	SIT DOWN (END)	End of a movement (sitting down on the edge of a bed) which is easily detectable in signal by sudden change of an acceleration amplitude



PIC. 35: LIE DOWN ON A BED

Second phase contains a specific set of motions which could be detectable in a processed signal. When a movement starts the legs are lifted from a floor, trunk is leaned back, legs are bent in knees and all the body is rotated around its own axis to 90°. In the end of this movement the legs strike on a bed.

LB	LEGS (BEGINNING)	Beginning of a movement (legs putting on a bed) which is detectable in signal by sudden change of an acceleration amplitude
O	HEEL AND TOE OFF	Heel and toe are lifting and starting to rotate demarcating by a sharp pulse in a signal right after a beginning of a

		movement for sensor placed on upper part of a body it is caused by muscles clenching during this motion so the pulse is not so sharp
TE	TURN END	End of a turn occurs in 1 or 2 seconds after a heel and toe lifting, in a signal it could be seen as a stopping of changing of an acceleration amplitude
HS	HEEL STRIKE	Heel strike on a bed is a next marker which could be detectable by a recurrence of change of an acceleration as a quick peak
LE	LEGS (END)	End of a movement (legs putting on a bed) which is detectable in signal by sudden change of an acceleration amplitude

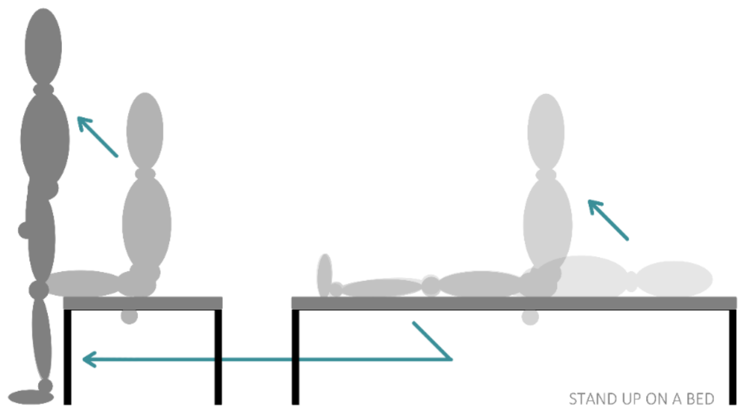
The last phase is quite simple in this type of bed exercise. When participant is lying on a bed his muscles are clenching to slow down the movement so back and head are put down softly.

SB	LIE DOWN (BEGINNING)	Beginning of a movement (lying on a bed) which is detectable in signal by sudden change of an acceleration amplitude
M	MUSCLES	Muscles clenching is a next step which marks start of an abdominal muscles clenching during a deceleration of a lying on a bed, in a signal is easily distinguishable as a quick oscillation of an acceleration amplitude
SE	LIE DOWN (END)	End of a movement (lying on a bed) which is easily detectable in signal by sudden change of an acceleration amplitude

3.3.2.2 BED – GET UP

Like a previous exercise when participant is lying down on a bed, the get up exercise could be divided into three phases too. In fact these are the same markers which are detectable in a signal as in exercise Bed – Lie down but just in a reverse sequence (PIC. 36). In addition in a first phase the new markers could be visible.

H	HEAD	Head lifting – head is a part of an upper body which is lifted first and it is detectable by the first acceleration amplitude change right after a beginning of a movement
P	PALM	Palms supporting – participant is supporting himself by palms and this motion could be in some cases detectable in a signal right before a M marker (muscles clenching) as an oscillation of amplitude (mostly measured by sensors positioned on an upper body)
M	MUSCLES	Muscles clenching – abdominal muscles are clenched when body is lifting up and in a signal is easily distinguishable as a quick oscillation of an acceleration amplitude

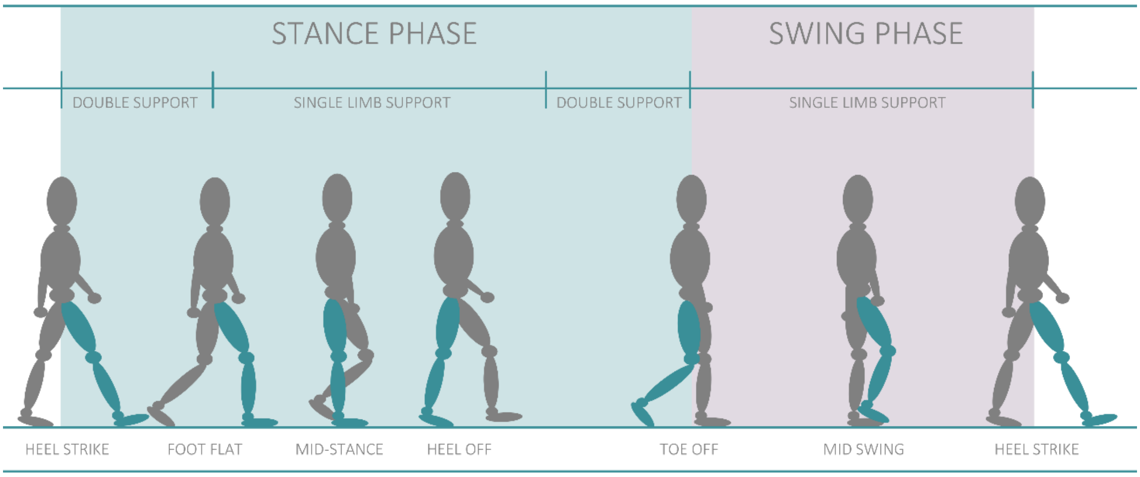


PIC. 36: GET UP ON A BED

3.3.3 GAIT EXPERIMENTS

Since the person's gait is in its own way periodic the repetitive pattern with minor variations could be seen. This gait cycle has several phases. For following experiments just one leg cycle is sufficient. (PIC. 37) One gait period has two phases – stance and swing phase. First marker in stance phase is a heel strike and it is an important marker which together with a toe off phase marker could be seen the most.

Experiments for gait comprise slow, normal and swift walk (3.3.3.1), slow, normal and swift walk with a turn (3.3.3.2) and walk downstairs (3.3.3.3) and upstairs (3.3.3.4).



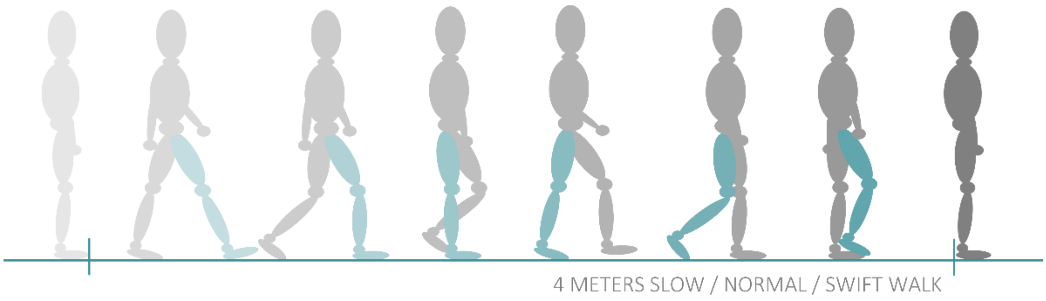
PIC. 37: GAIT CYCLE

3.3.3.1 SLOW / NORMAL / SWIFT WALK

This is a simple exercise when participant walks for four meters on a flat floor and then he stops. (PIC. 38) Three stages of a walk velocity (slow, normal and swift) will be measuared. The tempo is determined by participant.

H	HEEL STRIKE	Moment when heel strikes on a floor and an acceleration amplitude changes itself the very first time during this movement
F	FOOT FLAT	Foot is its entire surface in a contact with a floor which is distinguishable as immediate change of an acceleration amplitude in signal
M	MIDSTANCE	Foot is its entire surface in a contact with a floor and a body weight is transferred to this side which could be seen as a deceleration in a signal
O	HEEL AND TOE OFF	Heel and toe lifting from a floor is very important marker which could be detectable almost in every gait measurement record as a quick and high peak

S	SWING PHASE	Phase when a foot is not in any contact with a floor and acceleration is quite steady – the amplitude is very low in comparison with another phases of gait

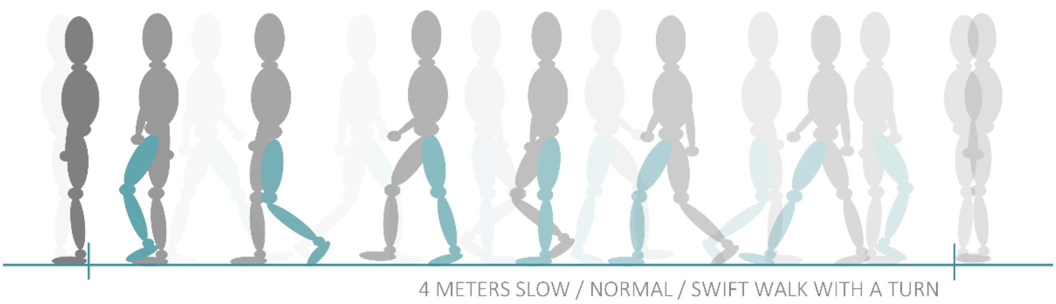


PIC. 38: 4 METERS SLOW / NORMAL / SWIFT WALK

3.3.3.2 SLOW / NORMAL / SWIFT WALK WITH A TURN

This is a same exercise as a previous one but with a turn at the end of a lane which a PIC. 39 shows. In this exercise same markers like in previous one (heel strike (H), foot flat (F), midstance (M), heel and toe off (O) and swing phase (S)) could be measured. The new ones are:

TB	TURN (BEGINNING)	Beginning of a movement (turn around) which is detectable in a signal by sudden change of an acceleration amplitude
TE	TURN (END)	End of a movement (turn around) which is also detectable in a signal by sudden change of an acceleration amplitude



PIC. 39: 4 METERS SLOW / NORMAL / SWIFT WALK WITH A TURN

3.3.3.3 WALK DOWNSTAIRS

This is a simple exercise when participant stands still and after a while walks downstairs and stops. (PIC. 40) The tempo is determined by participant. Detectable markers are the same as for previous exercise Gait – Slow walk. But the marker O (heel and toe off) there is more visible.

PIC. 40: WALK DOWNSTAIRS

3.3.3.4 WALK UPSTAIRS

This is a simple exercise when participant stands still and after a while walks UPSTAIRS and stops. (PIC. 41) The tempo is determined by participant. Detectable markers are the same as for previous exercise Gait – Slow walk. But the marker H (heel strike) there is more visible.

PIC. 41: WALK UPSTAIRS

3.4 DATA PREPROCESSING IN MATLAB

The first step of data preprocessing is data obtaining from the sensor Motion Processing Units MPU-6050. The measured data from sensor's UniversalStorage are accessible from Matlab (Matrix Laboratory).

Access to the database is easily mediated by the Matlab function `data_input` which was written. The input of this function is a record name. In a code segment below the function calling is shown.

```
record = double('PAT_chair_up_s_01');
[acc, gyro, ax, ay, az, wx, wy, wz] = data_input(record);
```

The function calls the database, sets a profil and selects the patient with the chosen record. Then obtains accelerometer's and gyroscops' values and stores them to variables `acc` and `gyro`. The output of this function are data from accelerometer and gyroscope which are separated into the independent variables `ax, ay, az, wx, wy, wz` which correspond to particular axis and are filtered by a median filter of the third order.

TABLE 7: THE ACCELEROMETER'S SENSITIVITY PER LSB

ASF_SEL	FULL SCALE RANGE	LSB SENSITIVITY
0	±2g	16384 LSB/g
1	±4g	8192 LSB/g
2	±8g	4096 LSB/g
3	±16g	2048 LSB/g

Here it is necessary to convert the raw data given by the accelerometer into the acceleration in meters per second. Due to the lowest sensitivity setup (TABLE 7) the full scale range is 2g and sensitivity is 16384 LSB/g. For recalculation the function `raw2clean` was writen and it was used for each axis separately. The output of this function are data of acceleration in m.s^{-2}.

```
MS2ax = raw2clean(fsr,sens,ax);
MS2ay = raw2clean(fsr,sens,ay);
MS2az = raw2clean(fsr,sens,az);
```

3.5 METHODOLOGY OF A SIGNAL EVALUATION USABILITY

Since data of acceleration in $m.s^{-2}$ were obtained by preprocessing in Matlab (3.4) it was possible to make graphs of acceleration signals. After a proper analysis of figures with consideration of movements in experiments the markers mentioned in the chapter 3.3 were adopted and described.

A tool in Matlab supporting evaluation according the developed methodology was designed. This tool helps with assessing of particular phases and markers in a specific type of experiment. For example for a gait analyze the `ginput_G()` function is called for all of three axes. The inputs of this function are a color matrix `map` for a markers' colors, a number `0, 20 or 40` which has to be attributed to an axis for a one plot figure of three signals with their own amplitude axis and one common time axis.

```
XY_x = ginput_G(map, 40, 1);
XY_y = ginput_G(map, 20, -1);
XY_z = ginput_G(map, 0, 1);
```

The `ginput_G()` function contains an information about all possible markers which could be obtained by a gait measuring by the wearable device. After a calling this function, the crosshairs raised in the current axes helps to identify markers in the figure by positioning the cursor with the mouse. When the marking is done the matrix of all values is saved.

TABLE 8: WEIGHTS OF MARKERS FOR THE MAIN EXPERIMENTS

MARKER FOR GAIT - SLOW WALK	H	F	M	O	S
WEIGHT	0.3	0.2	0.1	0.3	0.1
MARKER FOR CHAIR - SIT DOWN	B	T	D	S	E
WEIGHT	0.3	0.1	0.2	0.1	0.3
MARKER FOR BED - GET UP	SB	H	M	P	SE
WEIGHT	0.08	0.051667	0.07	0.051667	0.08
	LB	O	TE	HS	LE
	0.08	0.051667	0.07	0.051667	0.08
	STB	T	D	S	STE
	0.08	0.051667	0.07	0.051667	0.08

This method is purely subjective because of a hand-operated marking. Multiple-criteria decision analysis was used for evaluation. This MCDA problem is represented in the criterion space which is combined by a weighted linear function (TABLE 8). The highest weights are assigned to markers H (Heel Strike) and O (Heel and Toe Off) which are predicative about cadence. Particular weights are shown in a chapter 4 in tables TABLE 9, TABLE 10 and TABLE 11.

Sum of weights for one experiment is equal to one. The most important markers have the highest values of weights. These are markers for beginning and for the end of a movement or of phase of a movement.

After marking of specific graph was done, the evaluation was performed by values 0, 1, 2 and 3. Zero for markers which are not visible, 1 for such markers whose indications are visible, 2 for a partly visible markers and the number 3 for markers which are clearly visible. Total sum of weighted values for markers in a one axis is then calculated. The maximal total sum across all axes is choose to represent a suitability of a wearable device positioning for the specific movement.

4 RESULTS

In this chapter the measured data will be analyzed. First of all the experimental measuring with healthy participant was performed (4.1). Following the experimental protocols all the experiments were conducted. The goal of this experimental measuring is to find particular markers or phases of movements and assess which position of a wear able device is the most suitable for monitoring daily activities.

Second part of this chapter is the subhead Verification of experimental measuring (4.2). Another one healthy participant was measured for the most predicative experiments. These are Chair – Sit down, Bed – Get up and Gait – Slow walk. These results will be compared with results from figures for the first participant in reference to suitability wearable device positioning.

After both measuring the evaluation of the best position of a wearable device (4.3) has to be done. Then the practical measuring (4.4) could be performed. There will be presented results for seniors’ daily activities monitoring in chapter 4.4.1 and in the next chapter 4.4.2 the blind record will be analyzed.

4.1 EXPERIMENTAL MEASURING

Following the experimental protocols (TABLE 6) the experiments where performed. For each experiment all 8 positions of sensor (3.2) were used. The goal of this experimental measuring is to find particular markers or phases of movements and assess which position of a wear able device is the most suitable for monitoring daily activities.

The main phases and markers for every exercise where predicted in a chapter 3.3. Marker's presence has to be verified by experimental measuring. Participant of all experiments in this chapter was a man, 25 years old, 178 cm height and 68 kg weight, healthy, no problems with a musculoskeletal system, no problems with a stability or spatial orientation.

Three the most important experiments were chosen for evaluation. These experiments are Chair – Sit down (4.1.1), Bed – Get up (4.1.3) and Gait - Slow walk (4.1.5).

4.1.1 RESULTS OF THE EXPERIMENT CHAIR – SIT DOWN

As was already written in a chapter 3.5, the experiment Chair – Sit down was evaluated based on subjective visibility of specific markers which are beginning of the movement (B), tilt of a trunk (T), deceleration (D), shake (S) and end of the movement (E) (3.3.1.1). Score from zero to three was written down to the TABLE 9, then its total sum was calculated and the maximal value in axes was chosen as a criteria for the best positioning selection. Following this methodology suitability of wearable device positioning will be presented here for comparison in TABLE 9.

The set of placements contains caudal head, arm, trunk, wrist, thigh, hip, knee and ankle. Sensors placed on an upper body have a more predicative value then the rest of sensors caused by steady position of participant's legs and motions of a body during sitting down.

Detected phases in a signal depend on a sensor positioning on a participant's body and its rotation in space. There is almost none rotation during the sitting down in one axis.

4.1.1.1 RESULTS FOR A SENSOR PLACED ON A HEAD

Sensor positioned on a head recorded changes in acceleration amplitude just in two axes. (FIGURE 3) The velocity of a movement in x axis is almost constant so the changes of acceleration amplitude are not so visible in a graph. But it is possible to find an indications of all markers so the total sum of scores is 1.1 from 3. (TABLE 9) Z axis is more interesting. In a signal could be seen the beginning (B) and the end (E) of a movement very clearly by sudden change of an acceleration amplitude. Marker T for is partly visible too because a tilt of a trunk is causes the braking and a head does the same motion. Situation with a D (deceleration) marker is the same - body decelerates during this phase of a movement and in a signal is partly seen a recurrence of change of an acceleration. The S marker (shake of a body) is not visible at all and a total sum of scores is 2.4 from 3 in z axis, which is the second best maximal value. (TABLE 9).

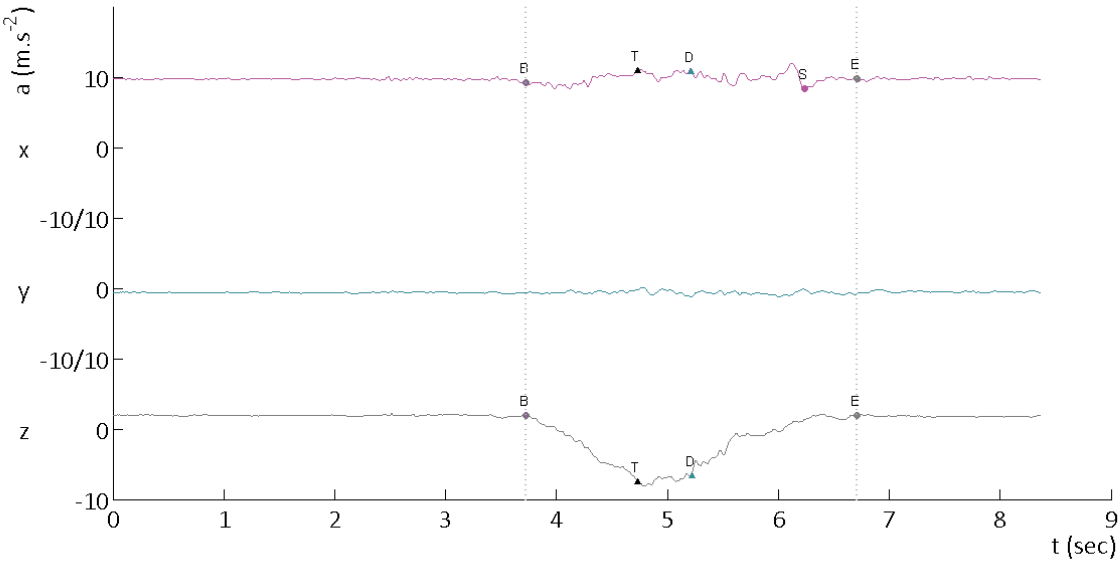


FIGURE 3: AC1 - HEAD, CHAIR, SIT DOWN, HEALTHY PARTICIPANT I

4.1.1.2 RESULTS FOR A SENSOR PLACED ON AN ARM

Sensor positioned on an arm recorded changes in acceleration amplitude clearly just in two axes. (FIGURE 4) Because this position causes sensor's rotation in space there is a detectable signal and indications of markers B and E (beginning and end of a movement) in x axis too. Total sum of scores for this axis is 0.6 from 3. (TABLE 9).

The total sum of scores the same – 1.8 from 3 for both axes y and z (TABLE 9) Marker B (beginning of a movement) is partly visible which is caused by a slower change of an acceleration amplitude. Marker for tilting of a trunk (T) is not visible in a signal because arms try to balance body during this movement. But deceleration (D) is visible very clearly following by shake of a body (S) phase which score is 3 too. There is only an indication of the end of a movement (E).

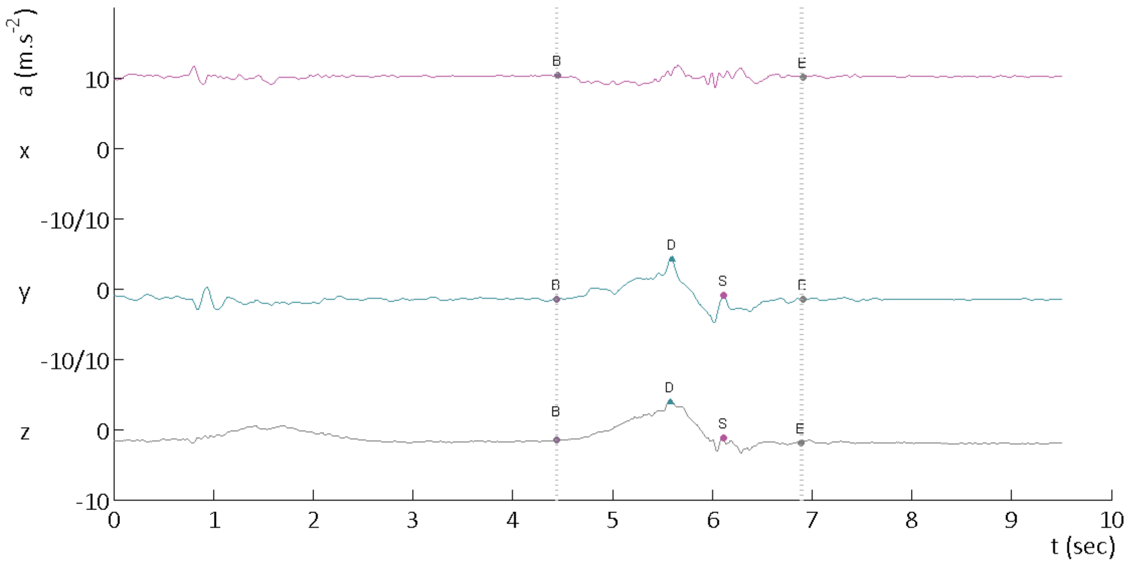


FIGURE 4: BC1 - ARM, CHAIR, SIT DOWN, HEALTHY PARTICIPANT I

4.1.1.3 RESULTS FOR A SENSOR PLACED ON A TRUNK

This positioning of a wearable device is the best of all for this movement. Total sum of scores for z axis is 2.8 from 3. (TABLE 9).

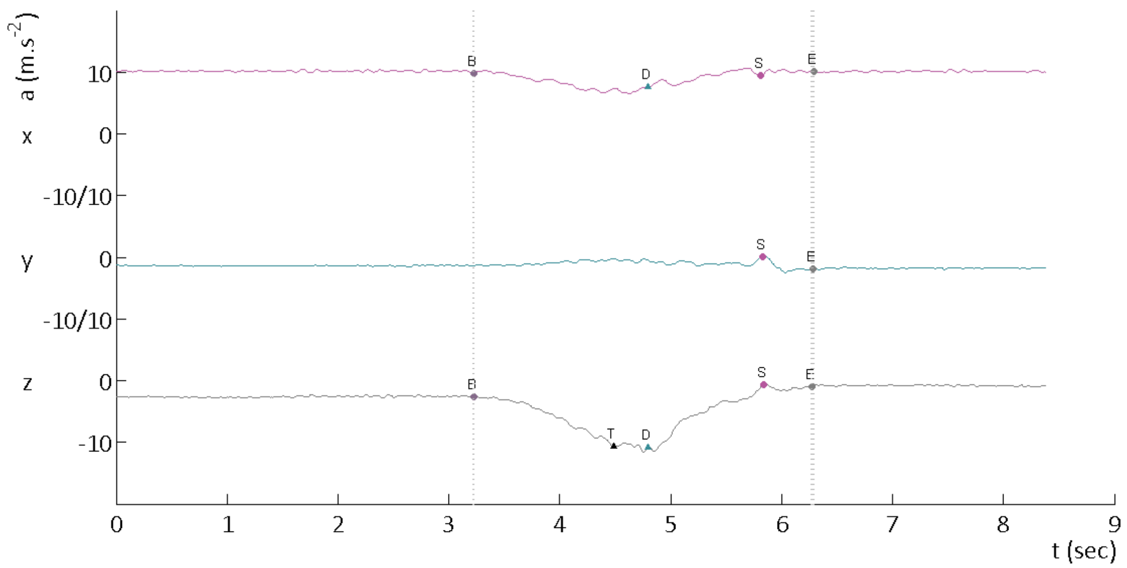


FIGURE 5: CC1 - TRUNK, CHAIR, SIT DOWN, HEALTHY PARTICIPANT I

Substantiation of changes in acceleration amplitude are the same as for a signal obtained from a sensor placed on a head. Since the second marker T is about a tilt of a trunk and deceleration (D) is almost immediate it has to be the highest value for the sum of these markers' scores. FIGURE 5 shows measuring results of acceleration of sensor which was fixed on a trunk.

4.1.1.4 RESULTS FOR A SENSOR PLACED ON A WRIST

Sensor positioned on a wrist didn't show changes in acceleration amplitude clearly in any of axes because this position causes sensor's rotation in space. Interferences in motions are much more apparent than in a signal from a sensor placed on an arm. The indication of a marker B (beginning of a movement) is visible only in x axis (FIGURE 6). Total sum of scores is only 0.9 from 3, which is the second worst maximal value. (TABLE 9).

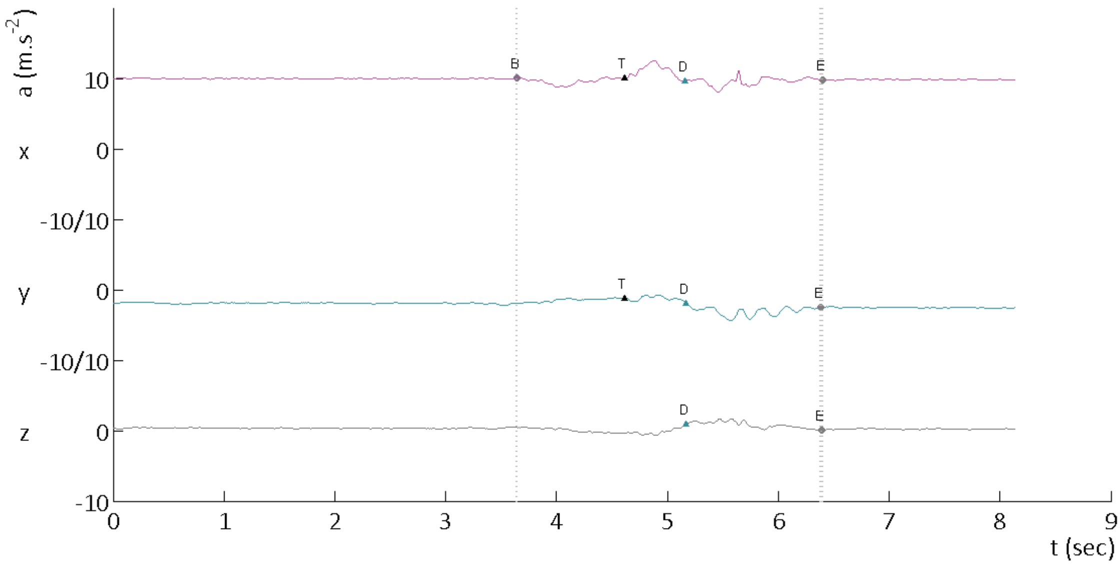


FIGURE 6: DC1 - WRIST, CHAIR, SIT DOWN, HEALTHY PARTICIPANT I

4.1.1.5 RESULTS FOR A SENSOR PLACED ON A HIP ON A BELT

Sensor placed on a hip on a belt rotates around y axis during the movement so the T (tilt of a trunk) and D (deceleration) markers could be visible in x a z axes. (FIGURE 7) Changes in acceleration amplitude are smaller than in signals from sensors placed on a head or on a trunk. Total sum of scores is only 1.2 from 3. (TABLE 9).

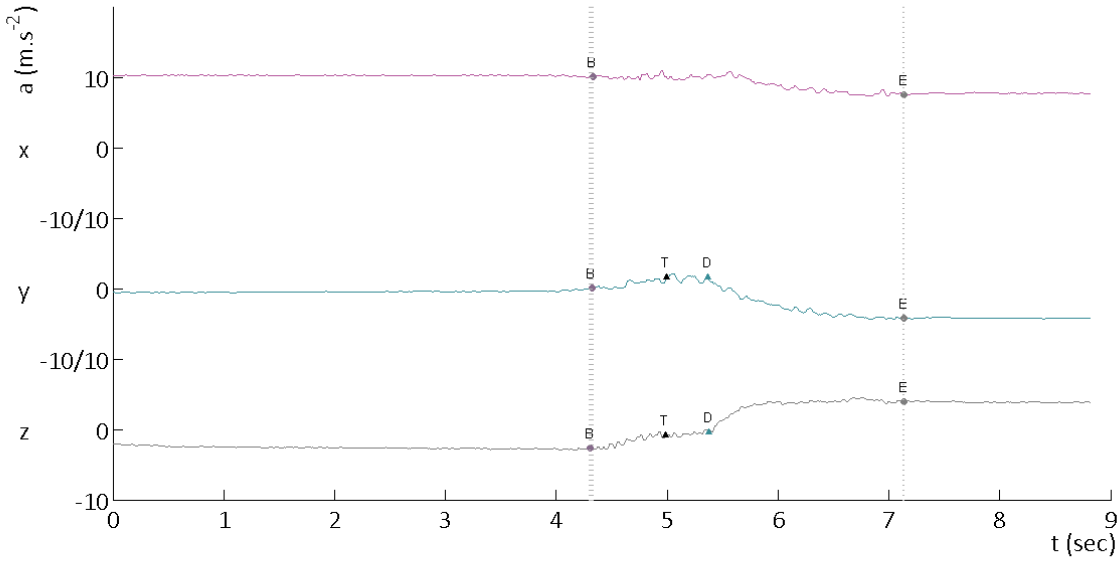


FIGURE 7: HC1 - BELT, CHAIR, SIT DOWN, HEALTHY PARTICIPANT I

4.1.1.6 RESULTS FOR A SENSOR PLACED ON A THIGH

The signal from a sensor placed on a thigh is different due to sensor's rotation about y axis during the sitting movement. Legs are bent in knees and position of a thigh is changed near to 90°. It is not possible to detect a tilt of a trunk (T) in a signal for this sensor positioning. (FIGURE 8) Total sum of scores is only 1.9 from 3. (TABLE 9).

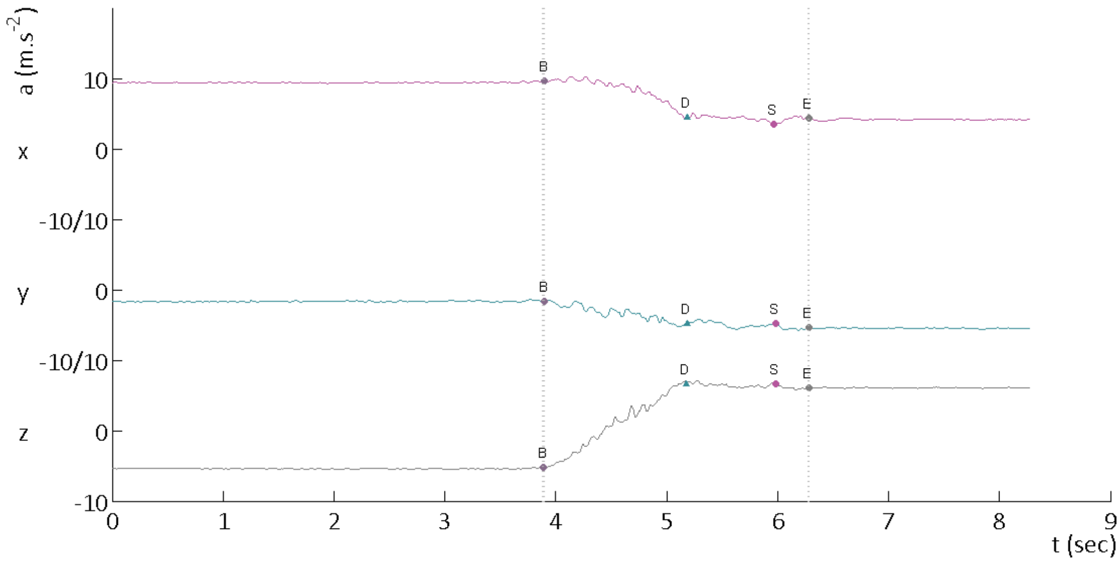


FIGURE 8: GC1 - THIGH, CHAIR, SIT DOWN, HEALTHY PARTICIPANT I

4.1.1.7 RESULTS FOR A SENSOR PLACED ON A KNEE

Participant's legs are in a steady position during all the movement, so there is no detectable marker in a signal but the beginning (B) and end (E) of it. (FIGURE 9) The total sum of scores is only 0.6 from 3. (TABLE 9).

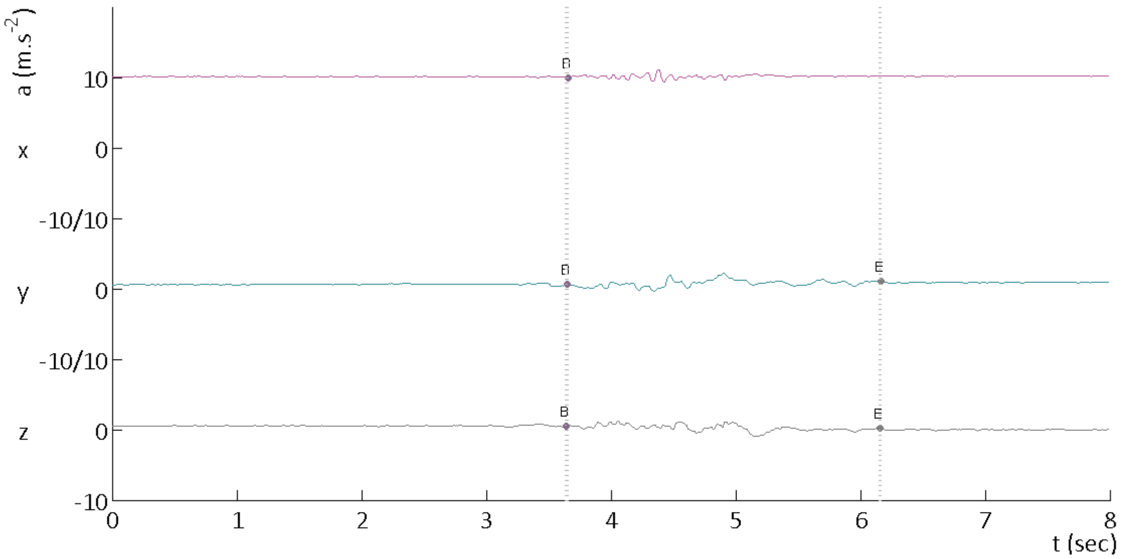


FIGURE 9: EC1 - KNEE, CHAIR, SIT DOWN, HEALTHY PARTICIPANT I

4.1.1.8 RESULTS FOR A SENSOR PLACED ON AN ANKLE

This is a same situation as for a sensor placed on a knee and it could be seen in a FIGURE 10. The total sum of scores is only 0.6 from 3 and together with scores of a sensor placed on a knee, this is the worst total sum of scores at all. (TABLE 9).

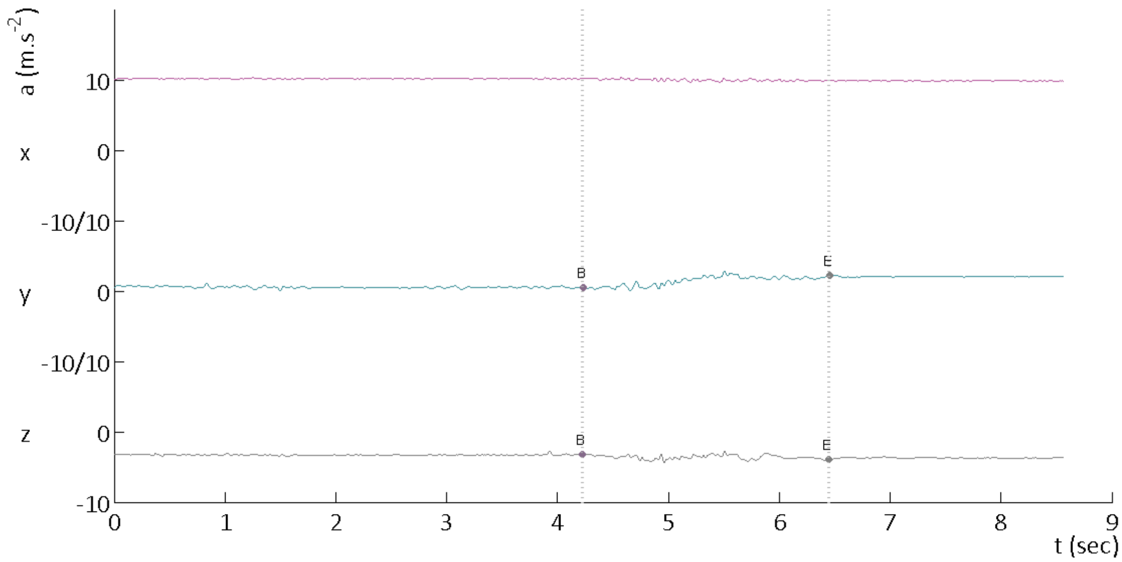


FIGURE 10: FC1 - ANKLE, CHAIR, SIT DOWN, HEALTHY PARTICIPANT I

4.1.2 EVALUATION OF RESULTS OF THE EXPERIMENT CHAIR – SIT DOWN

Results of the experiment Chair – Sit down confirm propositions which were stated in a chapter 3.2. For this movement the best of all positioning of a wearable device is on a trunk. Total sum of scores for z axis is 2.8 from 3. (TABLE 9). As was mentioned in chapters 4.1.1.7 and 4.1.1.8, the total sum of scores for sensor placed on an outer knee or on an ankle is only 0.6 from 3. (TABLE 9) So for this movement these are the worst positions for a wearable device. All results are shown in a TABLE 9 for comparison. The best and the worst variants are highlighted here.

TABLE 9: RESULTS OF THE EXPERIMENT CHAIR - SIT DOWN, HEALTHY PARTICIPANT I, THE BEST POSITION IS HIGHLIGHTED BY GREEN COLOR, THE WORST POSITION IS HIGHLIGHTED BY GREY COLOR

POSITION	AXIS	B	T	D	S	E	TOTAL	SUITABLE
	WEIGHT	0.3	0.1	0.2	0.1	0.3	1	
HEAD	X	1	1	1	2	1	1.1	2.40
	Y	0	0	0	0	0	0	
	Z	3	2	2	0	3	2.4	
ARM	X	1	0	0	0	1	0.6	1.80
	Y	2	0	3	3	1	1.8	
	Z	2	0	3	3	1	1.8	
TRUNK	X	1	0	1	1	1	0.9	2.80
	Y	0	0	0	3	1	0.6	
	Z	3	2	3	2	3	2.8	
WRIST	X	1	1	1	0	1	0.9	0.90
	Y	0	1	1	0	2	0.9	
	Z	0	0	1	0	1	0.5	
HIP	X	1	0	0	0	1	0.6	1.20
	Y	1	1	1	0	2	1.2	
	Z	2	1	1	0	1	1.2	
THIGH	X	2	0	2	1	2	1.7	1.90
	Y	2	0	1	1	1	1.2	
	Z	3	0	3	1	1	1.9	
KNEE	X	1	0	0	0	0	0.3	0.60
	Y	1	0	0	0	1	0.6	
	Z	1	0	0	0	1	0.6	
ANKLE	X	0	0	0	0	0	0	0.60
	Y	1	0	0	0	1	0.6	
	Z	1	0	0	0	1	0.6	

4.1.3 RESULTS OF THE EXPERIMENT BED – GET UP

As was already written in a chapter 3.5, the experiment Bed – Get up was also evaluated based on a subjective visibility of specific markers which are beginning of a movement (SB), head lifting (H), palms supporting (P), muscles clenching (M) and end of a movement (SE) for a phase when participant is sitting on a bed.

For a second phase when participant's body is rotating around its own axis and his legs are putting down on a floor there are detectable markers LB (beginning of a movement), O (heel and toe lifting), TE (end of a turn), HS (heel strike) and LE (end of a movement). Markers STB (beginning of a movement), T (tilt of a trunk), D (deceleration), S (shake of a body) and STE (end of a movement) could be visible during the standing phase which is the reverse movements to an experiment Chair - Sit down which was already evaluated in the foregoing chapter 4.1.2.

The same methodology as for an experiment Chair – Sit down (4.1.1) was used. Score from zero to three was written down to the TABLE 10, then its total sum was calculated and the maximal value in axes was chosen as a criteria for the best positioning selection.

Following this methodology all wearable device positioning for this experiment will be presented here for comparison. The set of placements contains caudal head, arm, trunk, wrist, thigh, hip, knee and ankle too.

Detected phases in a signal dependent on a sensor positioning on a participant's body and its rotation in space. As was said afore there is the most visible rotation of a body around its own axis in a signal.

4.1.3.1 RESULTS FOR A SENSOR PLACED ON A HEAD

Sensor positioned on a head recorded changes in acceleration amplitude just in two axes. (FIGURE 11) The velocity of a movement in y axis during the first phase is almost constant so the changes of an acceleration amplitude are not so visible in a graph. But it is possible to find an indications of markers SB, M and SE. The sensor placed on a head is rotated around y axis during this phase so there is a visible shift in a gravity acceleration in axes x and z. In both axes the beginning of the movement (SB) is clearly visible and in the axis z the head lifting (H) is clearly visible too which is caused just by subsequent change of a gravity acceleration. The muscles clenching (M) during the sitting phase is also partly visible in these two axes as a quick oscillation of an acceleration amplitude.

The most interesting in this experiment is the phase when participant's body is rotating around its own axis (TE) and his legs are putting down on a floor (HS). There is almost no change in an acceleration amplitude in x axis of a signal because the x axis is the one around which the body is rotating. (FIGURE 11)

Changes of amplitude in z axis are caused by tilting of a trunk during the movement but only partly visible markers are LB and LE (beginning and end of a movement of legs). But in y axis the amplitude of an acceleration is rapidly changing in and y axis which is caused by rotation around the x axis to the left side which is faster than the rotation of a trunk. Partly visible here in a signal are markers LB (beginning of a movement), TE (end of a turn) and HS (heel strike). The end of a signal (LE) is not clearly recognizable.

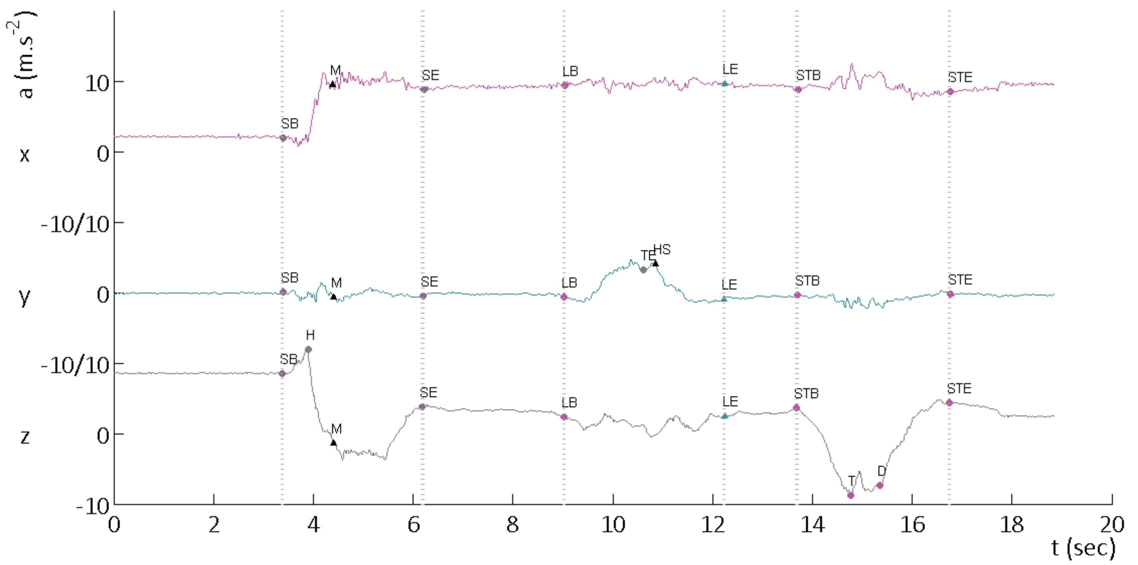


FIGURE 11: AB2 - HEAD, BED, GET UP, HEALTHY PARTICIPANT I

The last phase of a movement - the standing up from a bed is just a reverse motion to the experiment Chair - Sit down. Here are clearly visible all markers but S (shake of a body). The total sum of scores is 1.94 from 3. (TABLE 10)

4.1.3.2 RESULTS FOR A SENSOR PLACED ON AN ARM

Sensor positioned on an arm recorded changes in an acceleration amplitude in all axes because this position causes sensor’s rotation in space. Beginning of the first phase is clearly visible in all axes. During this phase the sensor's rotation is changing so there is also visible a change of a gravity force. The body support by palms (P) is here clearly visible in axes y and z. (FIGURE 12)

In axis z it is visible as a quick change of an acceleration amplitude and in y axis as an oscillations of a signal. Next marker is M (muscles clenching) which indications are visible in axes x and y and clearly visible as a rapid change of an amplitude in z axis.

The transition to the second phase is quite smooth and it is partly visible as markers SE (end of a movement of the first phase) and LB (beginning of a movement of the second phase). The O (heel and toe lifting) marker is clearly visible which is caused by supporting body by arms during heels lifting of a bed and beginning of a body rotation. In y axis is clearly visible TE (end of a turn) marker as a slow peak - this is a same case as for a sensor placed on a head. But because of an arm motion there is also TE marker (end of a turn) clearly visible in the z axis. The end of this phase (LE) is clearly visible in all axes.

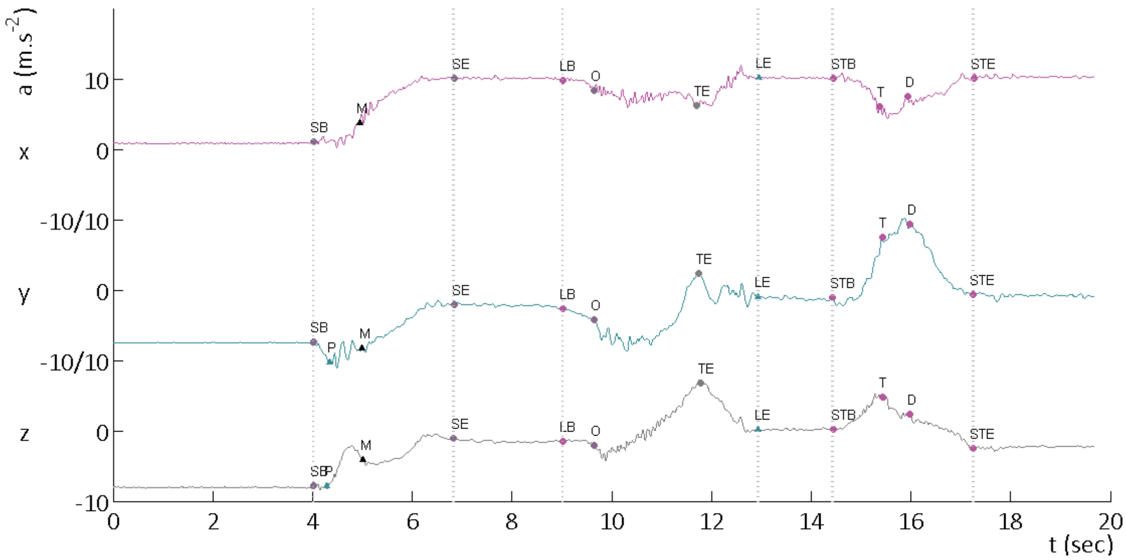


FIGURE 12: BB2 - ARM, BED, GET UP, HEALTHY PARTICIPANT I

The last phase is similar to the reverse motion of an experiment Chair - Sit up. For this movement this is the best of all positioning of a wearable device. The total sum of scores is 2.31 from 3. (TABLE 10)

4.1.3.3 RESULTS FOR A SENSOR PLACED ON A TRUNK

Substantiation of changes in an acceleration amplitude during the first phase are the same as for a signal obtained from a sensor placed on a head. But the visibility of marker H (head lifting) is lower and marker M (muscles clenching) is one of the most clearly visible markers for all of positioning of wearable device. (FIGURE 13) The oscillations of a signal are the highest in x axis during the sitting on a bed.

The situation for the second phase is different. Unlike the rapid change in y axis for a sensor placed on a head (FIGURE 11) which is caused by rotation around the x axes to the left side, the velocity of rotation of a trunk is constant. So there is no detectable marker in x and y axes. Changes of amplitude in z axis are caused by tilting of a trunk during the movement but there are only indications of markers TE (end of a turn) and HS (heel strike) in a signal.

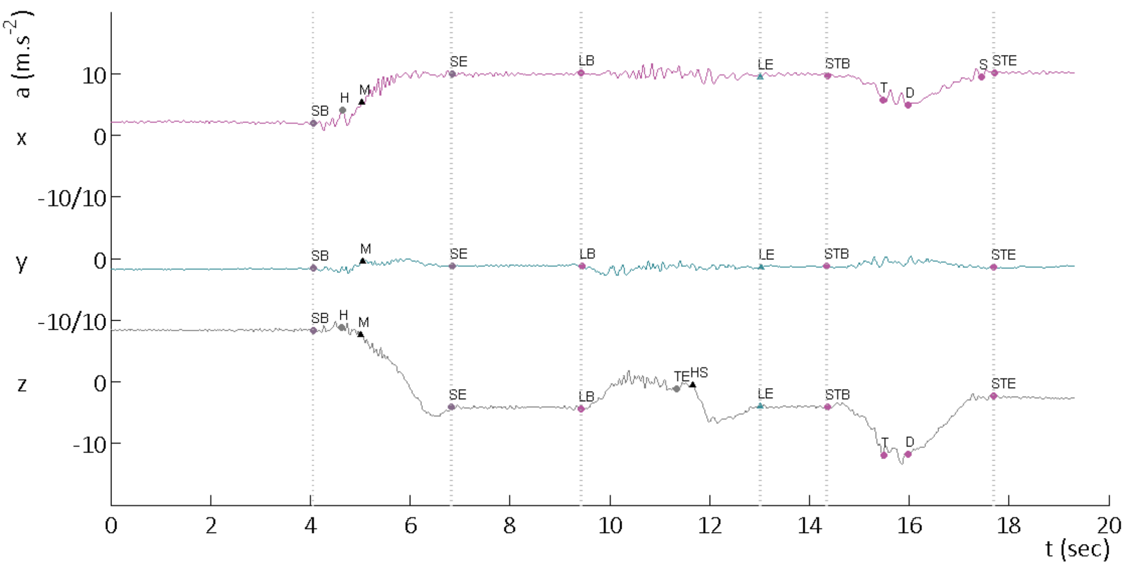


FIGURE 13: CB2 - TRUNK, BED, GET UP, HEALTHY PARTICIPANT I

The last phase is also similar to the reverse motion of an experiment Chair - Sit up. The total sum of scores is 1.92 from 3. (TABLE 10)

4.1.3.4 RESULTS FOR A SENSOR PLACED ON A WRIST

Sensor positioned on a wrist didn't record changes in acceleration amplitude clearly in any of axes but markers for beginning and ending of phases. The most clearly visible for all of positioning of wearable sensor is a marker P (palm supporting). (FIGURE 14) Sensor's rotation in space caused by its position makes interferences in a movement. These interferences are much more apparent than in a signal from a sensor placed on an arm. All amplitude changes are lower than in signal from sensor placed on an arm (FIGURE 13) but the total sum of scores is only 2.12 from 3, which makes it the second best maximal value (TABLE 10).

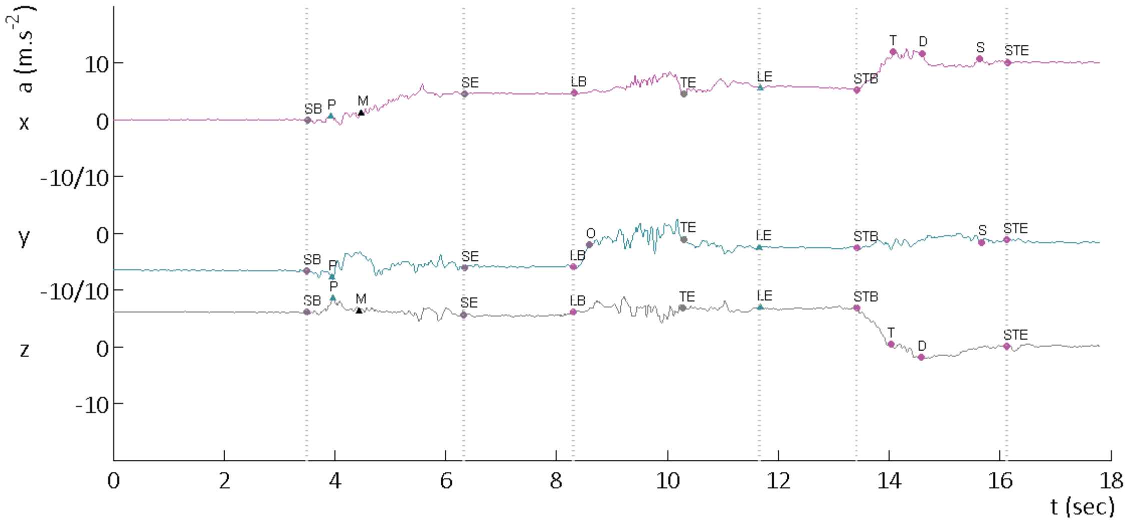


FIGURE 14: DB2 - WRIST, BED, GET UP, HEALTHY PARTICIPANT I

4.1.3.5 RESULTS FOR A SENSOR PLACED ON A HIP ON A BELT

Sensor placed on a hip on a belt is the worst variant of a wearable device for this experiment. The total sum of scores is only 1.72 from 3 (TABLE 10).

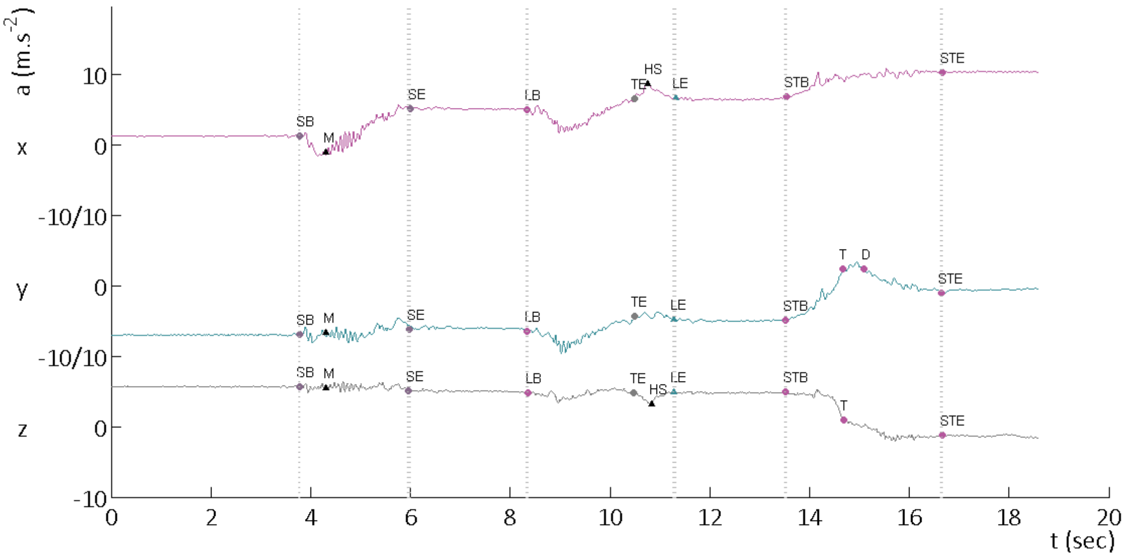


FIGURE 15: HB2 - BELT, BED, GET UP HEALTHY PARTICIPANT I

But marker M is one of the most clearly visible markers for all of positioning of wearable sensor. Because this placement is almost in a center of a movement gravity, there are just indications of markers TE (end of a turn) and HS (heel strike) in the second phase. The last phase is also similar to the reverse motion of an experiment Chair - Sit up. FIGURE 15 shows measuring results of acceleration of the sensor which was fixed on a hip on a belt.

4.1.3.6 RESULTS FOR A SENSOR PLACED ON A THIGH, KNEE AND ANKLE

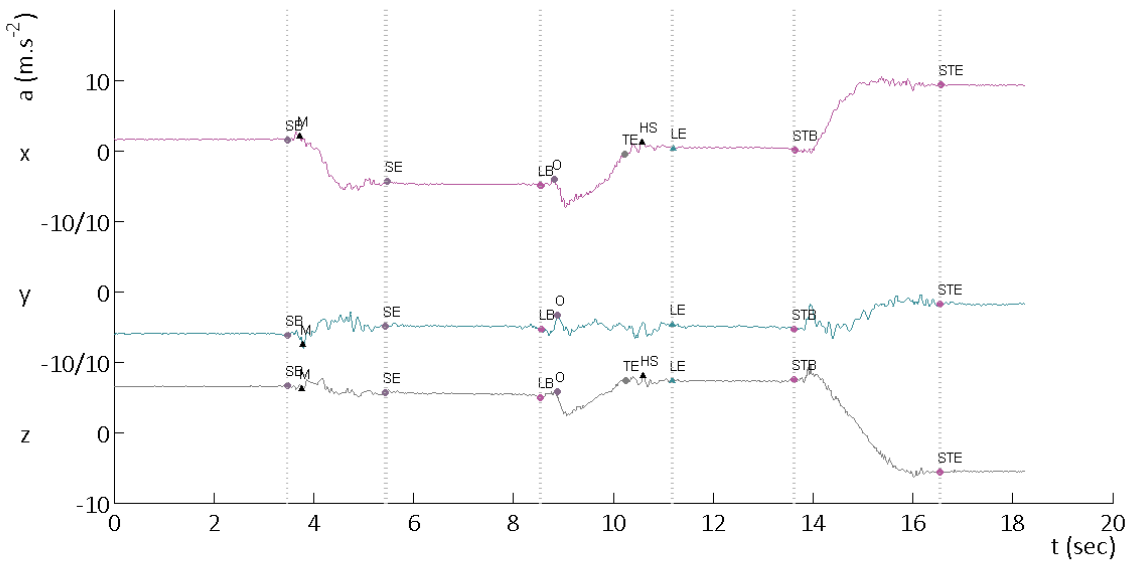


FIGURE 16: GB2 - THIGH, BED, GET UP, HEALTHY PARTICIPANT I

So there is no clearly detectable markers in a signal but the beginning and end of it. (FIGURE 16) Total sum of scores is only 1.81 – 2.00 from 3 for a sensor placed on a thigh (TABLE 10).

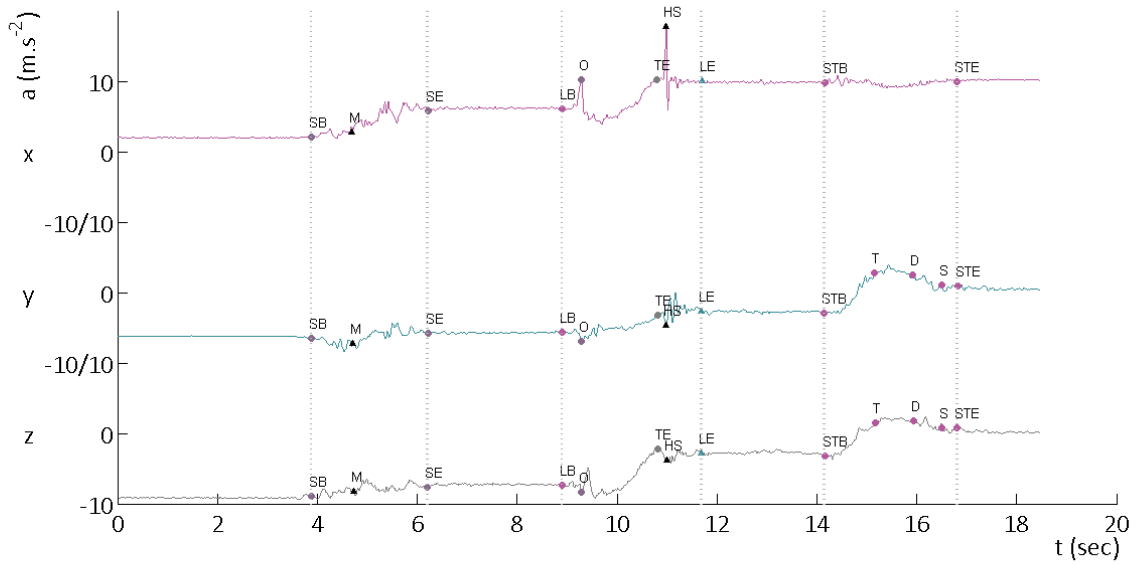


FIGURE 17: EB2 - KNEE, BED, GET UP, HEALTHY PARTICIPANT I

For a sensor placed on a knee the total score is 2.00 from 3 (TABLE 10)(FIGURE 17). For a sensor placed on a knee the total score is 2.00 from 3 (TABLE 10)(FIGURE 17). For a sensor placed on an ankle the total score is 1.82 from 3 (TABLE 10) (FIGURE 18).

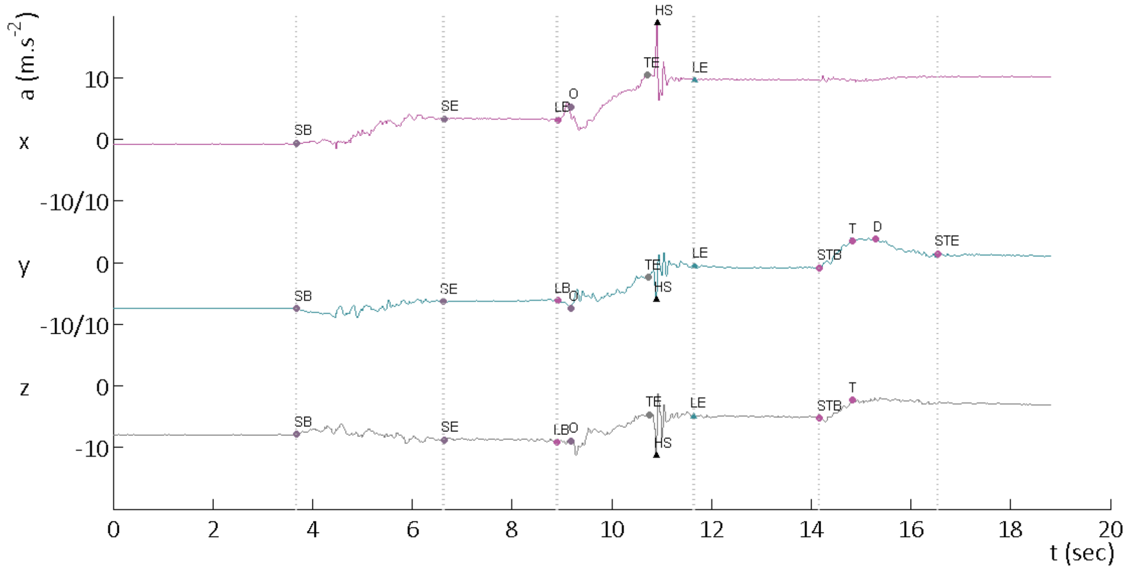


FIGURE 18: FB2 - ANKLE, BED, GET UP, HEALTHY PARTICIPANT I

4.1.4 EVALUATION OF RESULTS OF THE EXPERIMENT BED – GET UP

Results of the experiment Bed – Get up confirm presumptions which were stated in a chapter 3.2. For this movement the best of all positioning of a wearable device is on an arm. Total sum of scores for z axis is 2.31 from 3 (TABLE 10). As was mentioned in the chapter 4.1.3.5, the total sum of scores for sensor placed on a hip on a belt is only 1.72 from 3 (TABLE 10). So for this movement this is the worst position for a wearable device. All results are shown in a TABLE 10 for comparison. The best and the worst variants are highlighted here.

TABLE 10: RESULTS OF THE EXPERIMENT BED - GET UP, HEALTHY PARTICIPANT I, THE BEST POSITION IS HIGHLIGHTED BY GREEN COLOR, THE WORST POSITION IS HIGHLIGHTED BY GREY COLOR

POSITION	AXIS	SB	H	M	P	SE	LB	O	TE	HS	LE	STB	T	D	S	STE	TOTAL	SUITABLE
	WEIGHT	0.08	0.05	0.07	0.05	0.08	0.08	0.05	0.07	0.05	0.08	0.08	0.05	0.07	0.05	0.08	1	
HEAD	X	3	0	2	0	2	2	0	0	0	2	1	0	0	0	1	1.02	1.94
	Y	2	0	1	0	1	2	0	2	2	1	1	0	0	0	1	0.95	
	Z	3	3	2	0	3	2	0	0	0	2	3	3	3	0	3	1.94	
ARM	X	3	0	1	0	1	1	2	1	0	3	3	3	3	0	3	1.73	2.31
	Y	3	0	1	3	2	2	2	3	0	3	3	1	2	0	3	2.01	
	Z	3	0	3	3	2	2	3	3	0	3	3	3	2	0	3	2.31	
TRUNK	X	2	2	3	0	2	2	0	0	0	2	2	2	2	1	1	1.49	1.92
	Y	1	0	1	0	1	2	0	0	0	1	1	0	0	0	1	0.63	
	Z	2	1	2	0	3	3	0	1	1	3	3	2	2	0	3	1.92	
WRIST	X	2	0	1	3	2	2	0	2	3	1	3	2	2	2	1	1.75	2.12
	Y	2	0	0	2	3	3	1	1	1	1	2	0	0	1	1	1.29	
	Z	3	0	2	3	3	3	0	1	3	2	3	2	2	0	3	2.12	
HIP	X	3	0	3	0	3	3	0	1	2	2	3	0	0	0	2	1.66	1.72
	Y	3	0	3	0	2	2	0	1	0	2	3	2	2	0	3	1.72	
	Z	1	0	1	0	1	1	0	1	2	2	1	2	0	0	3	1.07	
THIGH	X	3	0	1	0	3	3	3	1	1	2	3	0	0	0	3	1.71	1.81
	Y	3	0	3	0	3	3	3	0	0	3	3	0	0	0	3	1.81	
	Z	1	0	1	0	1	1	1	1	2	1	3	0	0	0	3	1.10	
KNEE	X	2	0	2	0	3	3	3	2	3	1	1	0	0	0	1	1.47	2.00
	Y	2	0	1	0	2	3	3	1	2	1	2	2	2	1	1	1.57	
	Z	2	0	2	0	2	2	3	3	3	3	3	2	2	1	1	2.00	
ANKLE	X	2	0	0	0	2	3	3	2	3	3	0	0	0	0	0	1.25	1.82
	Y	2	0	0	0	2	3	3	1	3	3	3	2	2	0	2	1.82	
	Z	2	0	0	0	2	3	1	1	3	2	3	1	0	0	0	1.29	

4.1.5 RESULTS OF THE EXPERIMENT GAIT – SLOW WALK

As was already written in the chapter 3.5, the experiment Gait - Slow walk was evaluated based on a subjective visibility of specific markers which are H (heel strike), F (foot flat), M (midstance), O (heel and toe off) and S (swing phase) (3.3.3.1). The same methodology as before was used for evaluation. Score from zero to three was written down to the TABLE 11. Following this methodology all wearable device positioning will be presented here for comparison. The set of placements contains caudal head, arm, trunk, wrist, thigh, hip, knee and ankle.

Sensors placed on legs has a more predicative value then the rest of sensors caused by participant's gait cycle and markers which are observed. But there is a high probability for sensors placed on an arm or on a wrist because of the synchronous movement.

4.1.5.1 RESULTS FOR A SENSOR PLACED ON A HEAD

As was predicated before, the sensor placed on a head is the worst variant of the wearable device positioning for this experiment. In y axis there are indication of H (heel strike), O (heel and toe off) and S (swing phase) markers, so the cadence (frequency of steps) could be counted. In FIGURE 19 are shown results of an acceleration of the sensor which was placed on a head. The total sum of scores is only 0.8 from 3 (TABLE 11).

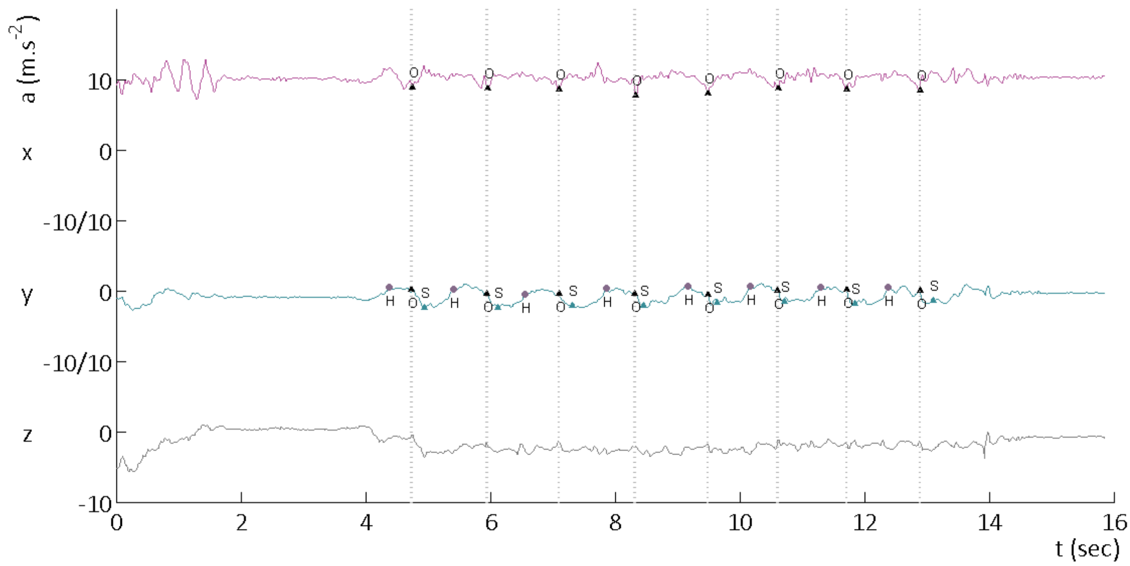


FIGURE 19: AG1 - HEAD, GAIT, SLOW WALK, HEALTHY PARTICIPANT I

4.1.5.2 RESULTS FOR A SENSOR PLACED ON AN ARM

For a sensor placed on an arm there are partly visible markers H (heel strike) an O (heel and toe off) in x axis (FIGURE 20). For a gait monitoring the most important is an information about gait velocity, cadence (frequency of steps) and stride length. All of these information could be obtained from such a signal because of the synchronous movement of arms and legs. The total sum of scores is 1.2 from 3 (TABLE 11).

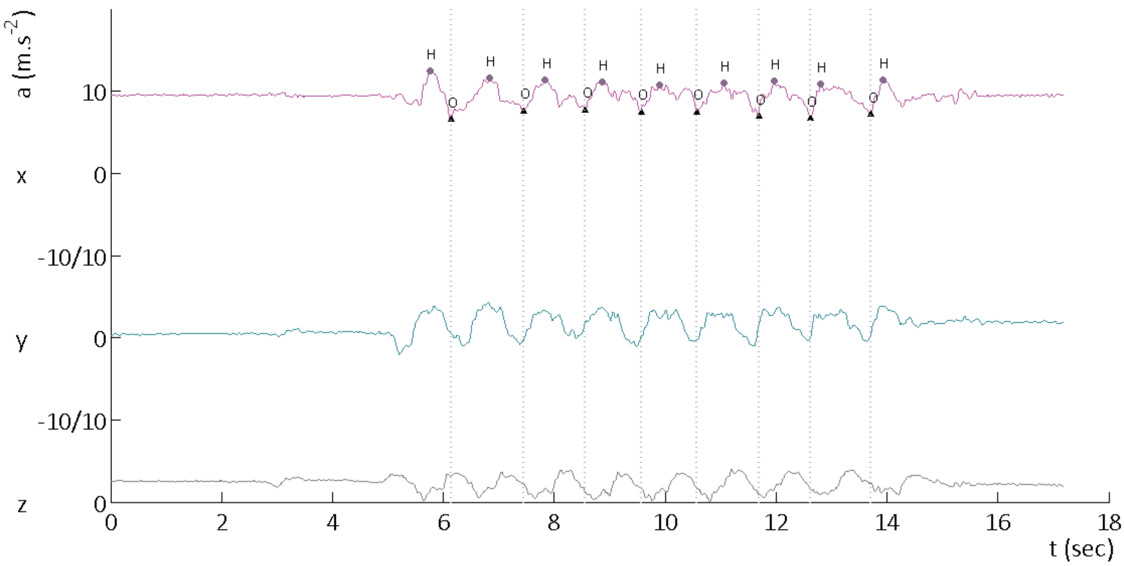


FIGURE 20: BG1 - ARM, GAIT, SLOW WALK, HEALTHY PARTICIPANT I

4.1.5.3 RESULTS FOR A SENSOR PLACED ON A TRUNK

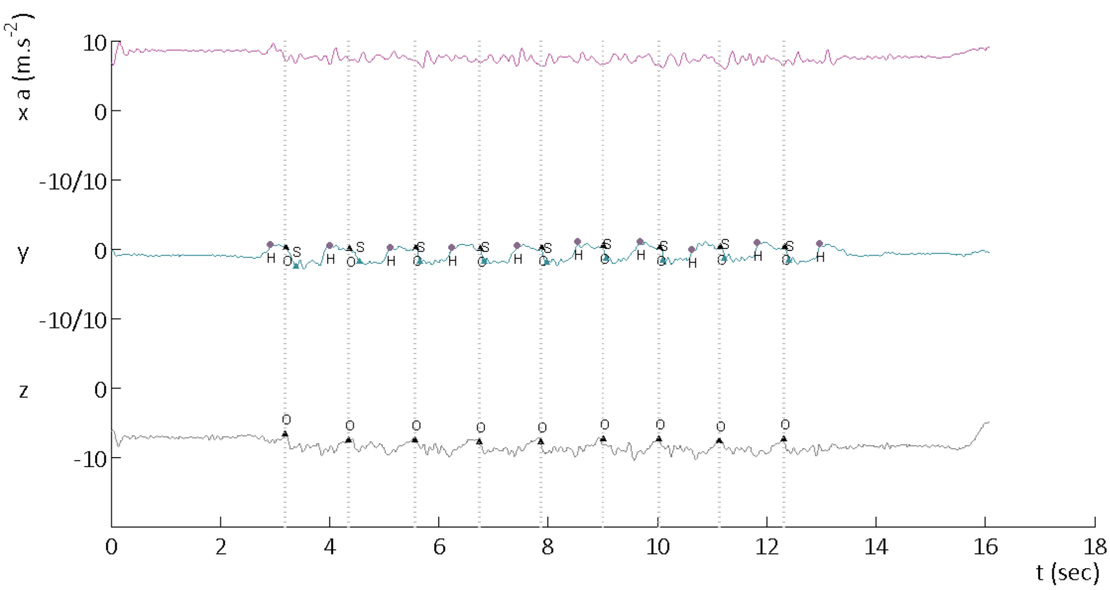


FIGURE 21: CG1 - TRUNK, GAIT, SLOW WALK, HEALTHY PARTICIPANT I

There could be seen a periodicity of a movement in y axis of a signal because the participant's body is waggling from side to side during the walk. It is possible to indicate markers H (heel strike), O (heel and toe off) and S (swing phase) in y axis. Trunk is also moving little forward and backward during this movement so O marker (heel and toe off) in z axis (FIGURE 21) is partly visible too. The total sum of scores is 1.1 from 3 (TABLE 11).

4.1.5.4 RESULTS FOR A SENSOR PLACED ON A WRIST

For a sensor placed on a wrist are also partly visible just markers H (heel strike) and O (heel and toe off). It is also caused by participant's body waggling from side to side during the walk like in a case of a sensor placed on a trunk. From periodicity of a movement which could be seen in z axis (FIGURE 22) the spatiotemporal parameters of gait such as gait velocity or stride length could be calculated. The total sum of scores is 1.2 from 3 (TABLE 11).

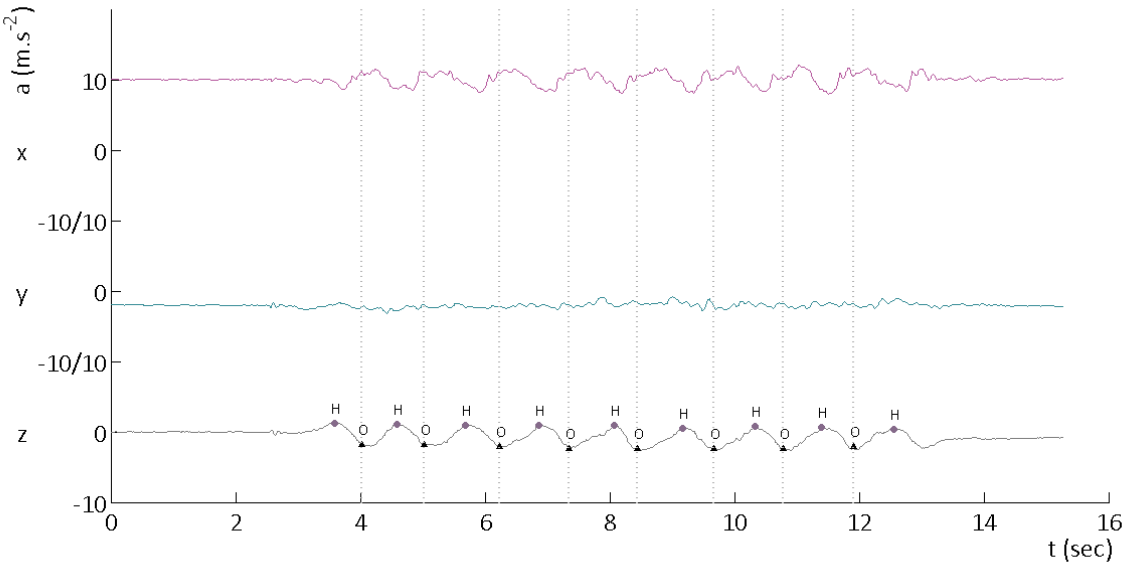


FIGURE 22: DG1 - WRIST, GAIT, SLOW WALK, HEALTHY PARTICIPANT I

4.1.5.5 RESULTS FOR A SENSOR PLACED ON A HIP ON A BELT

For a sensor placed on a hip on a belt there are no presumptions for good results. It is placed almost in a center of gravity, so the movement of legs couldn't be detected. In y axis of a signal there are indications of H (heel strike) marker caused by participant's body waggling like for sensor placed on a wrist or sensor which is fixed on a trunk. In z axis are partly visible markers H (heel strike) and O (heel and a toe off) which is caused by shakes of a body during the most recognizable motions such as just heel strike (H) and lifting a heel and toe of (O) the floor (FIGURE 23). The total sum of scores is only 0.9 from 3 (TABLE 11).

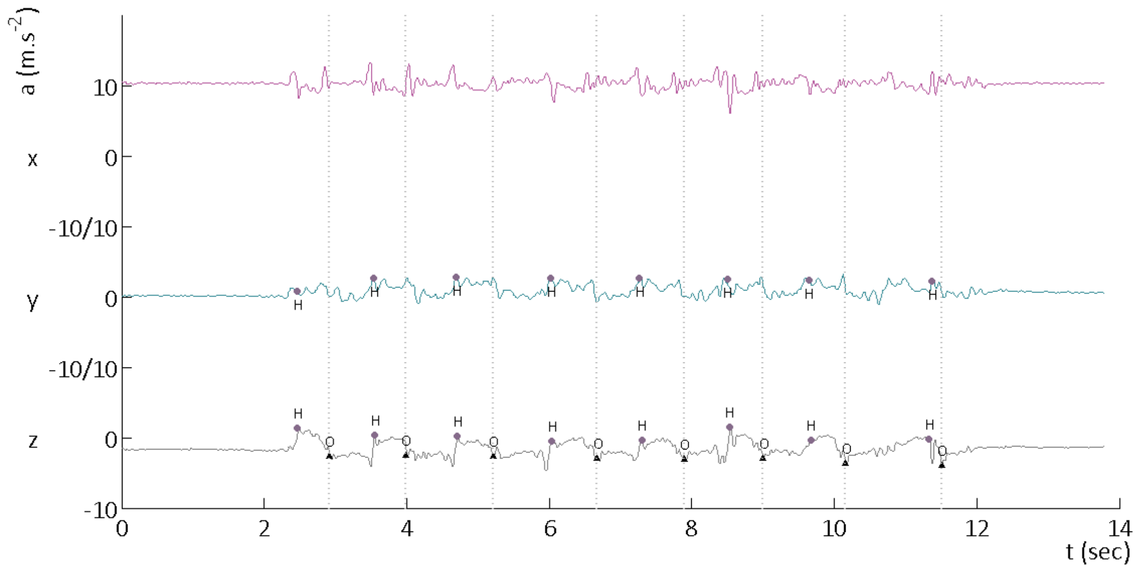


FIGURE 23: HG1 - BELT, GAIT, SLOW WALK, HEALTHY PARTICIPANT I

4.1.5.6 RESULTS FOR A SENSOR PLACED ON A THIGH

For a sensor which is placed on a thigh there are finally visible other markers in a signal.

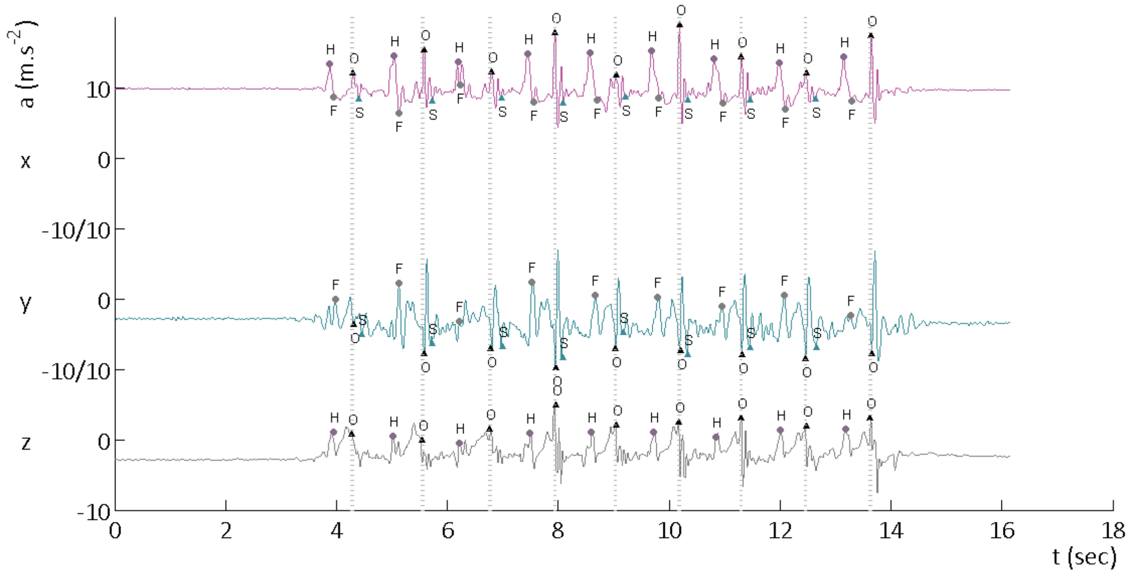


FIGURE 24: GG1 - THIGH, GAIT, SLOW WALK, HEALTHY PARTICIPANT I

The total sum of scores in x axis is 2.4 from 3 which makes it the second best score at all (TABLE 11). There are clearly visible markers H (heel strike) and O (heel and a toe off) which are usable for calculation of the spatiotemporal parameters of a gait. Markers F (foot flat) and S (mid swing) are both partly visible. These markers are also divided to axes y and z. For axis y they are flat foot (F), swing phase (S) and heel and toe off (O). For axis z they are just markers H and O (FIGURE 24).

4.1.5.7 RESULTS FOR A SENSOR PLACED ON A KNEE AND ON AN ANKLE

These positions of a wearable device are the best of all for this movement.

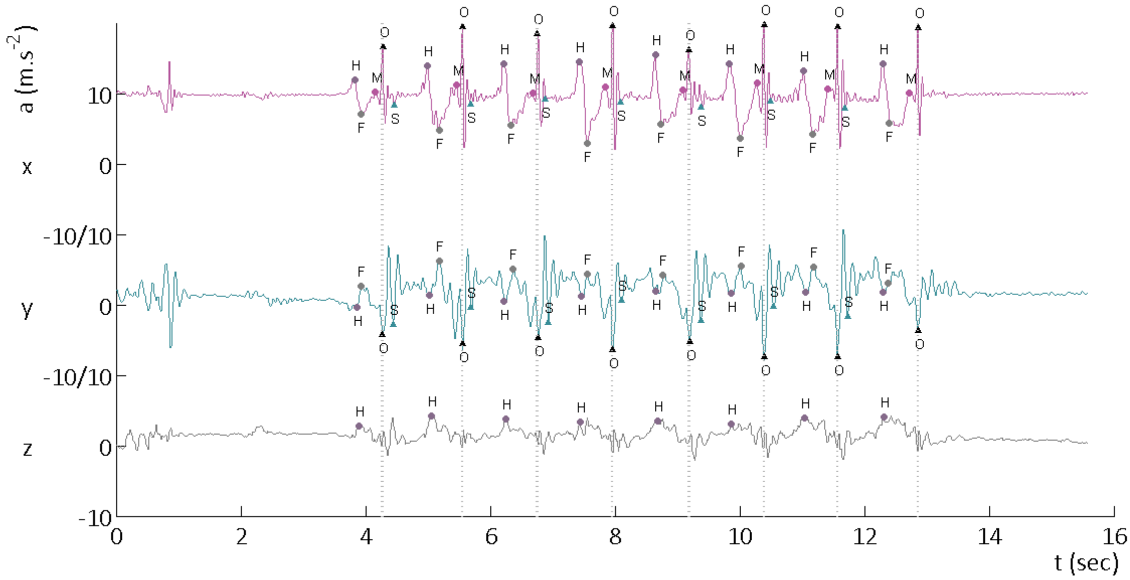


FIGURE 25: EG1 - KNEE, GAIT, SLOW WALK, HEALTHY PARTICIPANT I

The Total sum of scores is 2.9 from 3 for both of them (TABLE 11). The signal in x axis has the best visibility of all markers. It could be seen in FIGURE 25 and FIGURE 26.

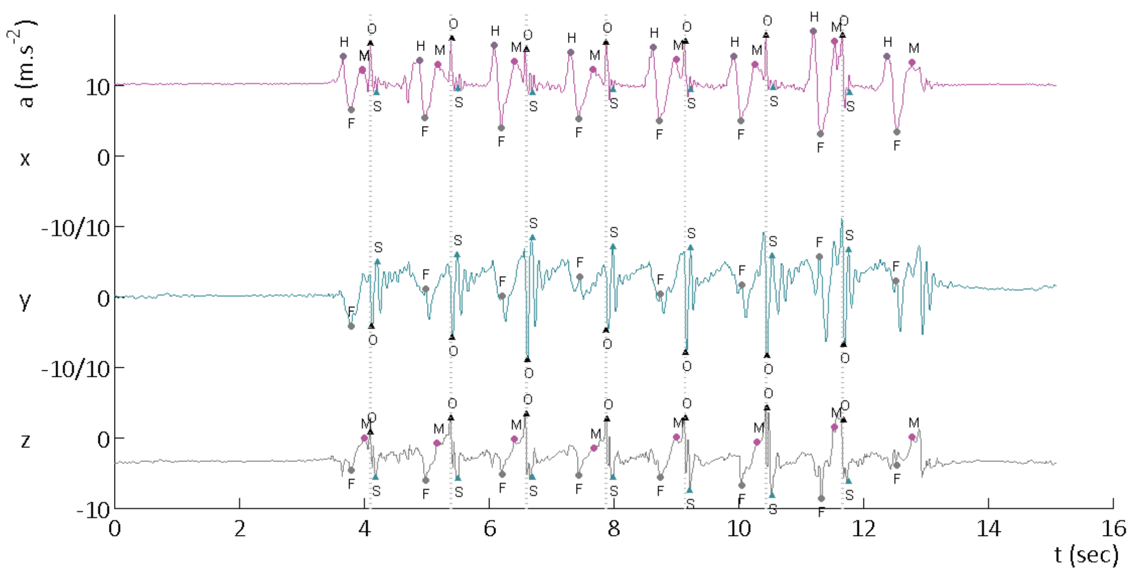


FIGURE 26: FG1 - ANKLE, GAIT, SLOW WALK, HEALTHY PARTICIPANT I

The O marker has the most rapid and the highest amplitude of acceleration caused by quick motion in an ankle joint during this phase of a walk. This marker is also the best one for calculation of the spatiotemporal parameters of gait.

4.1.6 EVALUATION OF RESULTS OF THE EXPERIMENT GAIT – SLOW WALK

Results of the experiment Gait – Slow walk confirm propositions which were stated in a chapter 3.2. For this movement the best of all positioning of a wearable device are on knee and on an ankle. Total sum of scores for x axis is 2.9 from 3 (TABLE 11). As was mentioned in the chapter 4.1.5.1, the total sum of scores for sensor placed on a head is only 0.8 from 3 (TABLE 11). So for this movement this is the worst position for a wearable device. All results are shown in a TABLE 11 for comparison. The best and the worst variants are highlighted here.

TABLE 11: RESULTS OF THE EXPERIMENT GAIT - SLOW WALK, HEALTHY PARTICIPANT I, THE BEST POSITION IS HIGHLIGHTED BY GREEN COLOR, THE WORST POSITION IS HIGHLIGHTED BY GREY COLOR

POSITION	AXIS WEIGHT	H 0.3	F 0.2	M 0.1	O 0.3	S 0.1	TOTAL 1	SUITABLE
HEAD	X	0	0	0	1	0	0.3	0.80
	Y	1	0	0	1	2	0.8	
	Z	0	0	0	0	0	0	
ARM	X	2	0	0	2	0	1.2	1.20
	Y	0	0	0	0	0	0	
	Z	0	0	0	0	0	0	
TRUNK	X	0	0	0	0	0	0	1.10
	Y	2	0	0	1	2	1.1	
	Z	0	0	0	2	0	0.6	
WRIST	X	0	0	0	0	0	0	1.20
	Y	0	0	0	0	0	0	
	Z	2	0	0	2	0	1.2	
HIP	X	0	0	0	0	0	0	0.90
	Y	1	0	0	0	0	0.3	
	Z	2	0	0	1	0	0.9	
THIGH	X	3	2	0	3	2	2.4	2.40
	Y	0	3	0	3	3	1.8	
	Z	3	0	0	2	0	1.5	
KNEE	X	3	3	3	3	2	2.9	2.90
	Y	2	2	0	3	3	2.2	
	Z	2	0	0	0	0	0.6	
ANKLE	X	3	3	3	3	2	2.9	2.90
	Y	0	1	0	3	3	1.4	
	Z	0	3	1	3	2	1.8	

4.1.7 EVALUATION OF RESULTS OF ALL EXPERIMENTS

Results of all experiments are shown in a TABLE 12 for comparison. Because the weights were set differently for each experiment and the number of markers was not the same, the methodology to recalculating results has to be designed. The methodology comes from the chapter 4.3.

TABLE 12: RESULTS OF ALL EXPERIMENTS, HEALTHY PARTICIPANT I, THE BEST POSITIONS ARE HIGHLIGHTED BY GREEN COLOR, THE WORST POSITIONS ARE HIGHLIGHTED BY GREY COLOR

POSITIONS	HEAD	ARM	TRUNK	WRIST	HIP	THIGH	KNEE	ANKLE
CHAIR - SIT DOWN	2.40	1.80	2.80	0.90	1.20	1.90	0.60	0.60
BED - GET UP	1.94	2.31	1.92	2.12	1.72	1.81	2.00	1.82
GAIT - SLOW WALK	0.80	1.20	1.10	1.20	0.90	2.40	2.90	2.90

4.2 VERIFICATION OF EXPERIMENTAL MEASURING

When the methodology was set the verification of experimental measuring had to be done. Another one participant was measured for the most predicative experiments. These are Chair – Sit down, Bed – get up and Gait - Slow walk.

The participant was a young man, 21 years old, 192 cm height and 73 kg weight, also healthy, no problems with a musculoskeletal system, no problems with a stability or spatial orientation.

The rest of figures which were not presented in text are in the appendix. The best and the worst of wearable device positions for the second participant will be presented in following chapters. These results will be compared with results of the first participant.

4.2.1 VERIFICATION OF RESULTS OF THE EXPERIMENT CHAIR – SIT DOWN

The second participant performed the same experiment Chair – Sit down under the same conditions. The total sum of scores is 2.3 from 3 for a sensor fixed on a trunk which is the best position for this type of experiment (TABLE 13). In FIGURE 27 are shown measuring results of an acceleration of sensor which was fixed on a trunk.

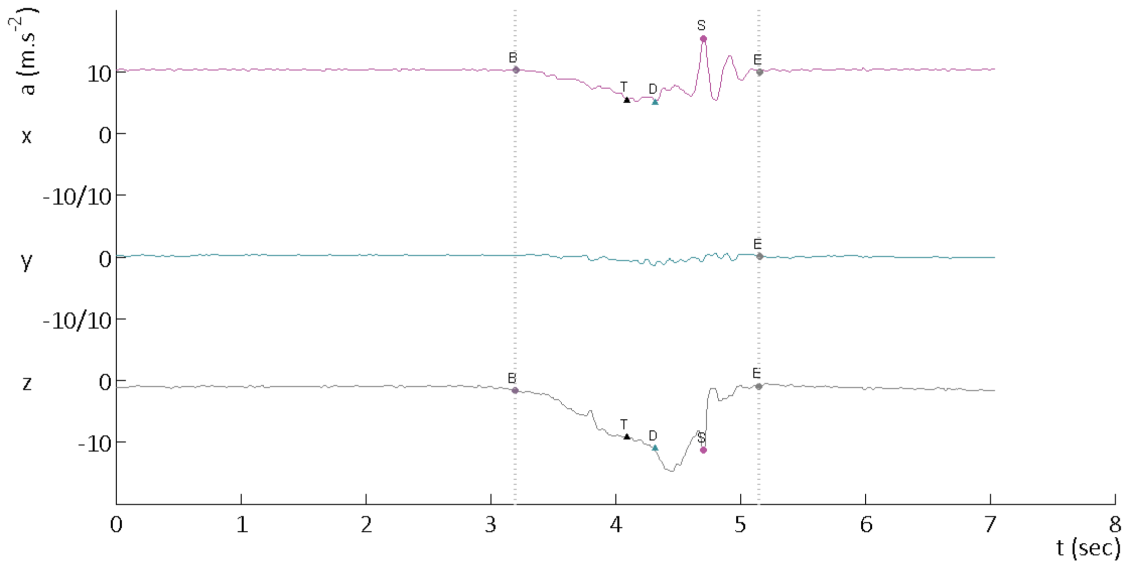


FIGURE 27: CC1 - TRUNK, CHAIR, SIT DOWN, HEALTHY PARTICIPANT II

Sensor placed on an ankle was the worst positioning of a wearable device during the experiment Chair – Sit down with the first participant. The verification measuring was done with the second participant too and its results are shown in FIGURE 28. The total sum of scores is only 0.6 from 3 (TABLE 13).

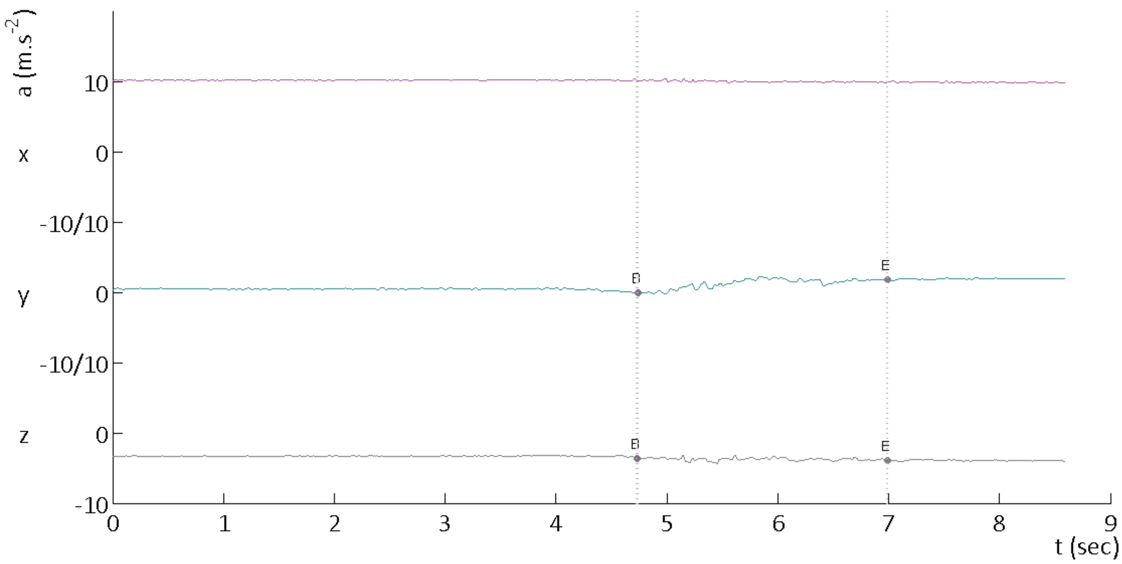


FIGURE 28: FC1 - ANKLE, CHAIR, SIT DOWN, HEALTHY PARTICIPANT II

Evaluation of the verification measuring with the second participant could be called as successful because of the very similar results (TABLE 13).

TABLE 13: RESULTS OF THE EXPERIMENT CHAIR – SIT DOWN, HEALTHY PARTICIPANT II, THE BEST POSITION IS HIGHLIGHTED BY GREEN COLOR, THE WORST POSITION IS HIGHLIGHTED BY GREY COLOR

POSITION	AXIS WEIGHT	B 0.3	T 0.1	D 0.2	S 0.1	E 0.3	TOTAL 1	SUITABLE
TRUNK	X	1	2	1	3	3	1.9	2.30
	Y	0	0	0	0	1	0.3	
	Z	2	1	2	3	3	2.3	
ANKLE	X	0	0	0	0	0	0	0.60
	Y	1	0	0	0	1	0.6	
	Z	1	0	0	0	1	0.6	

4.2.2 VERIFICATION OF RESULTS OF THE EXPERIMENT BED – GET UP

The second participant performed the same experiment Bed – Get up under the same conditions. The total sum of scores is 2.42 from 3 for a sensor fixed on an arm which is the best position (TABLE 14).In FIGURE 29 are shown measuring results of acceleration of sensor placed on an arm.

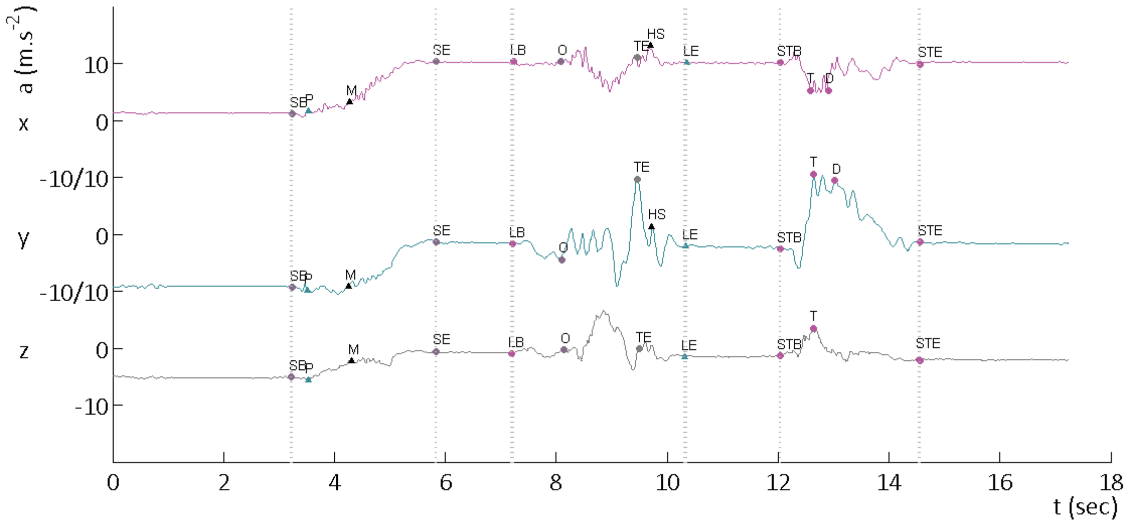


FIGURE 29: BB2 - ARM, BED, GET UP, HEALTHY PARTICIPANT II

Sensor placed on a hip on a belt was the worst positioning of a wearable device during the experiment Bed – Get up with the first participant. The verification measuring was done with the second participant too and its results are shown in FIGURE 30. The total sum of scores is only 1.53 from 3 (TABLE 14).

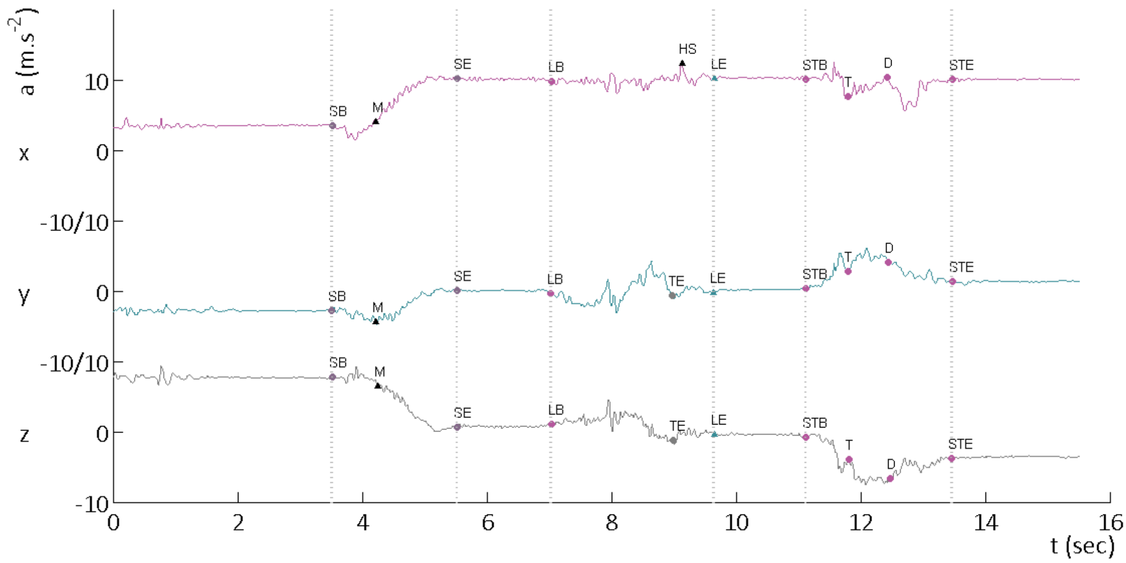


FIGURE 30: BB2 - BELT, BED, GET UP, HEALTHY PARTICIPANT II

Evaluation of the verification measuring with the second participant could be also called as successful because of the very similar results (TABLE 14).

TABLE 14: RESULTS OF THE EXPERIMENT BED – GET UP, HEALTHY PARTICIPANT II, THE BEST POSITION IS HIGHLIGHTED BY GREEN COLOR, THE WORST POSITION IS HIGHLIGHTED BY GREY COLOR

POSITION		AXIS	SB	H	M	P	SE	LB	O	TE	HS	LE	STB	T	D	S	STE	TOTAL	SUITABLE
		WEIGHT	0.08	0.05	0.07	0.05	0.08	0.08	0.05	0.07	0.05	0.08	0.08	0.05	0.07	0.05	0.08	1	
	ARM	X	3	0	2	1	3	2	3	1	3	2	3	3	3	0	3	2.22	
		Y	3	0	2	2	3	2	3	3	3	3	3	3	2	0	3	2.42	2.42
		Z	3	0	2	1	3	2	2	2	0	3	3	3	0	0	2	1.87	
	HIP	X	3	0	2	0	3	2	0	0	2	2	2	2	2	0	1	1.53	
		Y	3	0	2	0	2	3	0	1	0	1	3	2	1	0	1	1.42	1.53
		Z	3	0	2	0	3	2	0	1	0	1	3	2	1	0	2	1.50	

4.2.3 VERIFICATION OF RESULTS OF THE EXPERIMENT GAIT – SLOW WALK

The second participant performed the same experiment Gait – Slow walk under the same conditions as the first one. The total sum of scores is 3 from 3 for a sensor placed on an ankle which is the best position (TABLE 15). In FIGURE 31 are shown measuring results of an acceleration of a sensor which was placed on an ankle.

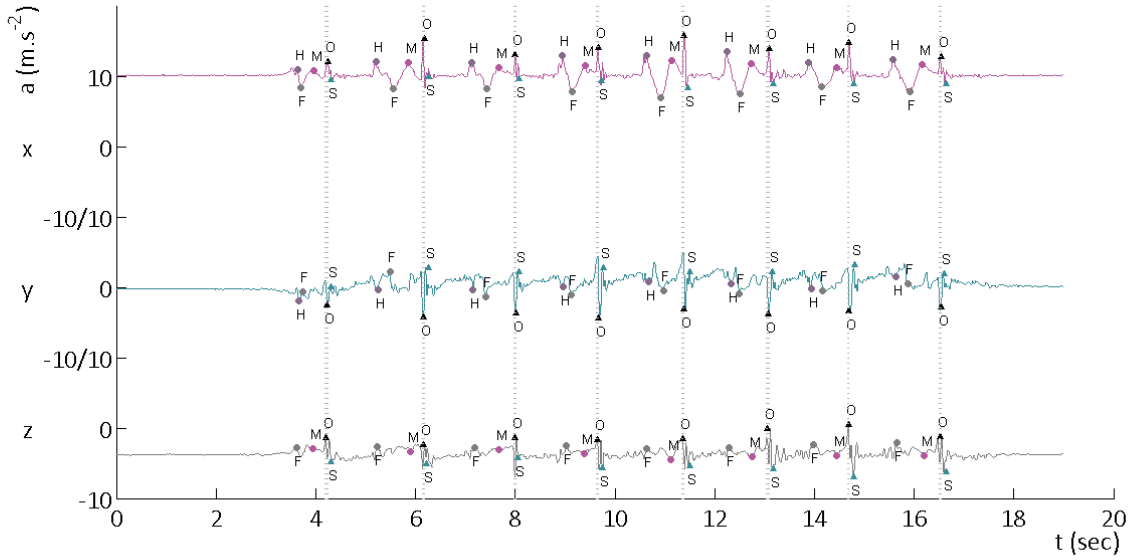


FIGURE 31: FG1 - ANKLE, GAIT, SLOW WALK, HEALTHY PARTICIPANT II

Sensor placed on a head was the worst positioning of a wearable device during the experiment Gait – Slow walk with the first participant. The verification measuring was done with the second participant too and its results are shown in FIGURE 32. The total sum of scores is only 0.6 from 3 (TABLE 15).

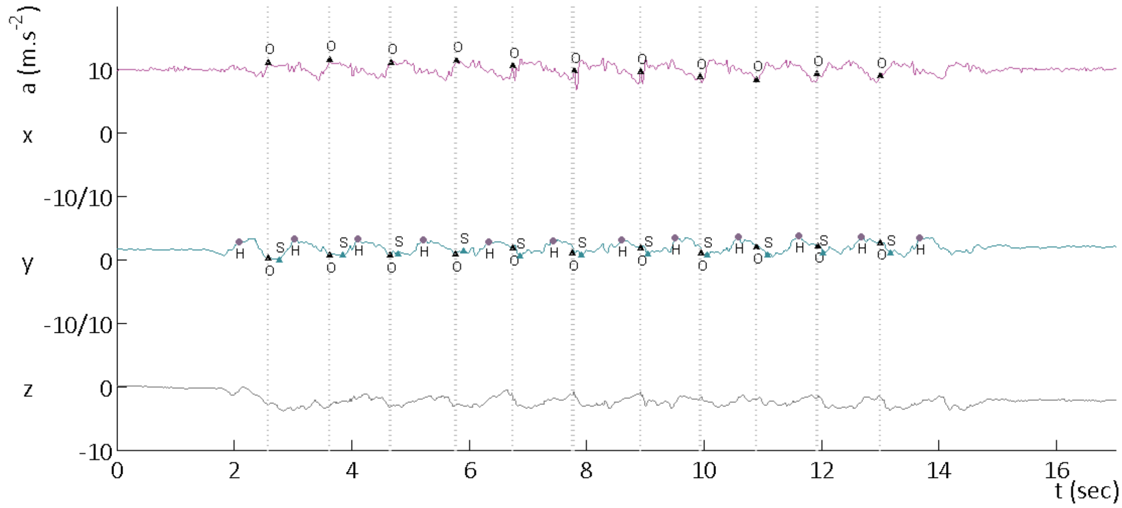


FIGURE 32: AG1 - HEAD, GAIT, SLOW WALK, HEALTHY PARTICIPANT II

Evaluation of the verification measuring with the second participant could be also called as successful because of the very similar results (TABLE 15).

TABLE 15: RESULTS OF THE EXPERIMENT GAIT - SLOW WALK, HEALTHY PARTICIPANT II, THE BEST POSITION IS HIGHLIGHTED BY GREEN COLOR, THE WORST POSITION IS HIGHLIGHTED BY GREY COLOR

POSITION		AXIS	H	F	M	O	S	TOTAL	SUITABLE
		WEIGHT	0.3	0.2	0.1	0.3	0.1	1	
	HEAD	X	0	0	0	2	0	0.6	1.00
		Y	1	0	0	2	1	1	
		Z	0	0	0	0	0	0	
	ANKLE	X	3	3	3	3	3	3	3.00
		Y	1	1	0	3	3	1.7	
		Z	0	2	1	3	3	1.7	

4.3 EVALUATION OF THE BEST POSITION OF A WEARABLE DEVICE

Since the best positions of wearable device for each experiment are known one of them has to be chosen for monitoring all daily activities.

For the first step in assessment of the best position of a device was used the multiple-criteria decision analysis (MCDA) (3.5). This MCDA problem is represented in the criterion space which is combined by a weighted linear function (3.5) (TABLE 8). This was already done and described in previous chapters (4.1, 4.2).

For the next step it is not appropriate to just sum all total sums for every placement of a sensor and sort them as a best to worst sequence. Based on this though the methodology for results recalculation was established.

Although there was a range from 0 to 3 for a possible score value, for each experiment the weights were set differently (TABLE 8) and the count of markers was not the same. Therefore the range of final total sums was height for experiments Chair – Sit down (2.2) and Gait – Slow walk (2.1) but very low for experiment Bed – Get up (0.58). So the range for each experiment had to be recomputed (the result of a suitability for the very position minus the minimum of all scores of suitability for the experiment is equal to recalculated result of a suitability into a new range) and then normalized (from 0 - 1). After that the results could be compared. Then the sum of results for each position were calculated.

TABLE 16: RESULTS OF ALL EXPERIMENTS TO CHOICE A BEST SENSOR POSITIONING, THE BEST POSITION IS HIGHLIGHTED BY DARK GREEN COLOR AND THROUGH WHITE COLOR TOWARD TO DARK GREY COLOR THE WORST POSITION IS HIGHLIGHTED

POSITIONS	HEAD	ARM	TRUNK	WRIST	HIP	THIGH	KNEE	ANKLE
CHAIR - SIT DOWN	2.40	1.80	2.80	0.90	1.20	1.90	0.60	0.60
BED - GET UP	1.94	2.31	1.92	2.12	1.72	1.81	2.00	1.82
GAIT - SLOW WALK	0.80	1.20	1.10	1.20	0.90	2.40	2.90	2.90
CHAIR - SIT DOWN - NEW RANGE	1.80	1.20	2.20	0.30	0.60	1.30	0.00	0.00
CHAIR - SIT DOWN (NORMALIZED)	0.82	0.55	1.00	0.14	0.27	0.59	0.00	0.00
BED - GET UP - NEW RANGE	0.22	0.58	0.19	0.40	0.00	0.08	0.27	0.10
BED - GET UP (NORMALIZED)	0.37	1.00	0.33	0.69	0.00	0.14	0.47	0.17
GAIT - SLOW WALK - NEW RANGE	0.00	0.40	0.30	0.40	0.10	1.60	2.10	2.10
GAIT - SLOW WALK (NORMALIZED)	0.00	0.19	0.14	0.19	0.05	0.76	1.00	1.00
SUITABLE	1.19	1.74	1.48	1.01	0.32	1.49	1.47	1.17

All values, calculations and results are shown in TABLE 16. Following the experimental measurement (4.1) wearable device placed on an arm was found the most suitable for daily activity monitoring with the highest score 1.74. On the other side the worst position for all daily activities is a sensor placed on a wrist like a watch with the lowest score 1.01. The best position is highlighted by dark green color and through white color toward dark grey color the worst position is highlighted in TABLE 16

4.4 PRACTICAL MEASURING

Since all experiments has been evaluated and the best wearable device positioning has been chosen, the daily activities could be monitored in practice. There will be presented results for seniors' daily activities monitoring in chapter 4.4.1. In the next chapter 4.4.2 the blind record will be analyzed. The best positioning of a wearable measuring device from 4.3 will be used.

4.4.1 SENIORS' DAILY ACTIVITIES MONITORING

In this monitoring three seniors were observed and measured during three experiments. The wearable measuring device which was placed on a seniors' arm wasn't uncomfortable for any of them. They told that wearing the device is like a measuring of a blood pressure which they do three times per day but much more comfortable. After a while they did used to it and they didn't apperceive it. They were not acquainted with previous experimental measuring. There were just ask for sit down on a chair, get up of a bed and walk for four meters distance. So they did it their own way.

Senior number 1 was a man, 83 years old, 158 cm height and 76 kg weight, nonsmoker, after two cardio operations, now with a cardio stimulator. Problems with gait velocity, short stride length, problems with stability.

Senior number 2 was a woman, 79 years old, 161 cm height and 67 kg weight, nonsmoker, back pain and knee pain suffering, partial problems with stability.

Senior number 3 was a man, 61 years old, 182 cm height and 76 kg weight, smoker, after multiple fractures of ribs and of the ankle. In the time of a measuring he has toe fracture on the right foot.

The rest of figures which were not presented in text are in the appendix. In following part the interesting results from figures will be presented. Foregoing figures contain various abnormalities that will be described.

The first movement was experiment Chair – Sit down. In FIGURE 33 is shown also the phase before a movement. This is a senior's body staying in front of a chair and turning around its own axis to finally sit down. This is an abnormality which could be seen in signals in practice. But the main movement is still detectable. There are clearly visible markers B (beginning of a movement), D (deceleration), S (shake of a body) and E (end of a movement) and partly visible marker T (tilt of a trunk) in both x and y axes.

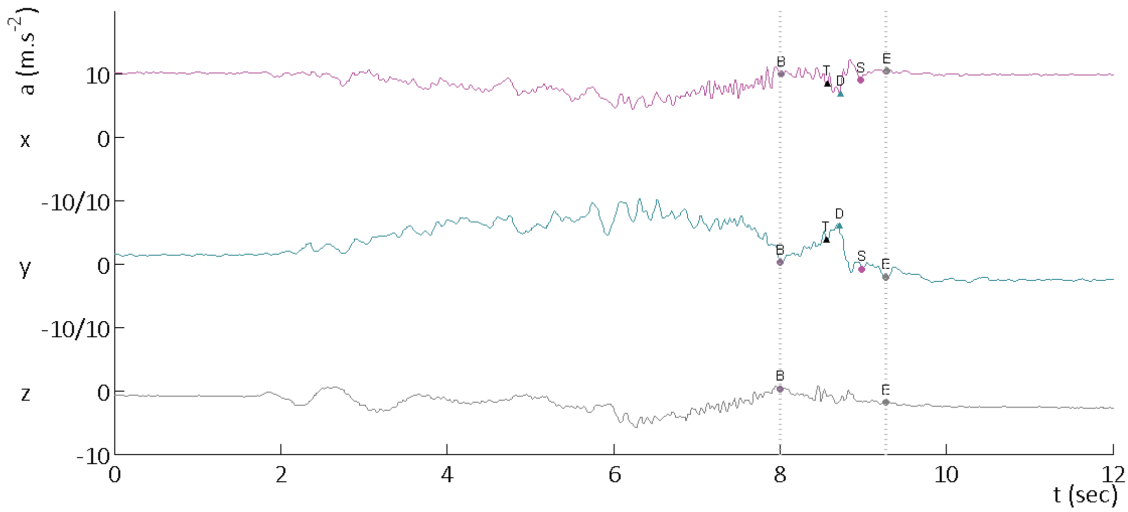


FIGURE 33: BC1 - ARM, CHAIR, SIT DOWN, SENIOR I

Results of the second movement during the experiment Bed – Get up are shown in FIGURE 34. Despite of any lags between phases of the movement all main markers are clearly visible too. The most difficult phase for this senior was getting up of the bed considering the velocity of the movement. The point of deceleration (D) is clearly visible in each axis. Because of the low velocity of the last phase of this movement, the marker S (shake of a body) is not visible in any axis but y.

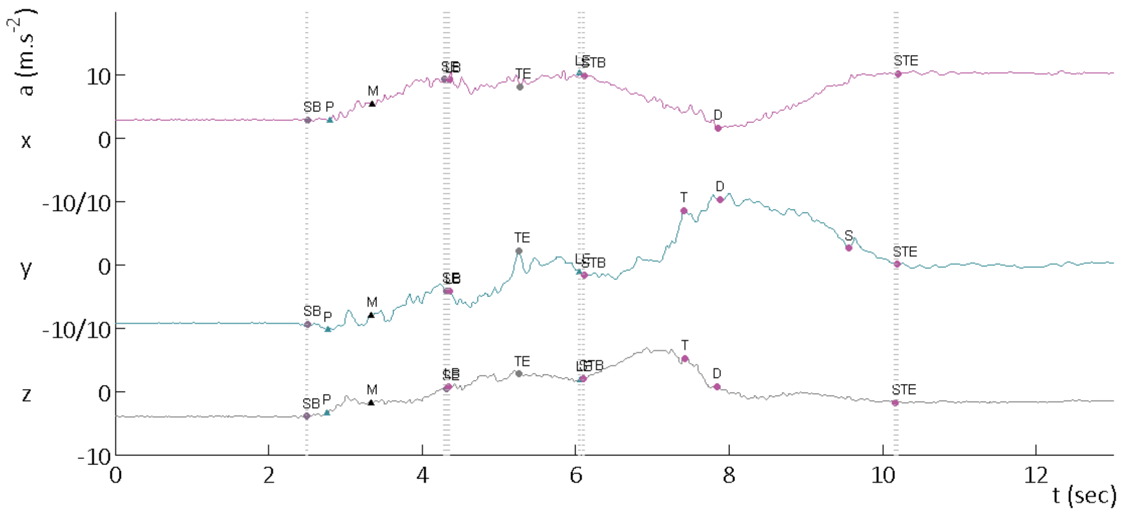


FIGURE 34: BB2 - ARM, BED, GET UP, SENIOR I

The last measuring was an experiment Gait – Slow walk. There are clearly visible markers H (heel strike), F (foot flat), O (heel and toe off) and S (swing phase) in a signal. There could be seen longer stride length in x and z axes of a signal in FIGURE 35.

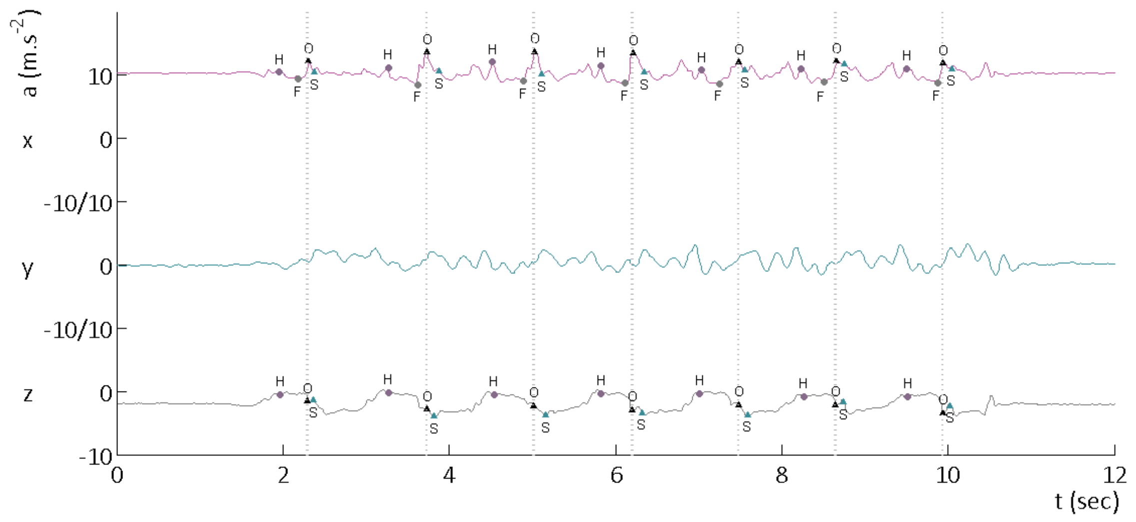


FIGURE 35: BG1 - ARM, GAIT, SLOW WALK, SENIOR III

4.4.2 BLIND RECORD OF A PATIENT'S DAILY ACTIVITIES MONITORING

For the final evaluation of suitability of the chosen wearable device positioning the blind record was measured. The participant was freely moving in his own home environment. After the measurement was done it was evaluated without a knowledge of what exactly participant was doing during that time. Results of the evaluation are shown in FIGURE 36.

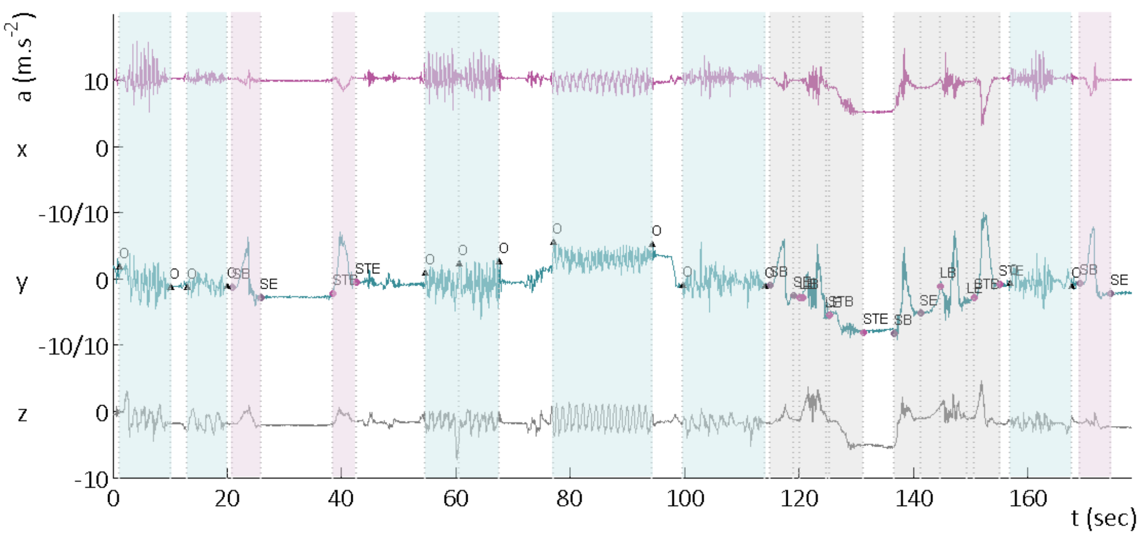


FIGURE 36: DAILY ACTIVITIES MONITORING (WITH MARKERS), HEALTHY PARTICIPANT I, GAIT EXERCISES ARE HIGHLIGHTED BY GREEN COLOR, CHAIR EXERCISES ARE HIGHLIGHTED BY PURPLE COLOR AND BED EXERCISES ARE HIGHLIGHTED BY GREY COLOR

Every movements and their phases were detectable in a signal of the blind record. There is a slow walk in first 10 s, then there is a steady state of participant and two steps towards the chair. After 20 s of record there is clearly visible that participant is sitting down, sitting steady and after another 20 s is standing up. The next part of a signal is a normal walk with a turn followed by slow walk when participant's body is tilted to the side which could be detectable as a change of an acceleration amplitude. In a time 100 s after a beginning of a signal there are visible few steps towards the bed. Next what is clearly visible is that participant is lying down on a bed, he is lying there for an almost 15 s and then he is getting up of a bed again. After that there are visible two steps towards the chair and Sit down movement.

5 CONCLUSION

The thesis deals with daily activity monitoring using a device with accelerometers and was performed based on the official task with 5 points of the instructions.

According to the first point of the task instructions the literature review was performed. For patients with neurodegenerative diseases for daily activity monitoring the most viable system includes accelerometers. The literature review was mainly focused on already existing devices but also to selected current projects over the World.

Suitable solutions of measuring wearable device positioning were presented in the chapter 3.2 as a second point of the task instructions. In order to verify individual solutions of measuring wearable device positioning the very device was constructed by which was fulfilled the fourth point of the task instructions. Assembling of measuring board was described in the chapter 3.1.

Experiments and experimental protocols to verify individual solutions of measuring were designed as the third point of the official task and they were explained in detail in the chapter 3.3. Final set of wearable device positioning were caudal head, arm, trunk, wrist, thigh, hip, knee and ankle (3.2). The three main exercises were Chair, Bed and Gait. Each of them contains two or more experimental protocols, which were presented in the chapters 3.3.1, 3.3.2 and 3.3.3. Data preprocessing in Matlab and the methodology of a signal evaluation usability could be found in chapters 3.4 and 3.5. A tool in Matlab supporting evaluation according the developed methodology was designed. This tool helps with assessing of particular phases and markers in a specific type of experiment. This method is purely subjective because of a hand-operated marking. Multiple-criteria decision analysis was used for evaluation. This MCDA problem is represented in the criterion space which is combined by a weighted linear function which was explained in detail in the chapter 3.5.

First of all the experimental measuring with healthy participant was performed (4.1). The goal was to find particular markers or phases of movements and assess which position of a wearable device is the most suitable for monitoring daily activities. Second part of measuring was verification of experimental measuring (4.2) with another one healthy participant. Evaluation of the verification measuring with the second participant was successful because of the very similar results. After both measuring the evaluation of the best position of a wearable device was done by the developed methodology in the chapter 4.3.

The most suitable for daily activity monitoring is a wearable device placed on an arm with the highest score 1.74. The worst position is on a wrist with the lowest score 1.01. The best position is highlighted by dark green color and through white color toward dark grey color the worst position is highlighted in TABLE 17.

TABLE 17: RESULTS OF ALL EXPERIMENTS TO CHOICE A BEST SENSOR POSITIONING, THE BEST POSITION IS HIGHLIGHTED BY DARK GREEN COLOR AND THROUGH WHITE COLOR TOWARD TO DARK GREY COLOR THE WORST POSITION IS HIGHLIGHTED

POSITIONS	HEAD	ARM	TRUNK	WRIST	HIP	THIGH	KNEE	ANKLE
CHAIR - SIT DOWN	2.40	1.80	2.80	0.90	1.20	1.90	0.60	0.60
BED - GET UP	1.94	2.31	1.92	2.12	1.72	1.81	2.00	1.82
GAIT - SLOW WALK	0.80	1.20	1.10	1.20	0.90	2.40	2.90	2.90
CHAIR - SIT DOWN - NEW RANGE	1.80	1.20	2.20	0.30	0.60	1.30	0.00	0.00
CHAIR - SIT DOWN (NORMALIZED)	0.82	0.55	1.00	0.14	0.27	0.59	0.00	0.00
BED - GET UP - NEW RANGE	0.22	0.58	0.19	0.40	0.00	0.08	0.27	0.10
BED - GET UP (NORMALIZED)	0.37	1.00	0.33	0.69	0.00	0.14	0.47	0.17
GAIT - SLOW WALK - NEW RANGE	0.00	0.40	0.30	0.40	0.10	1.60	2.10	2.10
GAIT - SLOW WALK (NORMALIZED)	0.00	0.19	0.14	0.19	0.05	0.76	1.00	1.00
SUITABLE	1.19	1.74	1.48	1.01	0.32	1.49	1.47	1.17

Then the practical measuring (4.4) was performed. There were presented results for seniors' daily activities monitoring in the chapter 4.4.1 and the blind record was analyzed in the next chapter 4.4.2

Then the practical measuring with three seniors was performed. The wearable measuring device which was placed on a seniors' arm wasn't uncomfortable for any of them. They were not acquainted with previous experimental measuring. There were just ask for sit down on a chair, get up of a bed and walk for four meters distance. Seniors' movement was different considering the experimental measuring that was strictly directed by experimental protocols. Nevertheless the main markers and phases were clearly or partly detectable.

The most interesting part was analysis of the blind record for the final evaluation of suitability of the chosen wearable device positioning. The participant was freely moving in his own home environment. After the measurement was done it was evaluated without a knowledge of what exactly participant was doing during that time (FIGURE 37).

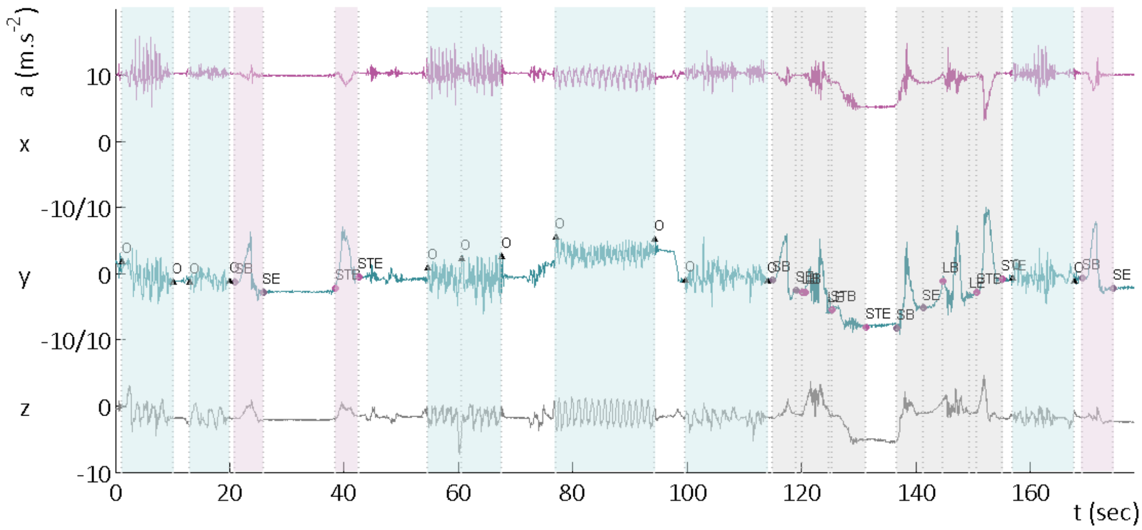


FIGURE 37: DAILY ACTIVITIES MONITORING (WITH MARKERS), HEALTHY PARTICIPANT I, GAIT EXERCISES ARE HIGHLIGHTED BY GREEN COLOR, CHAIR EXERCISES ARE HIGHLIGHTED BY PURPLE COLOR AND BED EXERCISES ARE HIGHLIGHTED BY GREY COLOR

Every movements and their phases were detectable in a signal of the blind record. There were seen a slow walk, steady state of participant or when he is sitting down, sitting steady and after a while is standing up. It is clearly visible when participant is lying down on a bed, he is lying there for a while and then he is getting up of a bed again. Evaluation of the blind measuring was successful.

These results support thought (3.2.2) that the sensor placed on an arm should be used for a long-term monitoring and also for a precise measuring of fractional movements of participants.

According to the literature review of commercial products (2.1.4.1) the most frequent positions of the sensor for a fall detection are on an arm and on a trunk. The most frequent positions of the sensor for long term monitoring supposed to be on a wrist and on an arm and they are mostly used for a real time position reporting (GPS location or entering/leaving geo-fences reporting). None of them is determined to an indoor patient monitoring of movements.

Regarding the project research in the chapter 2.1.4.2, no one is using a sensor placed on an arm. They all try new approaches to the patient monitoring for example with a sensor placed in a shoe, or on the head. Some of them are also using the second device such as Kinect and so on. These projects mostly try to find a solution to fall detection, stability examination or gait analyze but they focus just on one of these problems.

Contribution of this thesis Daily activity monitoring using a device with accelerometers could be divided into few parts.

First of all the documentation for assembling of the measuring board was formed. The simple and well-fixed sensor's covering was designed for experimental and practical measuring on various parts of a participant's body. Through detailed analysis the detectable phases of movements were introduced for typical daily activities. Visibility of these phases and markers helped to define the best positioning of the wearable device for patient's daily monitoring. This position of the sensor placed on an arm became the recommendation for another future projects which are based on monitoring of daily activities.

From the results of measurements it could be calculated the time which senior spends by sitting on a chair or by lying on a bed. Another usability of this measurement could be detection of spatiotemporal parameters of gait such as gait velocity or stride length. These could be detectable symptoms of Alzheimer's disease or another senior's dementia. Such a monitoring of daily activities could be helpful for seniors to stay at home longer with their families.

6 LIST OF ABBREVIATIONS

3D	Three-Dimensional Space
B	Beginning of a movement
CE	Current Era
CT	Computerized Tomography
CTU FBMI	Czech Technical University – Faculty of Biomedical Engineering
D	Deceleration of a movement
DMP	Digital Motion Processor
DPS	Degrees per second
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, 4th Edition
E	End of a movement
F	Foot flat
G SENSOR	Gravity sensor
GPS	Global Positioning System
H	Head lifting / Heel strike on a floor
HS	Heel strike on a bed
LB	Beginning of a movement (legs putting on/of a bed)
LE	End of a movement (legs putting on/of a bed)
LSB	Low Significant Bit
M	Muscles clenching / Midstance
MATLAB	Mathematical Laboratory

MCDA	Multiple-criteria Decision Analysis
MEMS	Microelectromechanical Systems
MPU	Motion Processing Unit
MRI	Magnetic Resonance Imaging
O	Heel and toe lifting
P	Palms supporting
PC	Personal Computer
PCB	Printed Circuit Board
RMS	Root Mean Square
S	Shake following after a seating / Swing phase
SB	Beginning of a movement (Lying on a bed / Sitting down on a bed)
SE	End of a movement (Lying on a bed / Sitting down on a bed)
SOS	The distress signal
STB	Sit down / Get up beginning of a movement
STE	Sit down / Get up end of a movement
T	Tilt of a trunk
TB	Beginning of a turn
TE	End of a turn
UN DESA PD	United Nations Department of Economic and Social Affairs, Population Division

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8 LIST OF TABLES

9 LIST OF REFERENCES

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11 LIST OF ELECTRONIC APPENDIX

./Masters_thesis	Text of the Master’s thesis in PDF format
./Software	M-files for data processing and data evaluation

12 LIST OF APPENDICES

APPENDIX I. FIGURES FOR EXPERIMENT CHAIR – SIT DOWN, PARTICIPANT II

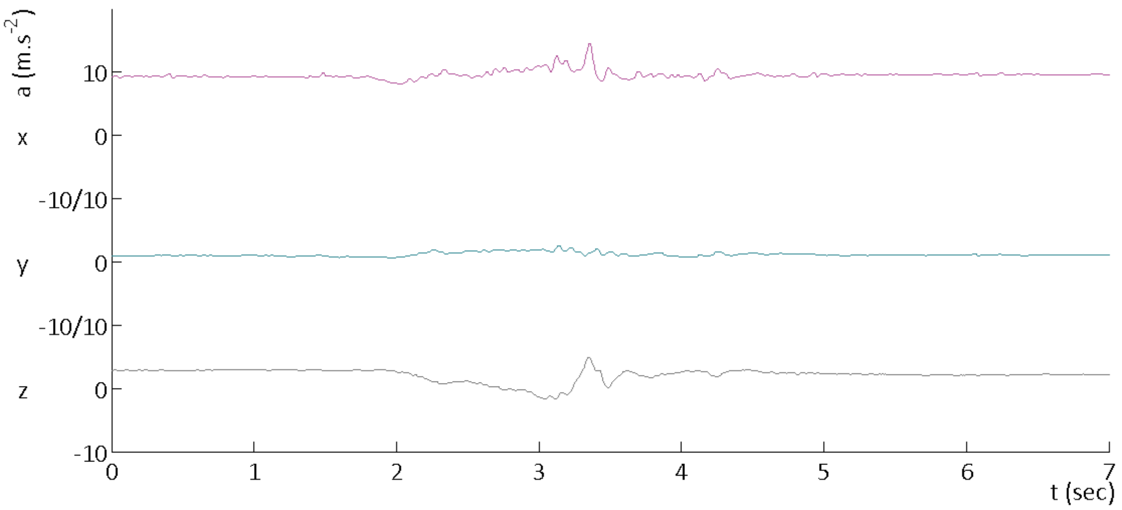

FIGURE 38: AC1 - HEAD, CHAIR, SIT DOWN, HEALTHY PARTICIPANT II

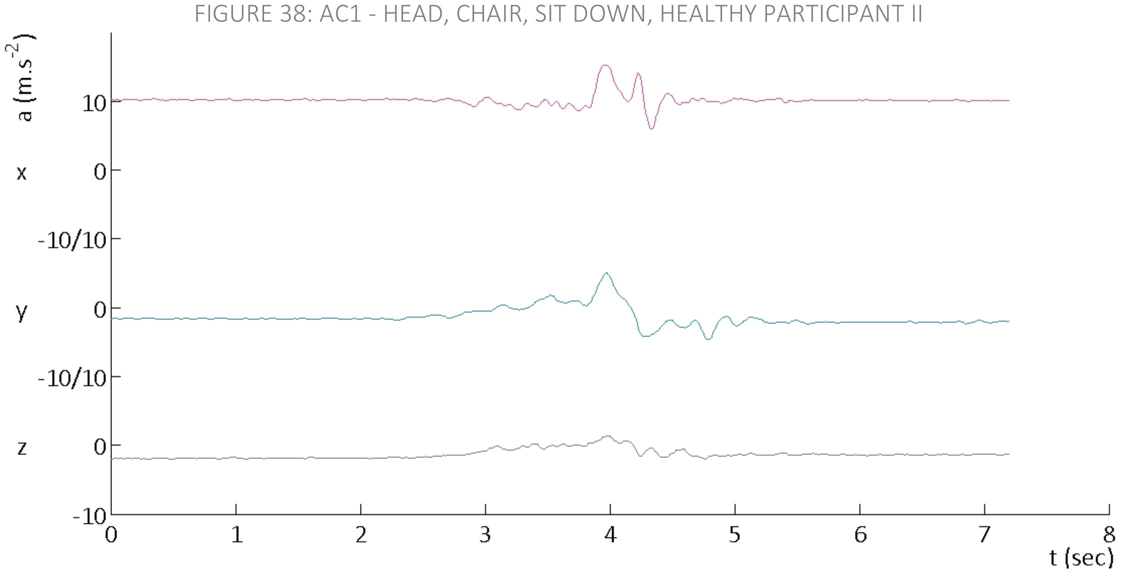

FIGURE 39: BC1 - ARM, CHAIR, SIT DOWN, HEALTHY PARTICIPANT II

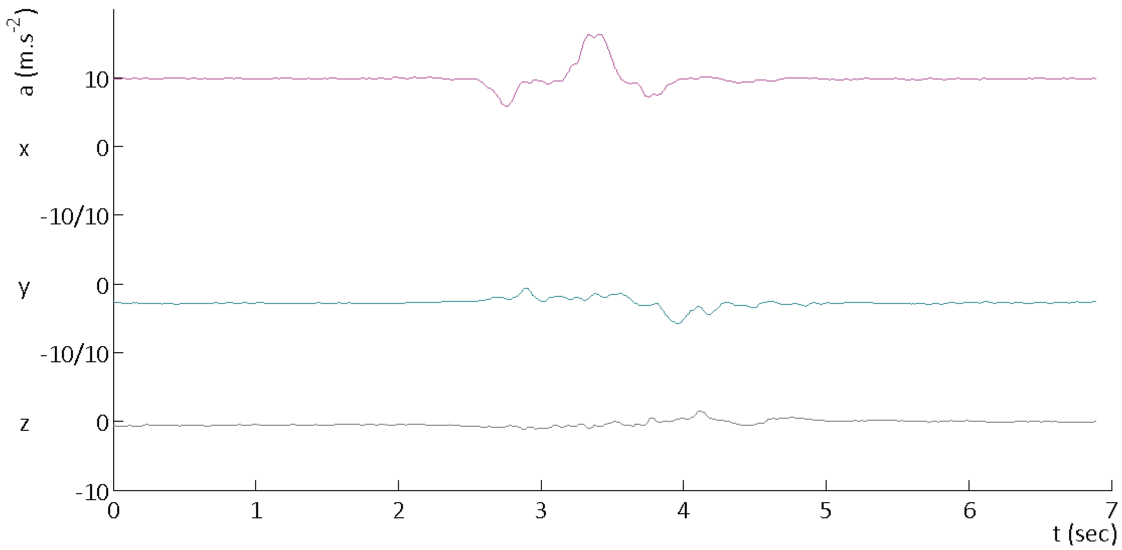

FIGURE 40: DC1 - WRIST, CHAIR, SIT DOWN, HEALTHY PARTICIPANT II

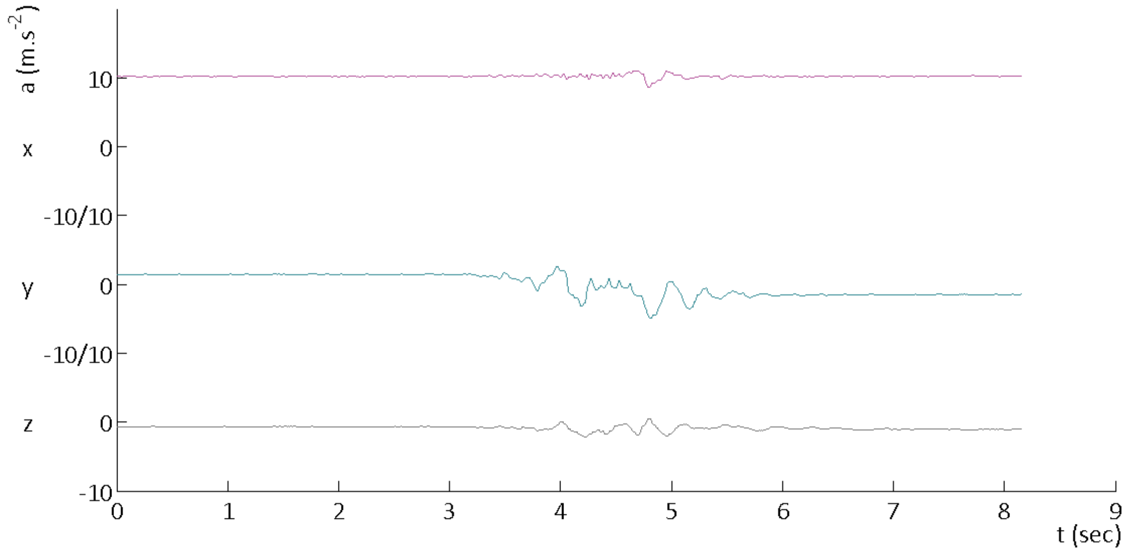

FIGURE 41: EC1 - KNEE, CHAIR, SIT DOWN, HEALTHY PARTICIPANT II

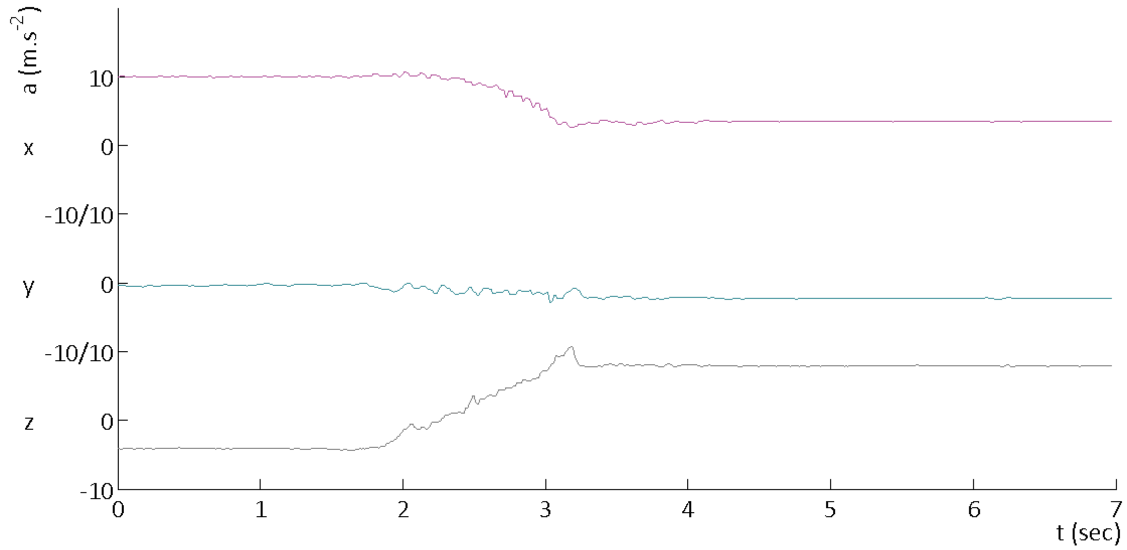

FIGURE 42: GC1 - THIGH, CHAIR, SIT DOWN, HEALTHY PARTICIPANT II

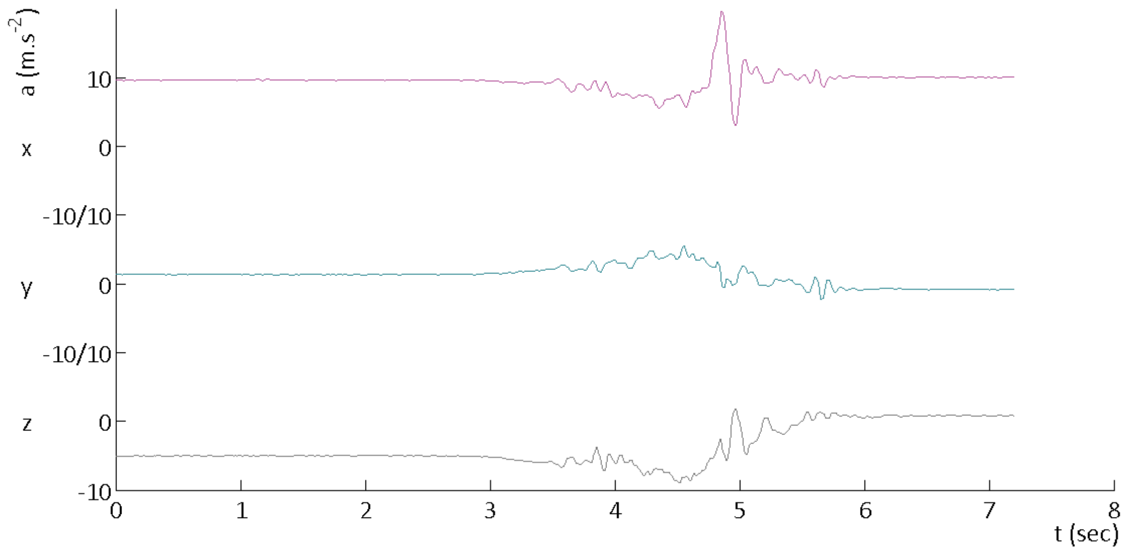

FIGURE 43: HC1 - BELT, CHAIR, SIT DOWN, HEALTHY PARTICIPANT II

APPENDIX II. FIGURES FOR EXPERIMENT BED – GET UP, PARTICIPANT II

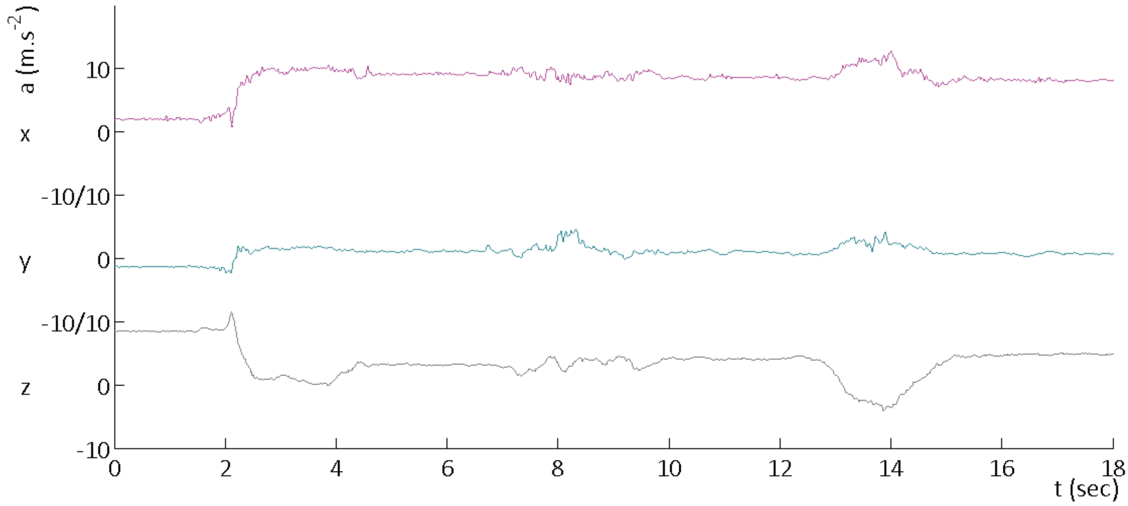

FIGURE 44: AB2 - HEAD, BED, GET UP, HEALTHY PARTICIPANT II

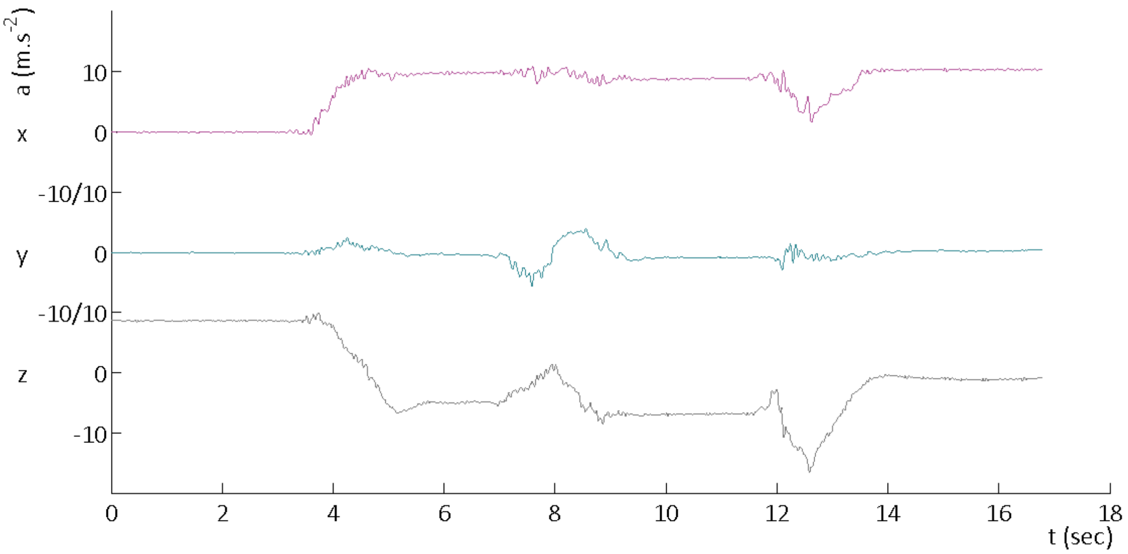

FIGURE 45: CB2 - TRUNK, BED, GET UP, HEALTHY PARTICIPANT II

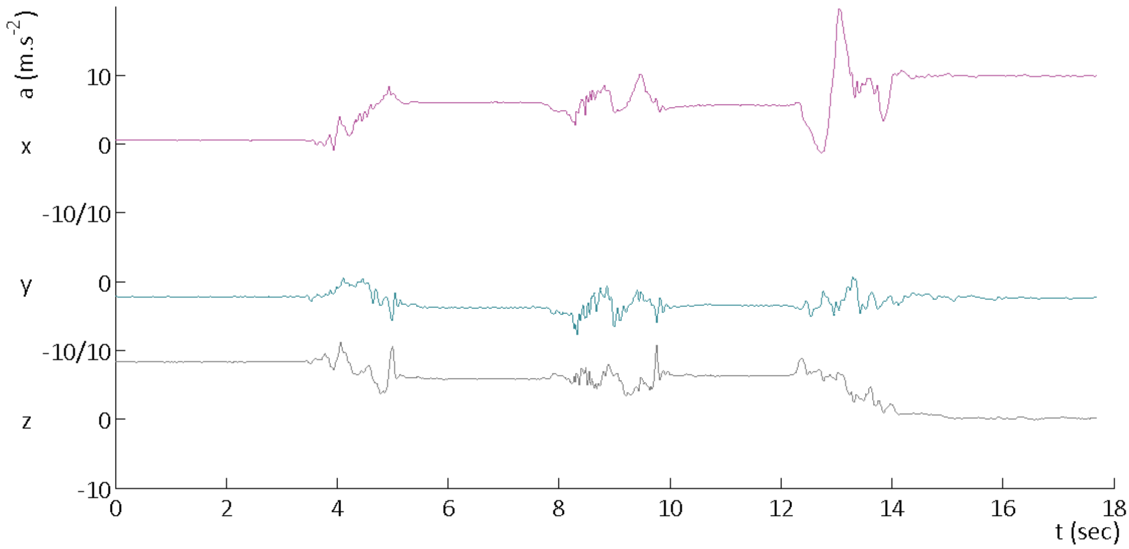

FIGURE 46: DB2 -WRIST, BED, GET UP, HEALTHY PARTICIPANT II

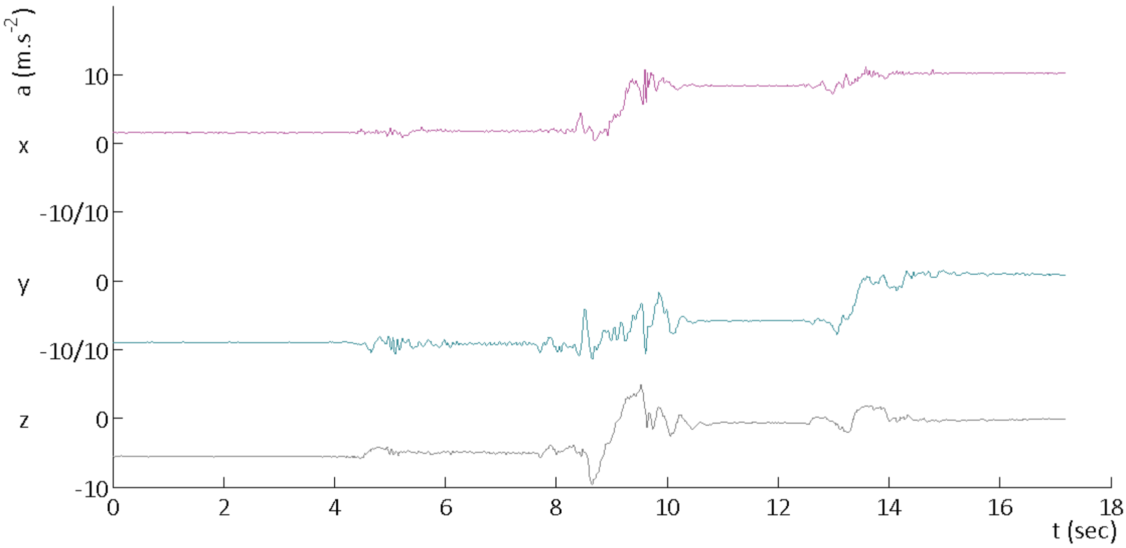

FIGURE 47: EB2 - KNEE, BED, GET UP, HEALTHY PARTICIPANT II

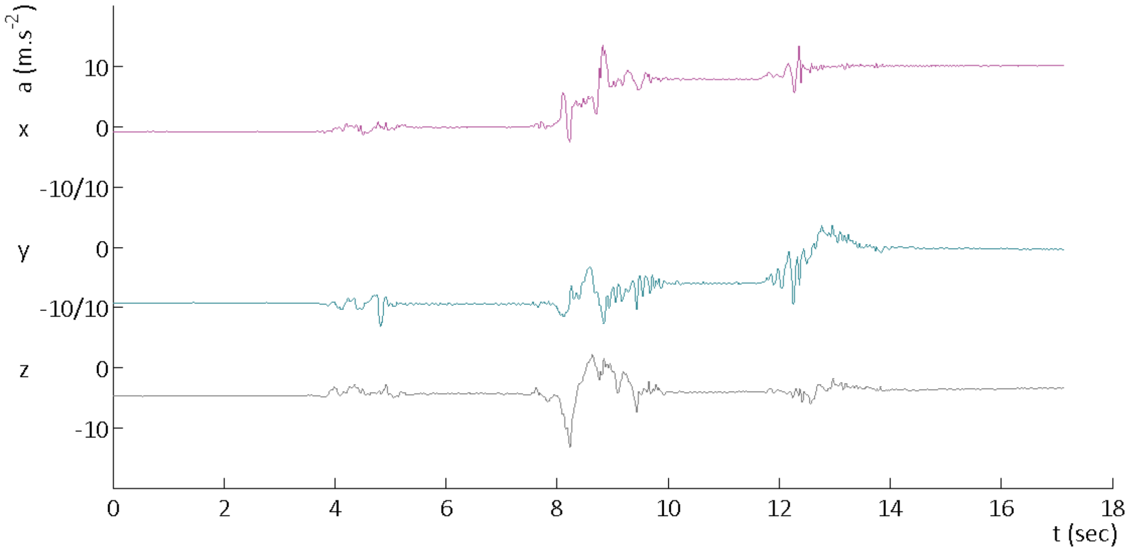

FIGURE 48: FB2 - ANKLE, BED, GET UP, HEALTHY PARTICIPANT II

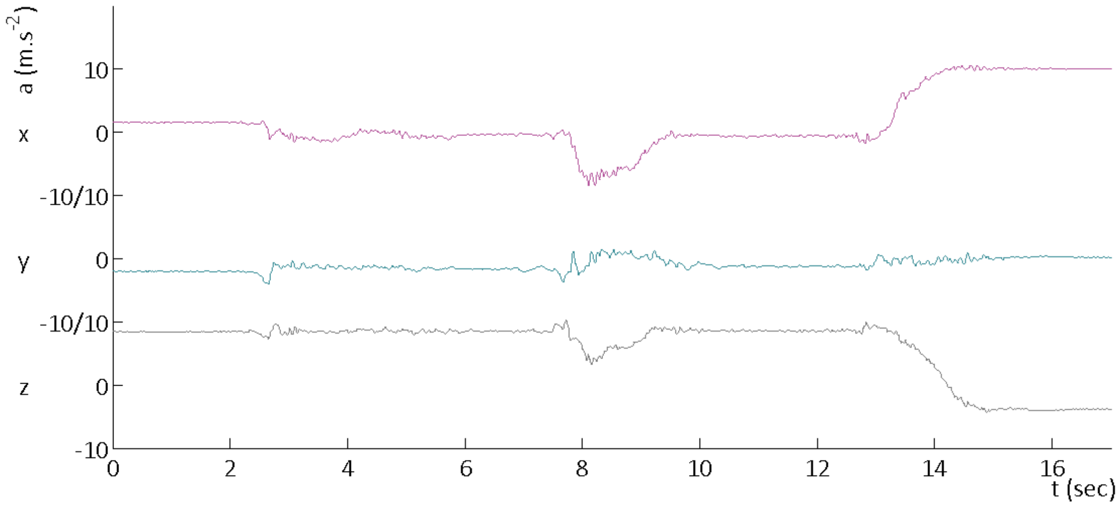

FIGURE 49: GB2 - THIGH, BED, GET UP, HEALTHY PARTICIPANT II

APPENDIX III. FIGURES FOR EXPERIMENT GAIT – SLOW WALK, PARTICIPANT II

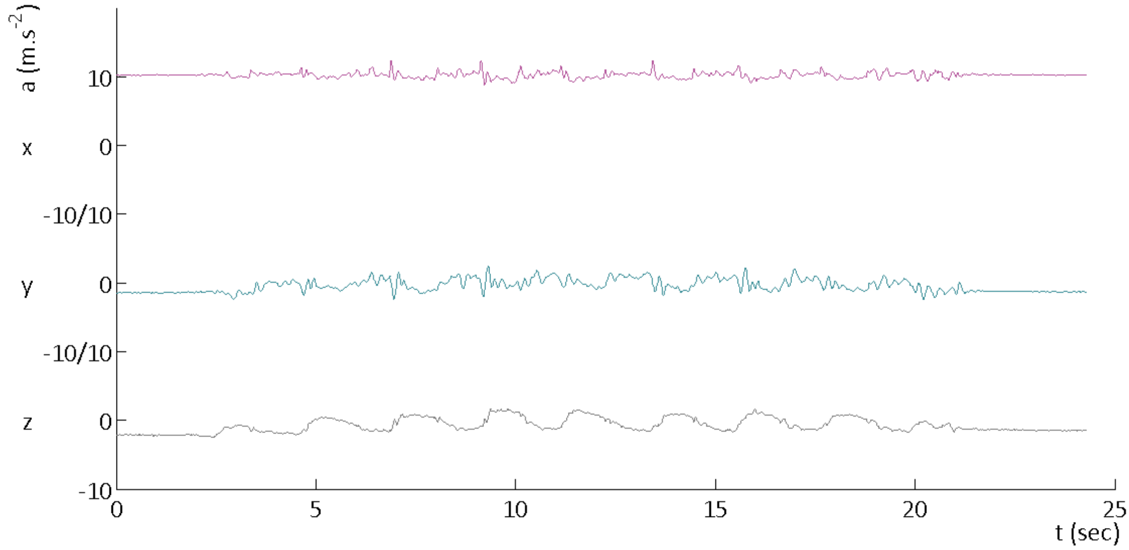

FIGURE 50: BG1 - ARM, GAIT, SLOW WALK, HEALTHY PARTICIPANT II

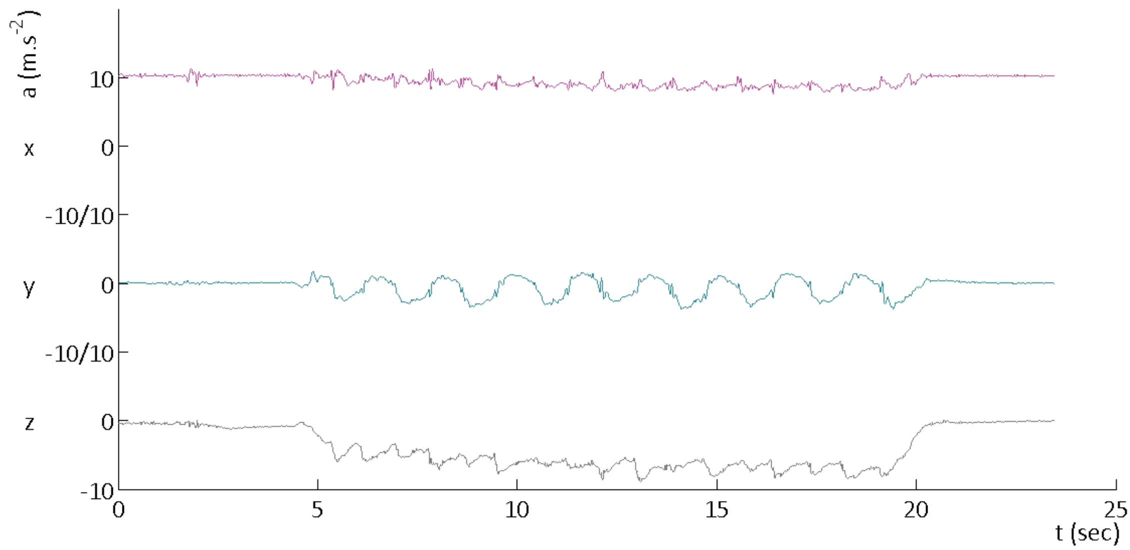

FIGURE 51: CG1 - TRUNK, GAIT, SLOW WALK, HEALTHY PARTICIPANT II

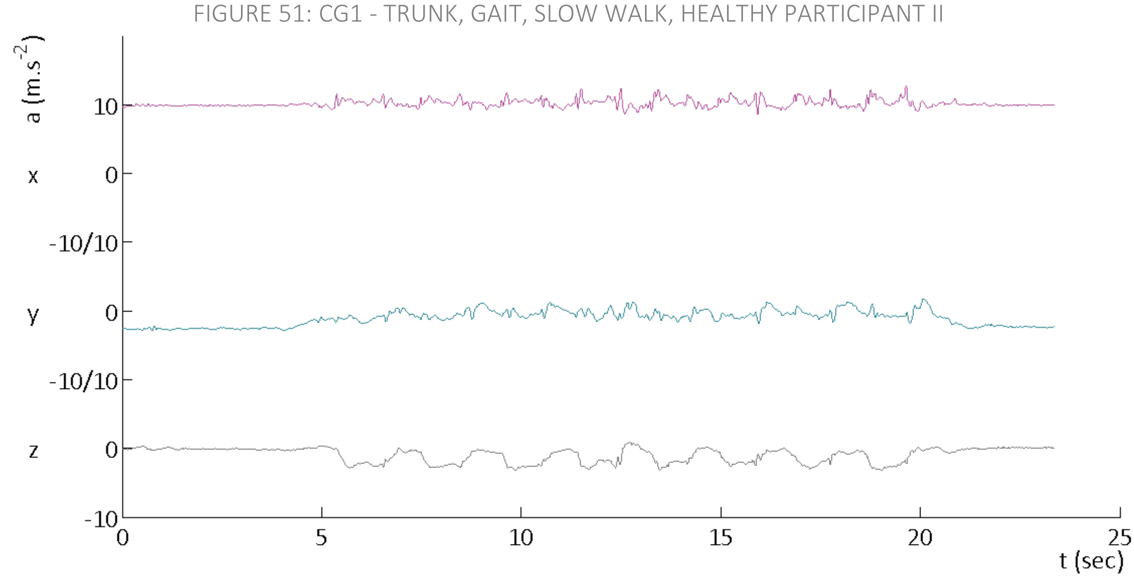

FIGURE 52: DG1 - WRIST, GAIT, SLOW WALK, HEALTHY PARTICIPANT II

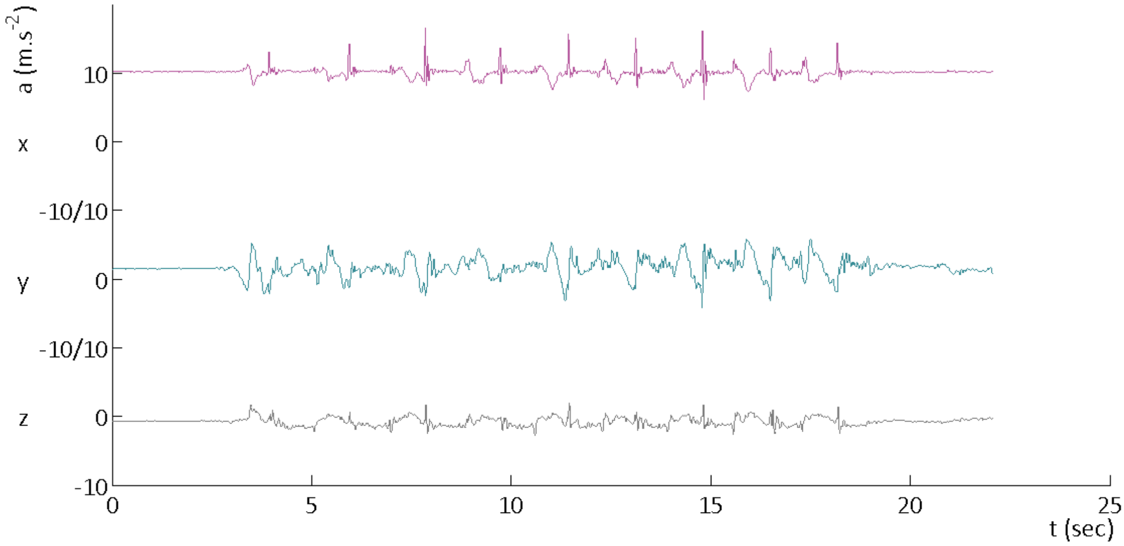

FIGURE 53: EG1 - KNEE, GAIT, SLOW WALK, HEALTHY PARTICIPANT II

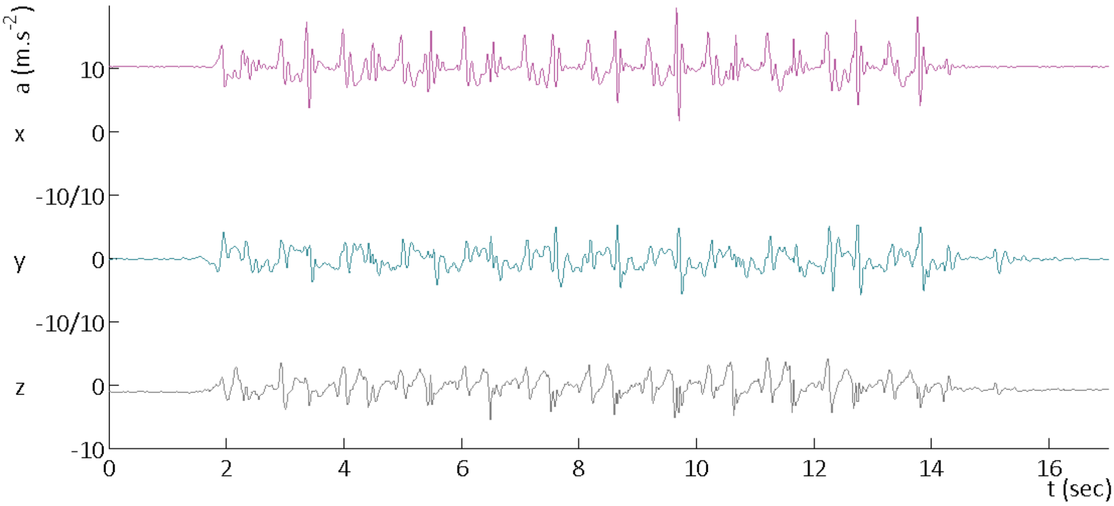

FIGURE 54: GG1 - THIGH, GAIT, SLOW WALK, HEALTHY PARTICIPANT II

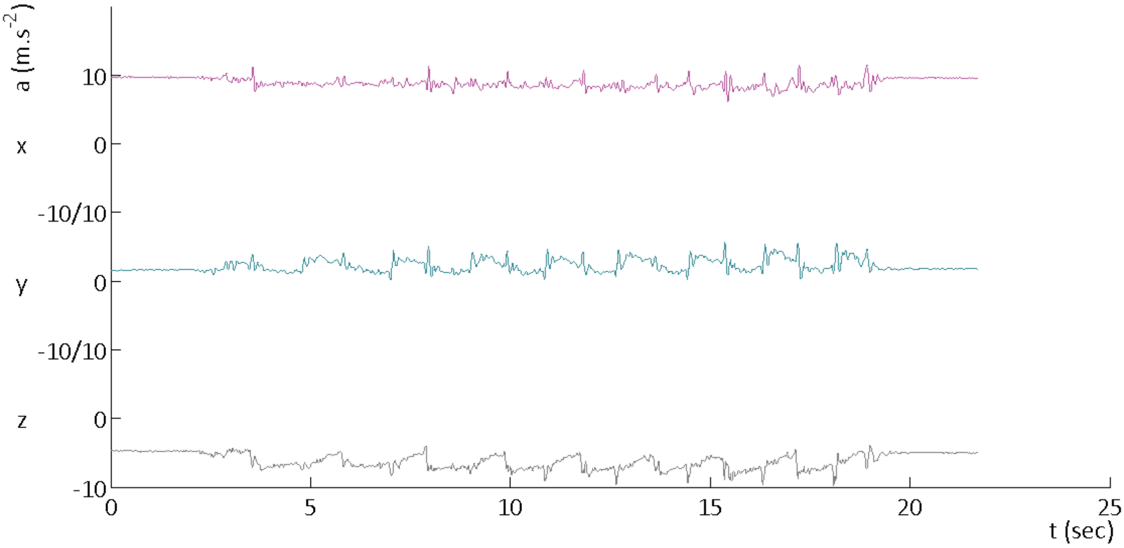

FIGURE 55: HG1 - BELT, GAIT, SLOW WALK, HEALTHY PARTICIPANT II

APPENDIX IV. FIGURES FOR ALL EXPERIMENTS CHAIR - SENIORS

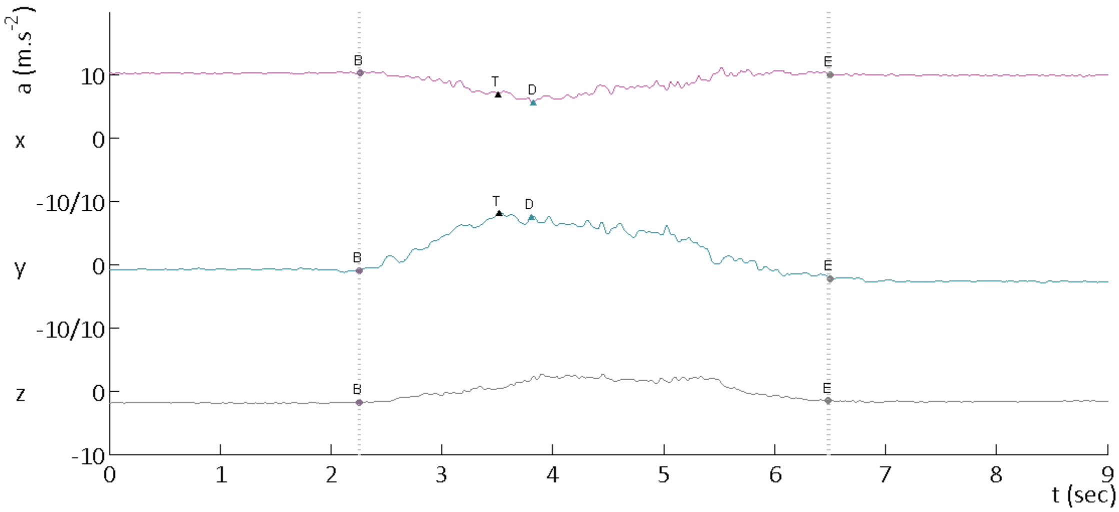

FIGURE 56: BC1 - ARM, CHAIR, SIT DOWN, SENIOR II

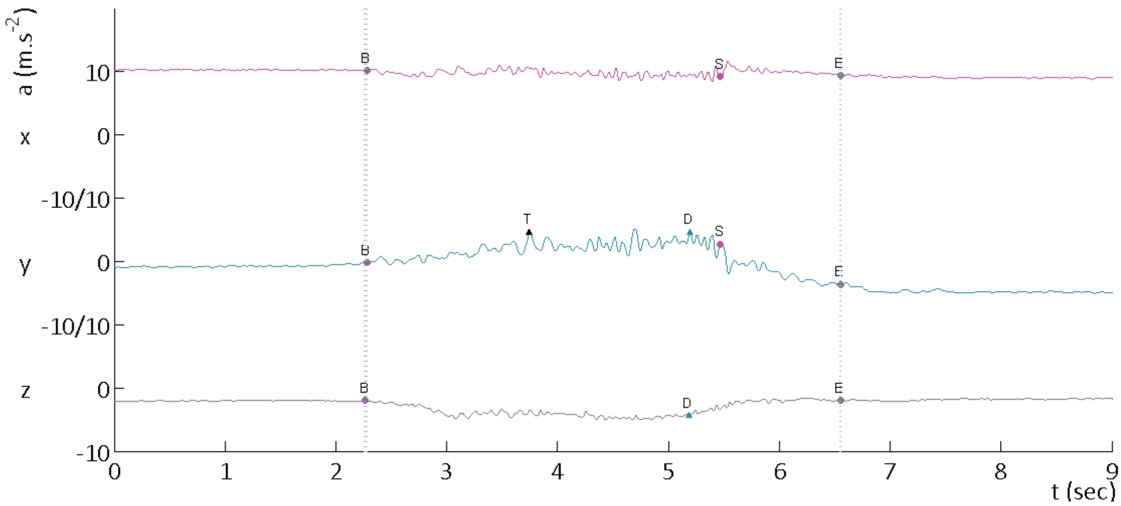

FIGURE 57: BC1 - ARM, CHAIR, SIT DOWN, SENIOR III

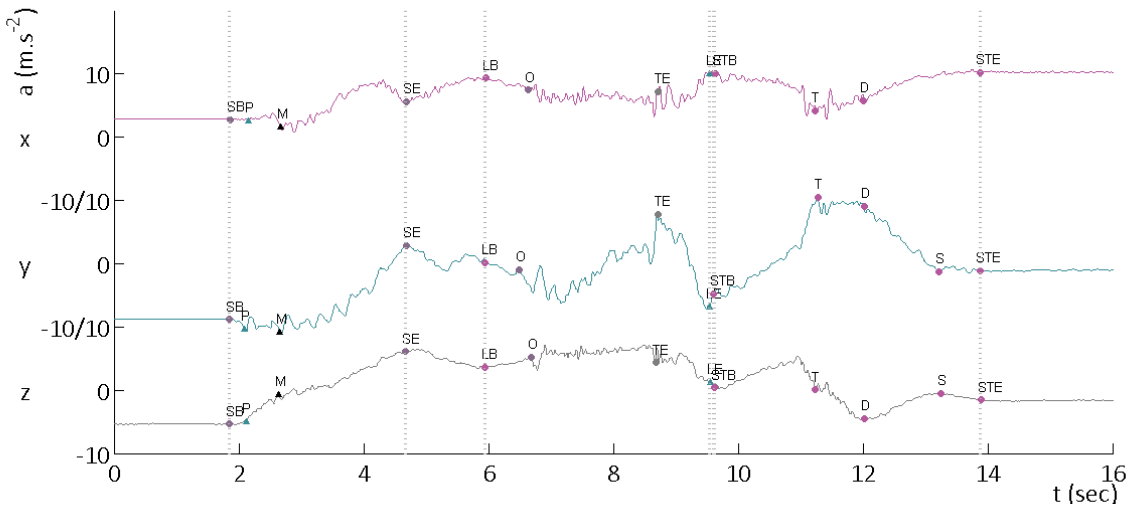

FIGURE 58: BB2 - ARM, BED, GET UP, SENIOR II

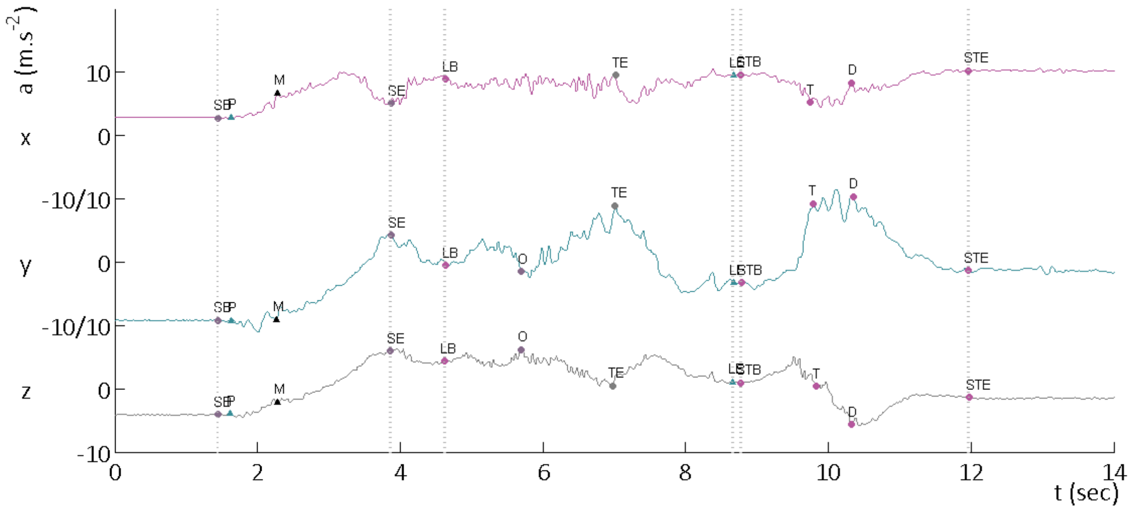

FIGURE 59: BB2 - ARM, BED, GET UP, SENIOR III

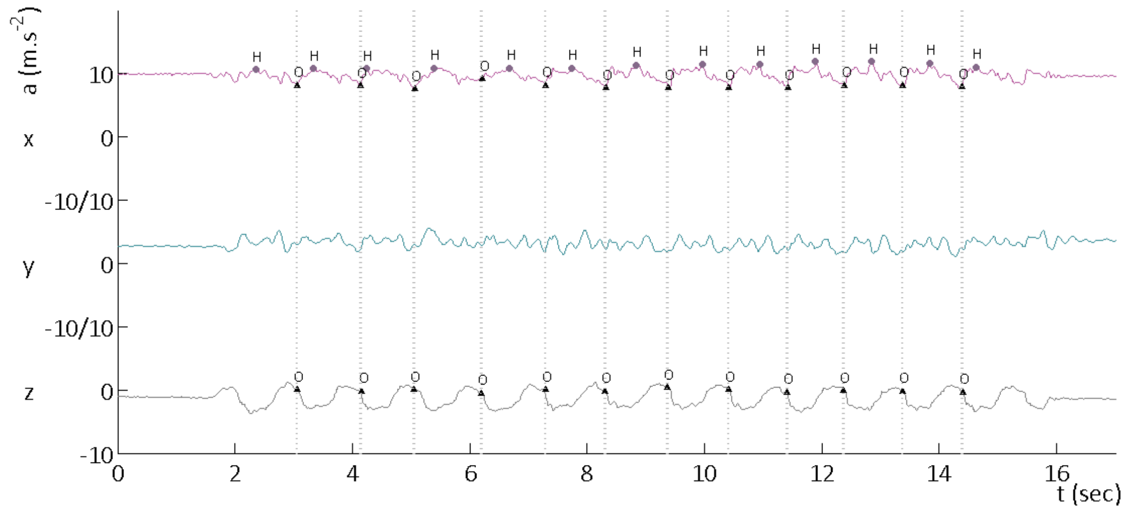

FIGURE 60: BG1 - ARM, GAIT, SLOW WALK, SENIOR I

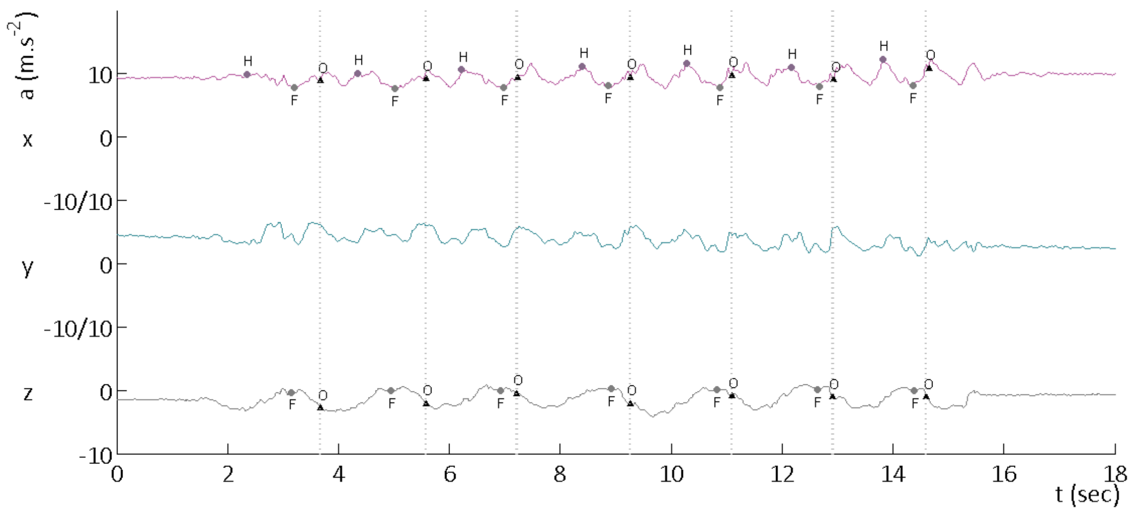

FIGURE 61: BG1 - ARM, GAIT, SLOW WALK, SENIOR II