Czech Technical University in Prague
Faculty of Electrical Engineering

Department of Cybernetics

BACHELOR PROJECT ASSIGNMENT

Student: Vladyslav L a r i o n o v

Study programme: Cybernetics and Robotics

Specialisation: Robotics

Title of Bachelor Project: Intelligent Bed

Guidelines:

1. Do literature search on the topics of intelligent bed and Internet of Things.
2. Design a suitable combination and placement of sensors. The sensors should acquire selected physiological parameters of a subject and selected events (e.g. presence on the bed, breathing, leg movements during sleep, differentiation between quiet and restless sleep).
3. Design experimental protocol for data recording from the sensor system.
4. Propose methods for data processing.
5. Realize the design and verify it in real environment. Evaluate the results.

Bibliography/Sources:

[1] Dobre Ciprian, Mavromoustakis Constandinos, Garcia Nuno, Goleva Rossitza, Mastorakis George - Ambient Assisted Living and Enhanced Living Environments - Butterworth-Heinemann, 2016
[2] Greengard Samuel - The Internet of Things (The MIT Press Essential Knowledge series), 2015
[3] Vermesan Ovidiu, Friess Peter - Internet of Things - from research and innovation to market deployment - Aalborg 2014

Bachelor Project Supervisor: doc. Ing. Lenka Lhotská, CSc.

Valid until: the end of the summer semester of academic year 2017/2018

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Prague, February 20, 2017

Czech Technical University in Prague
Faculty of Electrical Engineering

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Bachelor Thesis

Intelligent Bed

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Declaration

I declare that the presented work was developed independently and that I have listed all sources of information used within it in accordance with the methodical instructions for observing the ethical principles in the preparation of university theses.

Prague, May 26, 2017

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

V Praze, 26. května 2017

ABSTRACT

The purpose of this work is to study features of physical activity in the daily cycle “sleep - wakefulness” as well as changes in sleep under the influence of external factors using developed hardware - software monitoring system. In order to achieve this goal the following tasks were solved:

1. Evaluate the distribution’s character of physical activity of the participants of the study at night and daytime.
2. Identify the characteristics of motor activity of these two participants.
3. Evaluate relations of changes of physical activity indicators with increasing external influencing factors.
4. Evaluate the efficiency of actigraphy method during the research.

Keywords: sleep, Arduino, Intelligent Bed, monitoring system, sensors.

ABSTRAKT

Cílem této práce je studium rys fyzické aktivity v denním cyklu "spánek - bdění", stejně jako studium změn spánku pod vlivem vnějších faktorů pomocí vyvinutého hardware - softwarového monitorovacího systému. K dosažení tohoto cíle byly řešeny následující úkoly:

1. Vyhodnocen charakter distribuce fyzické aktivity účastníků studie v noci a ve dne.
2. Byla určena charakteristika motorické aktivity těchto dvou účastníků.
3. Byly vyhodnoceny vztahy změn ukazatelů fyzické aktivity s rostoucími vnějšími ovlivňujícími factory.
4. Byla vyhodnocena účinnost aktigrafie během výzkumu.

Klíčová slova: spánek, Arduino, inteligentní lůžko, monitorovací systém, senzory.

CONTENTS

TABLES

1.1. Sleep Monitoring

We spend a third of life sleeping. When we get tired or get sick, we have to recover in bed. Imagine all the power and utility of the assembly and analysis of data in such a constant environment where we spend so much time. The bed is a useful and multipurpose device for the collection of biometric data, which are then used to predict the state of a person, timely treatment, which contributes to improved health.

Accurate monitoring of biometric information is quite complex and routine task. Since the entire monitoring consists of many individual single-function solutions, most of which are incompatible with each other.

Traditional medical beds, with the capability of monitoring the biometric data are expensive and cumbersome. The average price is about 30 thousand dollars per bed, which makes them on the brink of affordability for many medical institutions. Also, a large number of sensors and wires which could be attached to a person directly, may also lead to greater patient fatigue [1].

It can be concluded that on the one hand this type of data collection is very useful because of the amount of time spent by the person in the bed; on the other hand, the patient may feel discomfort because of the abundance of sensors reading the information. All these factors form a push for development of Intelligent Beds which may become an ideal platform for improved control over the human health in the future and a powerful tool for health care in general.

One of the most important parameters that could be monitored on the "Intelligent Bed" is a dream. Sleep is one of the sources of physical and mental recovery. The bed allows the continuous monitoring of sleep patterns of both healthy people for prevention and prophylaxis of sleep, and people with sleep disorders, to diagnose, monitor the dynamics of the disease and for therapy correction. In this regard, this paper paid special attention to the development of tools for the automatic detection of a long sleep patterns and factors affecting the quality and duration of sleep.

1.2. Theoretical and practical significance of the work

The possibility of creating an "Intelligent Bed" with a minimal number of connected sensors was evaluated during the study. The aim is the registration of the main indicators - namely, temperature and motor activity of patients.

The link between the level of physical activity and the sleep disorder was proved. A characteristic change in motor activity with the increase both the noise level and the illumination at night sleep was also detected. The evidence of these theoretical assumptions led to the recommendation for people with sleep disorders to monitor noise and light at night during sleep.

Introduction the results of this study into clinical practice will improve the quality of diagnosis of sleep disorders in elderly persons.

Actigraphy may be used to confirm the diagnosis of insomnia of people who cannot confidently evaluate the quality of their sleep. Also, this method is important for the use of behavioural therapy to change the well-established negative perceptions about own people’s dreams, for non-compliance of objective sleep parameters to declared as well.

Objects of study. Patients without sleep disorders, being at home.

Subject of research. State of the physical activity of patients without disturbing both sleep and wakefulness cycles.

CHAPTER 2 LITERATURE REVIEW

2.1. Using Intelligent Beds

The development of "Intelligent Beds" began with a simple single-function electronically controlled hospital beds. Initially, these beds had only the ability to adjust the position and form of the bed. At that time, it was more about the bed itself than about the patient. The patient's general condition was not monitored. With the development of technologies "Intelligent Beds" have become more multifunctional which expanded the scope of their application. The inculcation of more "Intelligent Beds" in the health care system on the one hand will significantly reduce the amount of "paperwork"; on the other hand, on the other hand the processed data can represent a structured view on the patient during certain periods of time which in return will accelerate the process of planning treatment and rehabilitation of the patient. In addition, patient data can be stored and be easily accessible by doctors from the hospital's database system. This means that doctors do not need necessary be present in hospitals, but also they can access data remotely.

"Intelligent Bed" systems can also help people to prolong their life. Since the data about a person will be collected and analysed during sleep, it can be a successful preventive method of rapid detection of deviations from normal state and subsequent early treatment. Such systems can be installed both in hospitals and at home. Which will allow doctors to control the patient's condition, being at home at this time.

It is worth noting that the development of new technologies, including image processing and sensor mats, pave the way for a new system of breathing monitoring which will not limit the patient's vital activity. One of these solutions is Brink et al. They presented a method based on the installation of four force sensors with high resolution under the legs of the bed. Body movements associated with each beat of the heart and vibrations of the chest during breathing, cause small deviations of the patient's centre of gravity and the bed. These variations lead to a change in power distribution between the four sensors. Signals are received from different modules and then these signals are combined in purpose to form data reflecting cardiac and respiratory parameters. However, there are difficulties associated with data processing. Primarily due to the huge amount of data obtained from a large number of sensors.

In future every home will be equipped with an "Intelligent Bed" which will every morning provide a report to the person about his current state of health. This revolutionary approach to health care can significantly improve the rate of overall population health.

2.2. Monitoring system based on the sensors system

The "Intelligent bed" system uses technological advances to produce small-sized sensors which are easy to install and configure. Nevertheless, there are also many difficulties associated with their use. Primarily due to the huge amount of data obtained from a large number of sensors.

The purpose of the monitoring system be maximally universal requires reading many different parameters. The easiest way to implement this method is when a large number of sensors are installed to collect data. The problem is that the more sensors being installed and connected to the overall system, the more difficult becomes an overall system and becomes more difficult to maintain and control it. Also, the total cost of the system increases with increasing number of sensors. But on the other hand, we are getting a system that can collect comprehensive information about the patient [2].

Furthermore, each sensor must be suitable for each particular system. The sensor must comply with the requirements and objectives of the sensor system. Also, all the risks associated with the sensor during its using need to be identified.

During my research, I conducted the search and analysis of suitable sensors for my particular task. The monitoring system set up for my work is based on the integration of different sensors with cognitive features being under control of the central controller. Thus, I evaluate the state of a person using the system data collection and subsequent comparison with human current state stored in the "normal state".

2.3. Sleep and its monitoring

A significant part of our life takes a dream. We need sleep to gain strength without which it becomes very difficult to survive even one day. Scientists and manufacturers from all over the world and from different industries are committed to make our dream more efficient and useful for the organism.

Sleep is a vital process that takes an average of one third of a person's life and has an important effect on the health and activity for the remaining two-thirds of the earth's existence. The study of this important process, its mechanisms, functions and disorders has been a separate section of neurosciences – Somnology. The impetus for the development of scientific somnology was the discover of the electroencephalography by a German psychiatrist Hans Berger method in 1928 [3]. It is no wonder that such a mysterious condition like sleep caused the interest of people previously. First scientific attempts to identify the mechanisms and functions of sleep were made in XVII-XVIII centuries. But the absence of a method to distinguish a dream from the other states, such as coma, hypnosis, narcosis etc. and to determine the depth of a sleep, without disturbing a sleeping person, did not allow to develop a scientific knowledge.

Soon after the recognition of electroencephalography (in 1939) Alfred Loomis, E. Newton Harvey and Garret **Hobart** proposed the first classification of sleep stages [4]. According to this classification a dream is divided into: A phase (described as relaxed wakefulness) accompanied by an alpha-rhythm; B phase - analogue of the modern first phase of slow wave sleep; C phase - analogue of the modern second phase accompanied by the appearance of so-called “Sleep spindles”; D and E phases - analogue of the third phase (delta sleep) in the modern classification. Subsequently, each laboratory formed their ideas about the classification of sleep stages to a greater or lesser difference from each other. Therefore it was impossible to compare the results of the work performed by different research groups. In addition, REM sleep was discovered in the 1950s.

It was required to establish the common standards for sleep registration (polysomnography), decrypting it and unifying the classification of sleep. The book which name is “A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects” was published by a group of leading world Somnology experts in 1968 [5]. The compulsory registration of electromyogram of mouth muscle diagram and electrooculogram (eye movements) were introduced in this book. Also, a unified classification of sleep was formulated. Sleep was divided into 2 phases by A. Rechtschaffen and A. Kales: REM (sleep with rapid eye movements, also known as fast or paradoxical sleep) and non-REM (named in contrast to sleep with rapid eye movements; slow, or slow wave sleep). The last one has 4 stages: from stage 1 (light sleep) to stage 4 - deep delta sleep. Formulated guidelines existed unchanged until 2007 when they were slightly modified by an American Academy of Sleep Medicine. Major changes touched stages 3 and 4, as well as the additional description of respiratory parameters and movements.

Polysomnography is known as the gold standard for the study of qualitative and quantitative sleep parameters. It is the most accurate method of evaluating the state of the body during sleep, when during the night time the registration of electroencephalogram, EOG and EMG is conducted. All of this allows to quantify the state of sleep and its stages. Some of these studies are carried out by means of special sensors, and others - by video (in the room where polysomnography is performed, the camcorder is set, often - with infrared illumination, which provides to get images even in complete darkness) [6]. On this basis, polysomnography requires laboratory conditions, which is a disturbing factor and a "First night effect" could lead to a change in the typical daily routine of sleep parameters in surveyed, reduction in total sleep time and sleep efficiency [7,8]. Thus, the conclusion of polysomnography received on the first night, will not reliably reflect the structure and sleep disorders of patient. It is also known that for those who suffer insomnia the substantial variability in sleep parameters from night to night is pertaining. Whereby a significant drawback of polysomnography is the impossibility to carry out research for a long time [9].

Another possible way for an objective assessment of human sleep is actigraphy. Actigraphy is a control method (evaluation) of human physical activity using accelerometers (actigraphs or inclinometers) - sensors which measure the projection of the sum of all the forces applied to his body (excluding the effect of gravity) [10]. This allows to register motor activity of the patient for a long period of time (1-2 weeks), then the software allows to select periods of low activity which are in congruence with bedtime. Normally during a night's sleep a healthy person commits a 40-60 movements which vary in duration and the inclusion of muscle groups. Movements with duration of more than 10 seconds lead to some activation according to electroencephalography which is reflected in the change of stages of sleep or awakening. Also, the number of awakenings may be indicative of the depth of sleep. Compared with polysomnography much less parameters are being recorded during an actigraphy. Recent years studies have shown a high compliance of actogram dynamics and the dynamics of the main monitored polysomnographic parameters, such as oculogram and myogram of facial muscles [11,12]. Therefore, actigraphy has been widely used for the monitoring of physiological sleep (and basically on healthy people) in evaluation of functional deviations, and to determine the optimal time for awakening [12].

So, a research during normal daily life can be conducted using actigraphy, continuously 24 hours a day during a long time [13].

2.4. The importance of sleep for a person

Violations of the quality and quantity of sleep at night cause a reduction in the quality of daytime wakefulness: decreased performance, fatigue, inattention, decreased cognitive ability, lethargy [14]. Additionally, sleep disorders can worse both the liptomic and psychogenic dizziness [15].

Sleep disorders are the cause of aggravation of hypertension, coronary insufficiency, and therefore, a risk factor for myocardial infarction and stroke [16]. In addition, the lack of quality and quantity of sleep affects the psycho-emotional state of the patient, provokes anxiety and depressive reactions during wakefulness [17]. In addition, there are several diseases which have completely different course during sleep: night myocardial infarction, stroke, angina, nocturnal paroxysmal atrial fibrillation, epilepsy, panic attacks, asthma, gastroesophageal reflux disease, and many others [18].

The sleep duration affects life expectancy. It was found that the sleep duration of less than 6 hours causes the increased mortality rate among men by 1.7 times, among women - 1.6 times [19]. Several studies have demonstrated a link between an insomnia and the increased mortality risk in elderly [20]. According to the M.A.Dew experiment which was based on a research carried out with the use of PSG, the risk of death in healthy elderly with difficulty falling asleep increases 2.14 times [21]. The increase in the risk of death among the elderly who complained of insomnia was discovered by K.Manabe [20]. Availability of daytime sleep or drowsiness is also associated with increased mortality [30]. While other studies suggest that this dependence is levelled, taking into account other known risk factors [20].

2.5. Sleep hygiene

To maintain a good night's sleep, especially in the elderly, the general principles of sleep hygiene are recommended by many authors [22]:

1. Exception of caffeine and nicotine in the late evening.
2. Exception of alcoholic beverages before bedtime, because they often cause a sleep fragmentation.
3. Avoiding of heavy meals before bedtime.
4. Reducing the amount of drinking water during the second half of the day.
5. Maintaining a comfortable temperature in the bedroom.
6. Bedroom blackout.

With aging, sensitivity to changes in photoperiod increases. People, especially those who is older than 75 years, have a positive phase shift (about 1.5-2 hours) with its subsequent desynchronization [23]. It is desirable to be exposed to the sunlight at least for 30 minutes in the morning [24].

The allocation of time to relax before bed, a warm shower or bath before bedtime. Daily physical activity is important for maintaining a healthy sleep, but can break it if execute them before bedtime. Therefore it is important to avoid long (1.5 hours) or intense exercises before bedtime [25].

2.6. A healthy sleep mode

Exclusion both daytime sleep and evening nap periods. Shortness of switching phases of sleep, frequent awakenings during the night, daytime drowsiness and a tendency to wake up at dawn, weak ability to maintain an uninterrupted night sleep – all of this characterizes the change in the rhythm of sleep-wakefulness in people of older age groups. There is no doubt that, compared to younger adults, older people significantly more likely practice naps [26]. The impossibility of a long wakefulness may reflect age-related change in the homeostatic regulation of sleep. Daytime drowsiness in the elderly is the result of many factors – from subclinical therapeutic or psychiatric diseases to functional reduction of sleep homeostasis [27].

There is not a full agreement about the impact of sleep in the daytime towards the sleep quality at night. Some authors point to the negative impact of sleep in the daytime towards the sleep quality. So it says that a nap during the day causes a disturbance of sleep-wake cycle and exacerbates the disorder of sleep at night. For elders who have nap periods in the evenings, a high frequency of nocturnal awakenings is characterized, and a decrease in total sleep time compared to people of the same age who do not have naps in the evenings [26]. Older people who practice naps have a large incidence of respiratory disorders during sleep and periodic limb movement [28]. S.E. Goldman (2008) noted the great length of time of increased motor activity during a night sleep in elderly patients, who were sleeping in the afternoon. But at the same time there was not any depending on the duration of night sleep revealed [28]. At the same time, not all researchers agree with the negative impact of daytime sleep. There is a point of view that a daily nap, practiced for a month, improves the functioning in the waking hours state. And not only does not negatively impact on the night's sleep, but also has a positive effect on the quality [29]. It is noted that daily naps for 2 hours lead to an increase in daily bedtime [29] by an average of 81 minutes [29] in elderly. The impact of daytime sleep for the next night's sleep was limited to a slight increase of a sleep onset. But there were any changes in sleep efficiency, sleep quantity or sleep phases ratio in patients sleeping in the afternoon [29].

CHAPTER 3 SLEEP STUDYING SYSTEMS

3.1. Stationary system of sleep studying

At this level of development of microelectronics, the stationary system of sleep study can not necessarily be large and bulky: modern devices are compact, achieving the size of mobile devices. As mentioned above, a sleep study may be performed in a hospital or at home using a stationary or mobile polysomnographic systems correspondingly.

The main difference between the two types of polysomnography is the need for a permanent presence of staff during the study, or “the night duty” in other words. The reason is if doctor detects a sensor which have fallen down, he can immediately come into the room and set it in place.

One more characteristic feature is the need for a separate area for research.

3.2. Mobile system of sleep studying

Modern mobile polysomnographic system is absolutely not inferior to a stationary polysomnographic system by the number of channels. However, the study is conducted in a comfortable environment for the patient - at home (and this is an obvious advantage for many people) or in any hospital room. During the night, the data is being accumulated in the mobile unit's memory and after awakening of the patient it is copied to the computer. A sleep study at home does not envisage the presence of doctors and does not require patient’s isolation in some special individual rooms in hospitals.

However, it also has its disadvantage - there is no possibility of correction signal violations. For example, in case of disconnection of the electrode (in case it happens) one of the indicators of the study becomes uninformative.

3.3. Sleep studying using actigraphy

Today, clinicians are forced to use research methods, which in itself can disturb sleep. Thus, there is a challenge to the specialists because it is necessary to obtain the maximum amount of information without violating the patient's quality of sleep. All diagnostic techniques described above require the placement of a large number of diagnostic equipment on-site of investigation, that is carried out by medical personnel or by the patient itself. The number of sensors connected to the patient is reduced to the units when using actigraphy.

Some authors point out a good competitive ability between actigraphy and polysomnography [30]. At the same time, actigraphy was more successful in sleep detecting (sensitivity) compared with the wakefulness detecting [31]. Low specificity (about 50%) of wakefulness detection was mainly caused because of defining the sleep period during an inactive wakefulness [32]. The biggest impact of this lack of actigraphy is in determination of such parameters as the awakening during a sleep time and sleep onset [33].

According to V.Natale, the combined use of indicators of total sleep time, sleep latency time, and the presence of more than 5 awakenings during sleep are the most effective ways to diagnose insomnia using actigraphy [34].

At the same time, there is an evidence that such values of indicators as total sleep time, wake after sleep onset and sleep efficiency do not significantly differ in the study using polysomnography and actigraphy [35].

There are reports about a successful use of actigraphy in determining the state of sleep and wakefulness, diagnostic of insomnia, circadian rhythm disturbances, periodic limb movements [36].

Thus, despite the significant number of publications devoted to the problems of registration of sleep disorders, many of issues still have not been solved yet. There is no consensus on the meaning and methods of use of actigraphy in the diagnosis of sleep disorders. Daily motor activity features depending on age, physical, neurological and psychiatric status, the effects of noise, illumination, and the association of these characteristics with the quality of sleep also did not find an adequate description in the literature. All the above leads to the relevance of the study.

3.4. Use prospects by older population

Recent statistics indicate that the percentage of the elderly population is growing in the world. Also, statistics show that during the last years the number of elderly people has increased significantly over the period 10-20 years ago. The number of people in our society who because of age, loss of memory and personal beliefs cannot always be under the supervision of doctors in specialized institutions all time long, because they feel themselves uncomfortable and think that by doing this they limit their personal freedom of movement and independence. Such people prefer to live alone and independently, but nevertheless, they need their health status being constantly monitored so that, if necessary, medical care could be provided immediately. As the quality of sleep is directly dependents on the general state of health, accordingly to this, the use of the results of this study at home will improve the timely response in diagnosis of sleep disorders in elderly persons.

With the help of this system and subsequent collection and analysis of data you can create a person’s profile can be created that could help to determine its "normal state". Any deviation from this state will be recorded and referred to as "abnormal activity".

CHAPTER 4 DEVELOPED SYSTEM

4.1. Description of the developed system

Monitoring of the patient, especially an elderly person, who would rather be at home, than in a specialized institution, is based on determining differences in its normal state from a state in which deviations are observed. Status parameters of the person are measured for diagnostic purposes. In particular, parameters which characterize human sleep are measured. There are many development platforms that allow the collection and measurement of given parameters in today’s world. Starting from independent chips, finishing with platforms which give the possibility of using certain operating systems. I chose to work with Arduino platform.

Arduino is an open platform that allows to collect all kinds of electronic devices. The platform has advantages over its competitors, among which are the following:

- intuitive programming environment;
- relatively low price and a big amount of expansion modules.

There are separate versions of the platform, depending on the developer and the requirements of the tasks. During my working on the project the Arduino UNO platform was used. This platform consists of hardware and software parts.

4.2. The hardware part of Arduino UNO platform

Arduino board consists of a AVR family microcontroller - Atmel AVR (ATmega328 and ATmega168 in new versions and ATmega8 in older) and binding elements for programming and integration with other circuits.

Figure 1 shows the individual elements of the platform Arduino Uno:

1) RESET button. The purpose of this button is to start the execution of the downloaded program from the beginning.
2) B type USB connector.
3) Alternative power source connector. It is used in case of the voltage is not supplied at the module by means of USB.
4) ICSP programmer to program the USB serial converter.
5) USB serial converter. The function of the converter is the communication between the main chip and PC.
6) LED diodes L, Rx and Tx. L diode is connected to pin 13, which allows it to blink when the pin 13 is set to HIGH. Diodes Rx and Tx blink when communication takes place via a serial bus.
7) The main chip of the entire module.
8) LED diode ON. It lights when a voltage source is connected to the module.
9) ICSP programmer for the main chip programming.
10) Digital pins.
11) Outputs for powering additional modules from the board by itself.
12) Analog inputs.

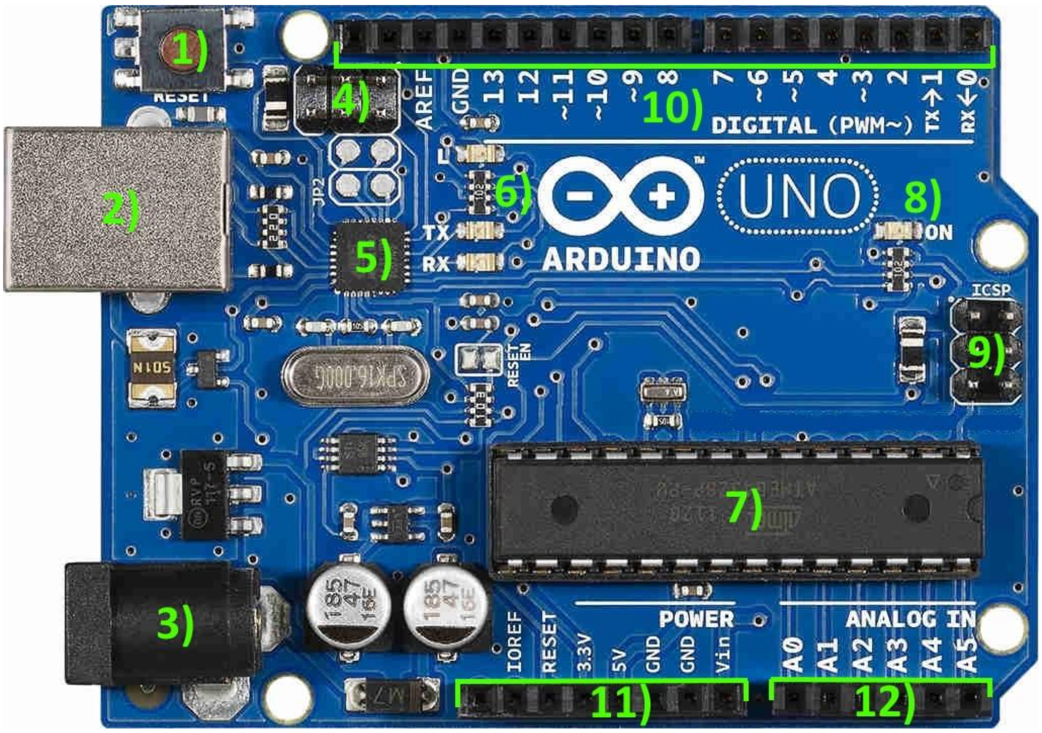

Figure 1: Arduino UNO board

Arduino Uno can be powered from the USB connection, and from the external source: batteries or regular electrical network. The source is determined automatically. The platform can be operated with a voltage of 6 to 20 V. However, at a voltage of less than 7 the board may work unstable. Also, the voltage bigger than 12 V can lead to overheating and damage. Therefore, the recommended range is: 7-12 V.

The Arduino provides the following contacts for accessing the supply:

- *Vin* provides the same voltage that is used to power the platform. It is equal to 5 V when is connected via USB.
- *5V* provides 5 volts regardless of the input voltage. The processor works at this voltage. Maximum allowable current received from this contact is 800mA.
- *3.3V* provides 3.3 volts. Maximum allowable received from this contact is 50mA.
- *GND* states for ground.

On-board microcontroller has in its disposal a 32-kB flash-memory for programs, 2-kB of which is reserved for a so-called bootloader. It allows to change an Arduino firmware from a desktop computer, via USB. This memory is constant and is not designed to be changed during the operation. Its purpose is keeping software and related static resources.

There is also a 2-kB SRAM-memory which is used to store temporary data such as program variables. It is an operating memory of the platform, in fact. SRAM-memory is cleared after being de-energized. There is also a 1-kB EEPROM-memory for a long-term data keeping.

Arduino UNO platform is equipped with 14 pins which can be used for digital input and output. The role each contact play depends on the software configuration of input-output port. All ports operate with a voltage of 5 V and designed for current below 40mA. Also, each contact has a built-in but disabled by default 20-50 kiloohm resistor.

In addition to digital input/output pins Arduino board has 6 analog input contacts each of which provides a 1024 graduation resolution. The value is measured between the ground and 5 V by default, but it is possible to change the upper limit, by submitting the required value of the voltage at the special AREF pin. Besides there is an input Reset pin on the board. Its setting in a logic zero will reset the processor.

Arduino Uno has several methods of communicating with other Arduino boards, microcontrollers and regular computers. The platform allows to set a consistent (Serial UART TTL) connection through contacts 0 (RX) and 1 (TX). ATmega16U2 chip which is mounted on the platform transmits a connection via USB: a virtual COM-port becomes available on the computer. Arduino software part includes a utility that allows the exchange of text messages on this channel.

4.3. The software part of Arduino UNO platform

A simplified version of C++ is used for programming this board, known as well as Wiring. It is actually does not exist, as there is any Wiring compiler – programs written in Wiring language are converted (with minimal changes) into a C / C ++ language program, and then are compiled with a AVR-GCC compiler.

Development of the code in this paper was carried out by using the Arduino IDE free environment that is a cross-platform application in Java, including a code editor, compiler and firmware transmission unit into the board. This environment supports such operating systems as Windows, MacOS X and Linux.

4.4. Assembly of the experimental scheme

Actigraphy was carried out with the use of Gy-521 module based on 3D-accelerometer which is made using the chip MPU6050, which is a 3-axis gyroscope and accelerometer. It allows to determine the position and movement of the device in space: angles of heel, trim (pitch) guided by the gravity vector and a rotation speed. It determines the linear acceleration and angular velocity on three axes while moving, which gives a full picture of position.

3D-accelerometer "feels" the projection of the acceleration in the X, Y and Z axes. If the device is placed horizontally and is not moving, the projection of gravity acceleration on the X and Y axes is equal to zero. The gravitational force is perceived only by sensor elements of vertical Z axis. The object is constantly accelerating or slowing down during the movement. A perfect steady motion does not exist. This allows the use of an accelerometer, not only to determine the position of the object, but also to determine the dynamic parameters of the motion.

Triaxial Gyro - The object angle sensor, which allows to calculate the angles of rotation of the axes X, Y, Z by determining the angular velocity. A gyroscope is represented by a piezoelectric vibrating plate. The plate is curved by turning and its electrical parameters change which in its turn is registered by the chip.

Gy-521 module is connected to the Arduino Uno board by the following scheme which is shown in Fig.2. The protocol by which data is transmitted from a 3D-accelerometer (SCL and SDA pins) on the Arduino Uno board (A5 and A4 pins) is a standard electrical serial bus interface I2S.

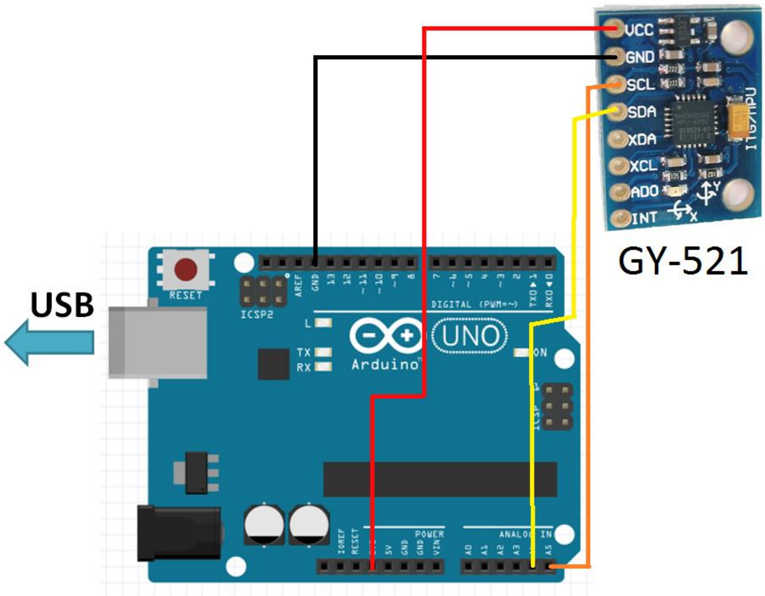

Figure 2: Connecting scheme of GY-521 module

The standard library was installed to work with the module GY-521. And also was written a program indicating the address of 0x68 to work through the I2S protocol. Because the developed hardware scheme part of a monitoring system – microcontroller, - must detect when the patient is present on the bed and when not, a sensor based on registration of the change of infrared radiation (PIR-sensor) was selected for this purpose.

Pyroelectric (PIR) motion sensor consists of two main parts. Each of these parts include a special material that is sensitive to infrared radiation. In this case, the lens is not particularly affect the operation of the sensor, so that we see two sections of the entire module sensitivity. When the sensor is at rest, both sensors determine the same amount of radiation. For example, it may be building radiation or the environment in the street. When warm-blooded object (a person) passes, it crosses the first sensor sensitivity zone. Whereby two different values of the radiation are generated in the PIR sensor module (Fig.3). When a person leaves the sensitivity zone of the first sensor, the values are aligned. Then changes in the readings of the two sensors are recorded and HIGH or LOW pulses are generated on the output.

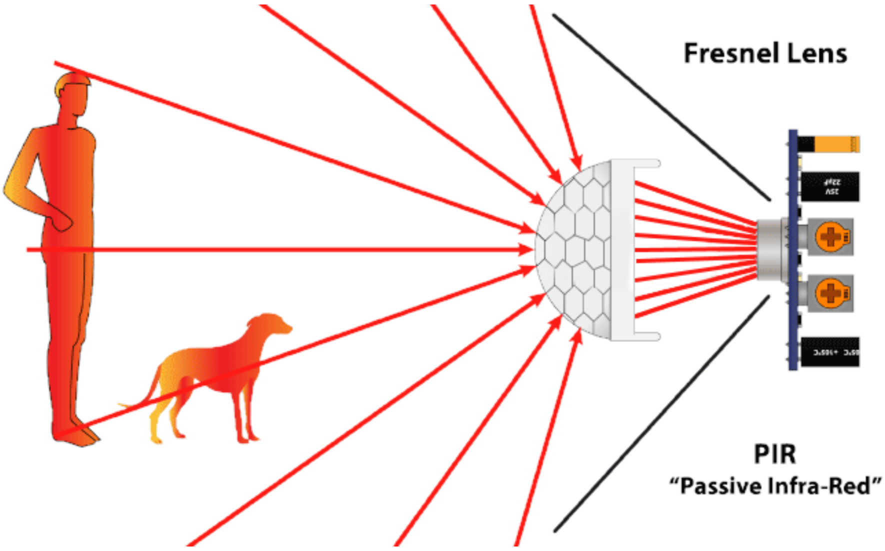

Figure 3: PIR sensor (operation for motion)

PIR sensor is connected to the Arduino Uno board by the following scheme which is shown in Fig.4. Sensor's output has discrete values: logical 0 (no motion) or logic 1 (the motion is detected in the sensor sensitivity zone). Sensor output OUT is connected to any of the digital inputs/outputs of Arduino board (in developed system sensor was connected to the 2nd input). The sensor is powered by voltage +5V.

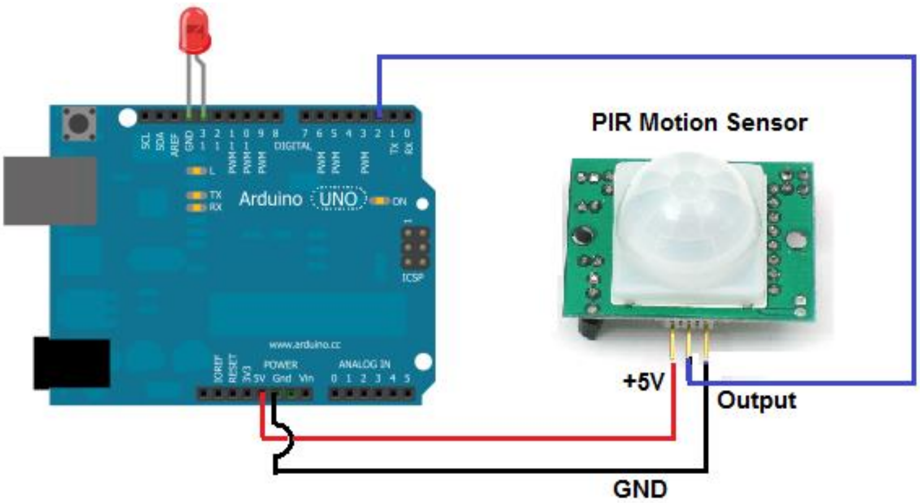

Figure 4: Connecting scheme of PIR sensor

There are several possibilities of sensor's application in the field of "Intelligent bed":

1) The patient is not in bed at the beginning of the usual sleep time.
2) The patient continues to sleep at the time of the usual awakening.
3) The patient is constantly moving on the bed which may indicate a troubled sleep or health problems.

The research module of the KY-037 type was selected for the noise level registration in the room where the research was conducted. This high sensitivity microphone module has two outputs: digital and analog. Determination of excess volume threshold is done by LM393YD chip comparator. Setting the threshold of activation is performed by a potentiometer located on the module. If the volume threshold is exceeded, a high voltage level appears on an output. The voltage level on the analog output A0 corresponds to the volume of ambient noise. A module is connected to the Arduino Uno board by the following scheme which is shown in Fig.5. The noise sensor is powered by voltage +5V.

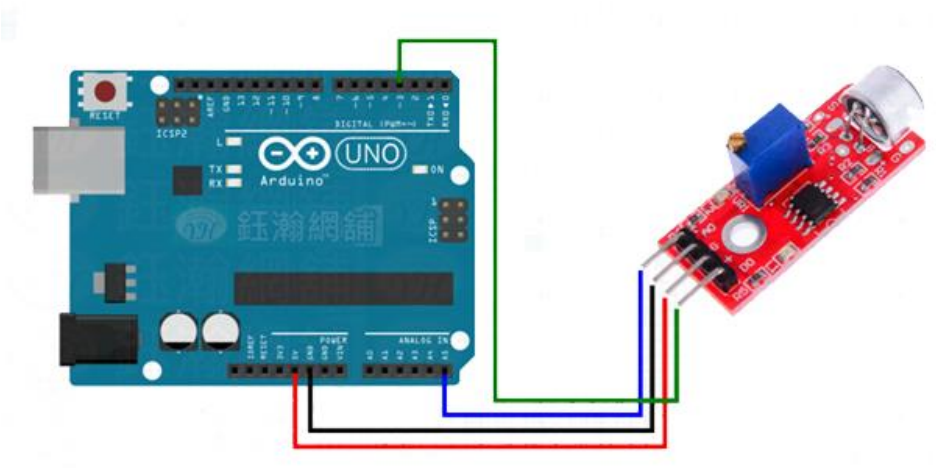

Figure 5: Connecting a noise sensor module

As a temperature sensor, a DS18B20 type sensor produced by Maxim Integrated Products was selected. Its purpose is to detect the ambient temperature and the patient temperature. Figure 6 shows a connection scheme. Figure 7 shows the real scheme photo with a temperature sensor.

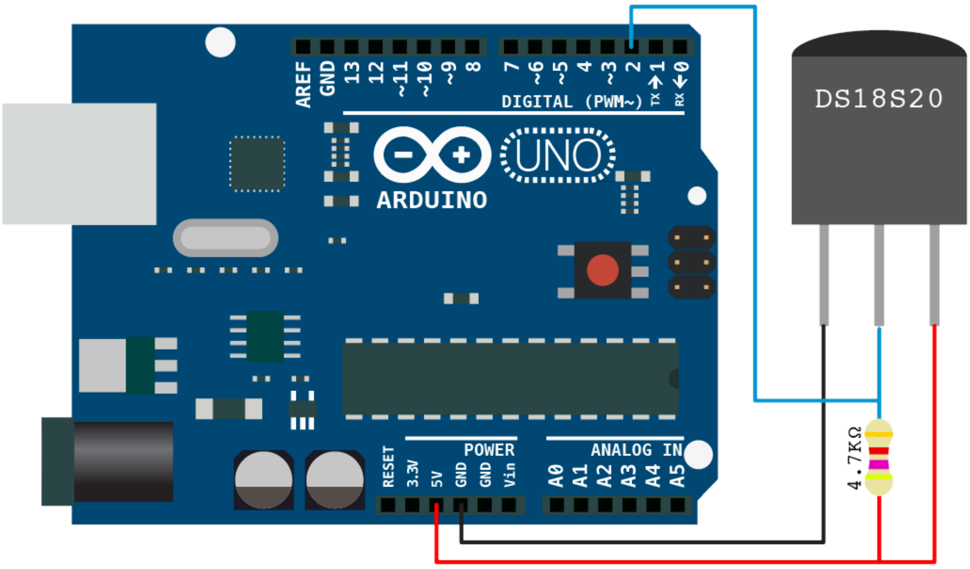

Figure 6: Connecting a temperature sensor

DS18B20 has a digital interface, which means it does not need to be calibrated. Since the sensor exchange data on a 1-Wire protocol with a unique address that is wired at the factory, the number of sensors connected to the one line in parallel can reach 127 (Fig.8).

The program which scan the entire address space was written to determine sensors' addresses. Since there are only two DS18B20 sensors being used in the developed system, the written program detected the following two addresses: the first address is 8A 2D 26 07 00 00 2C, and the second address is 0C DD 1E 00 00 80 70.

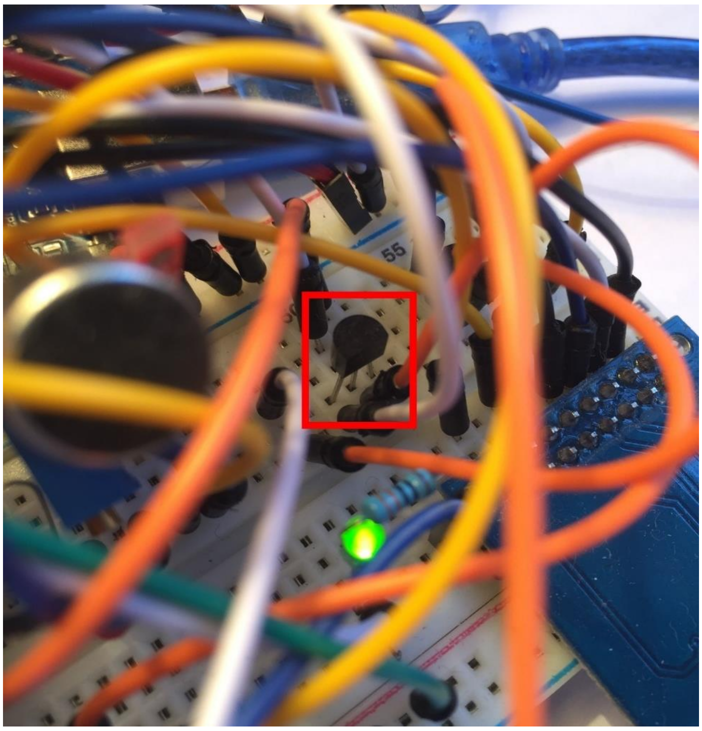

Figure 7: Photo of developed device (a red rectangle shows a DS18B20 type temperature sensor)

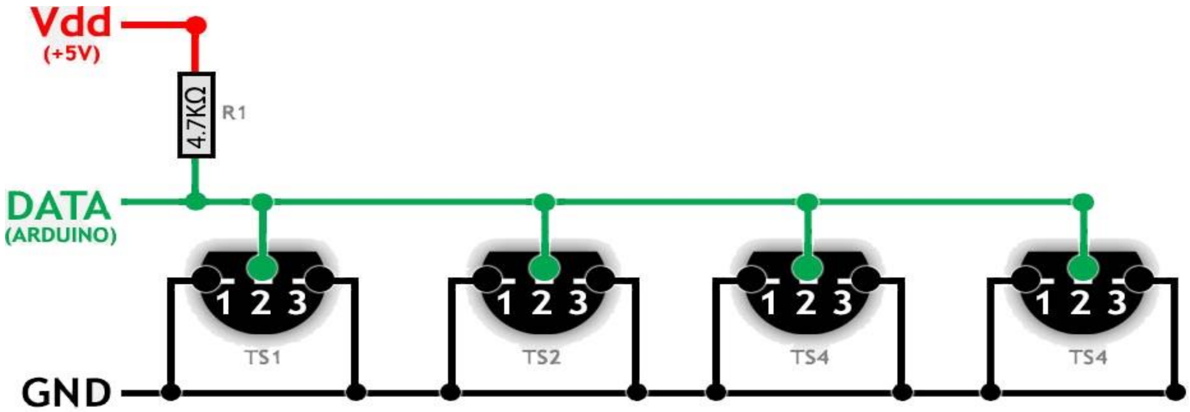

Figure 8: Connecting sensors in line

A brand MLG5516B photoresistor was included to the developed system to investigate the effect of light exposure on patients. Photoresistor is an element that changes its resistance according to the amount of light. As an output of a light sensor is an analog signal, so it is easy to connect it to an analog input on the Arduino board. A photoresistor is connected to the Arduino Uno board by the following scheme which is shown in Fig.9. Figure 10 shows the real scheme photo with a photoresistor.

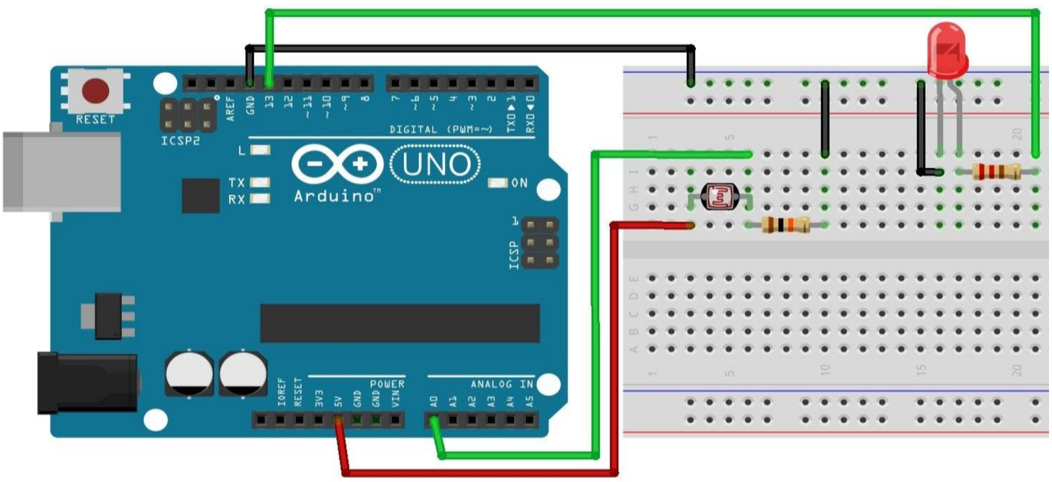

Figure 9: Connecting a photoresistor

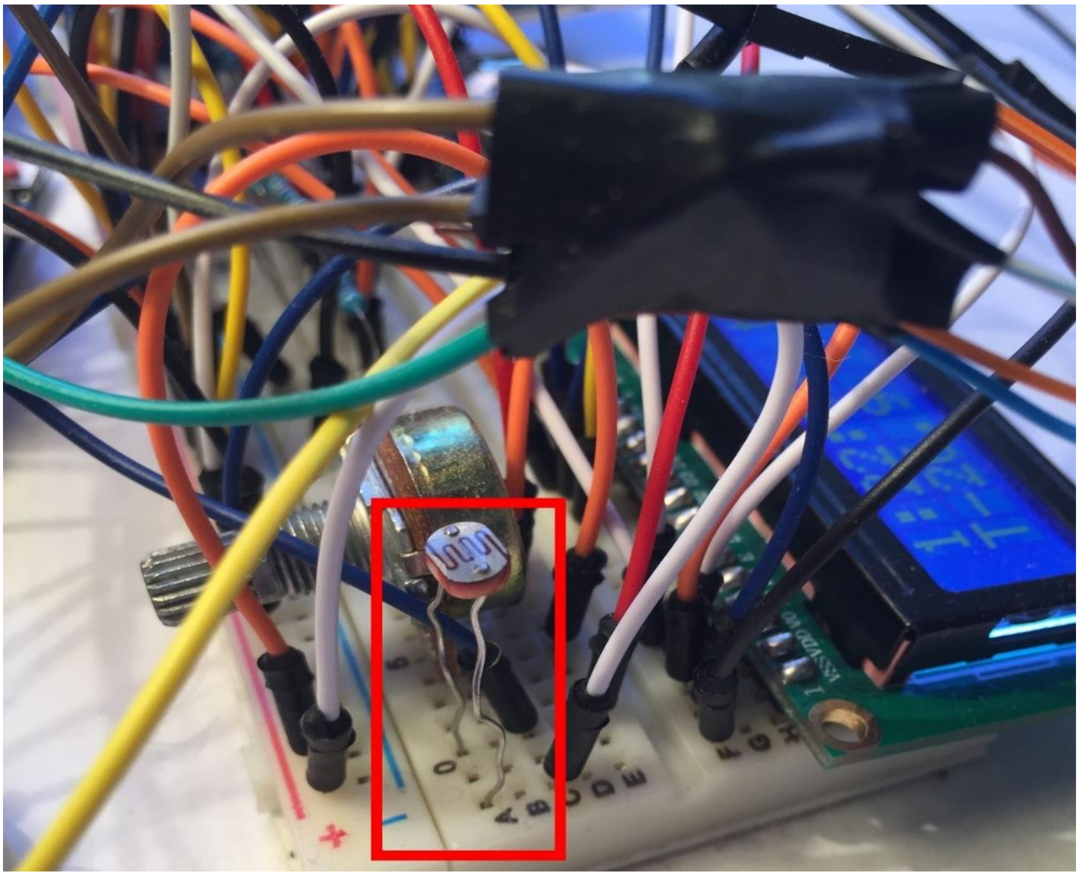

Figure 10: Photo of developed device (a red rectangle shows a MLG5516B type photoresistor)

During the running of developed system it became necessary to synchronize all readings from all sensor. For this purpose, the scheme was completed with a module that performs the function of a real-time clock based on a DS1307 chip. Continuous timing is possible due to self-powered battery installed in the module. The module contains two chips at once: DS1307 (a real-time clock with I2C - interface) and AT24C32 (32-kB EEPROM memory chip which retains information when all the power is turned off). Memory and clock linked by a common I2C bus interface. Only a DS1307 real-time clock chip was used in my thesis project. A connection scheme is shown in Figure 11:

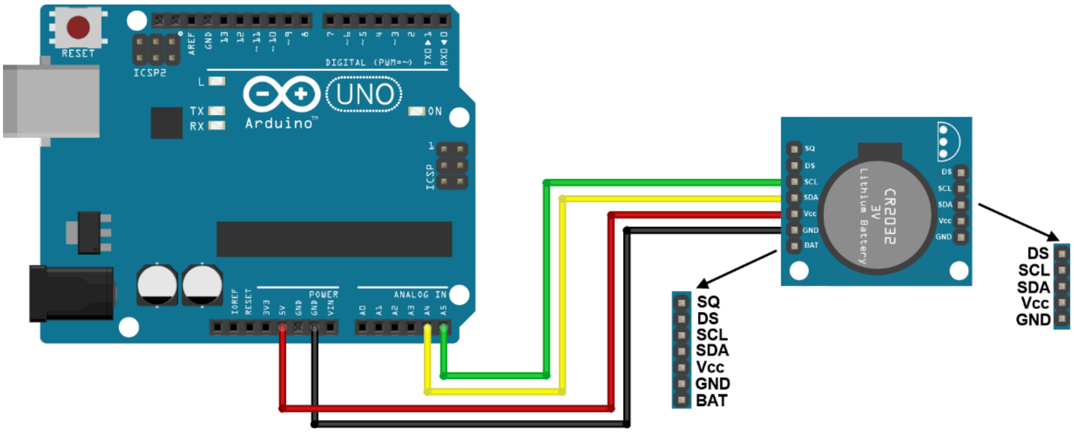

Figure 11: Connecting DS1307

Pin assignment on the DS1307 chip board:

- 5V are used to power the RTC chip module when you make a request to it to obtain data about the time. If 5V are not received, the chip turns into a "sleep" mode.
- GND - common ground.
- SCL - I2C clock contact, - is necessary to communicate with the real-time clock.
- SDA - contact through which data is transmitted by I2C from a real-time clock.
- SQW allows to customize the output data in the form of square-wave. This contact is not used in this paper.

SD CARD module was used to store data received from all sensors. Micro SD CARD module allows recording files with the CSV extension to an SDHC Memory Card with FAT32 file system. Micro SD CARD module is connected to the Arduino UNO board via the SPI interface.

SD card is very sensitive - the use of resistors and long conductors in connections leads to a significant drop in data transmission rate. Therefore, the best way to solve this issue is to use as short connectors as possible and to avoid resistors in logic supply chain. Wiring diagram is shown in Figure 12:

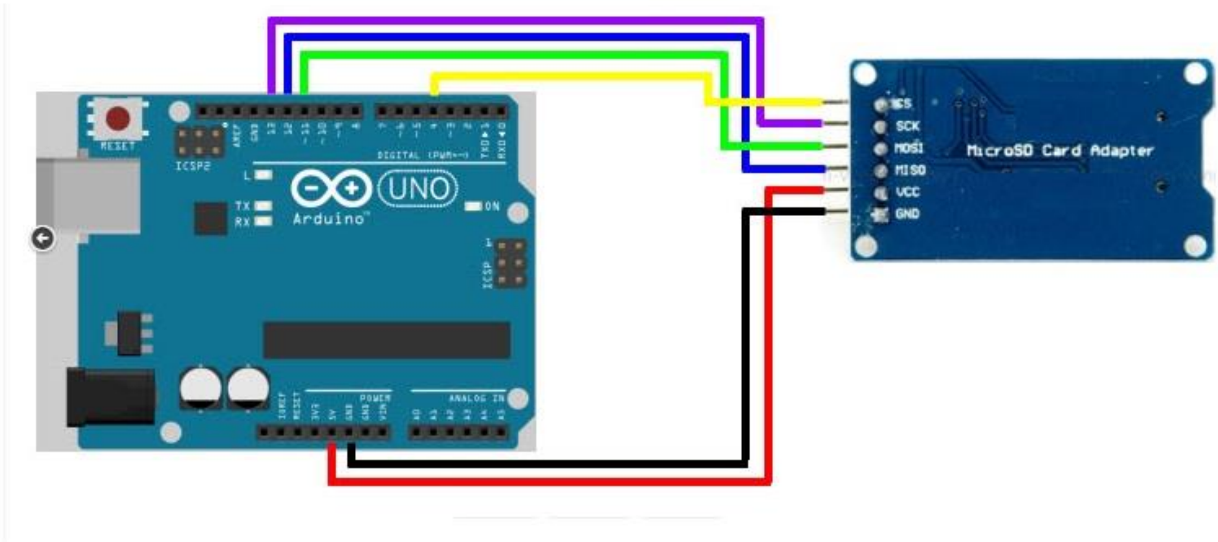

Figure 12: Connecting Micro SD CARD module

A liquid crystal display with a HD44780 microcontroller developed by Hitachi company was also added for clarity and fast determination of a violation of the whole developed system. The display has an optional backlight and can display 2 rows of 16 characters. Character Resolution is 5x8 points. The microcontroller receives commands and describes symbols on the LCD display.

The display can operate in a 2-modes:

- 8-bit (when contacts from D0 to D7 are used for information exchange), data is transferred in one cycle.
- 4-bit (only D4 - D7 contacts are used for communication). In this case, data is sent in two cycles: firstly, high-order 4th bits, then low-order 4th bit.

Display connection outputs are shown in Figure 13:

The display has a 16pin connector. Outputs are marked on the back side of the board.

1) (VSS) - Controller's power source (-)
2) (VDD) - Controller's power source (+)
3) (VO) - contrast control output
4) (RS) - Register Selection
5) (R / W) - read/write (recording mode when connected to ground)
6) (E) – Enable
7) (DB0-DB3) - low-order bits of 8-bit interface
8) (DB4-DB7) - high-order bits
9) (A) - The anode (+) of the power's backlight.
10) (K) - The cathode (-) of power's backlight.

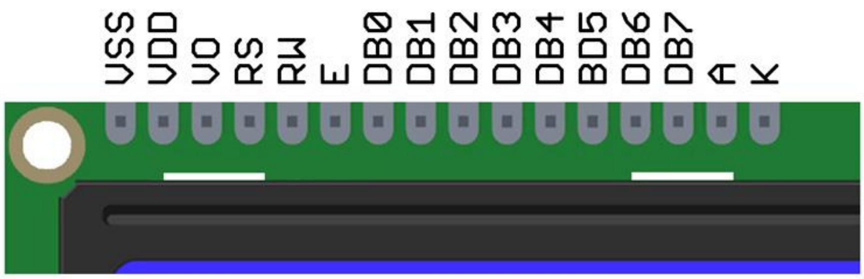

Figure 13: Connecting LCD display's pins

Connection begins with applying the voltage to the controller itself (VSS and VDD), powering a backlight (A and K) and then adjust the contrast. To adjust the contrast, we use the potentiometer with value of 10 kiloohms. Extreme inputs are supplied with +5V и GND, the central input is connected to VO output. To display the text, we need to connect following outputs: RS, E, DB4, DB5, DB6, DB7 to the output of the controller. They can be connected to any Arduino pins (Figure 14), wherein the sequence of connections is recorded in the code.

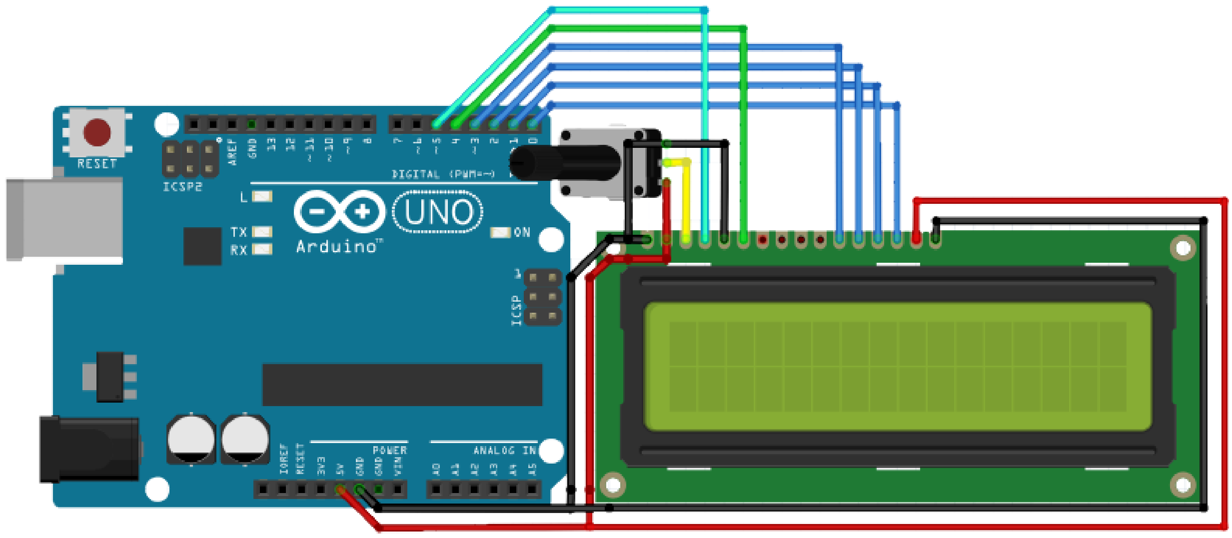

Figure 14: Connecting LCD display to Arduino

After all stages of modulo connection, the real registration system of basic parameters of patients is shown in Fig. 15 and working Arduino Uno board is shown in Fig. 16.

The assembly was carried out on the basis of the breadboard. Breadboard consists of a plurality of sockets (outlets), separate groups of which are electrically interconnected. At the bottom of the breadboard (within the plastic body) are strips with metal contacts, which interconnect group nests and form a conductive circuit. Two external board areas are used (as a rule) for the power supply. Such board's components are designated with colours: red colour states for a positive power supply, black or blue colours – negative source.

It is important to note that breadboard power lines work only by a half of the length of the board.

The process of construction of the developed system included steps of pre-planning and special planning including the design of a scheme and a concept of the placement of components on the board.

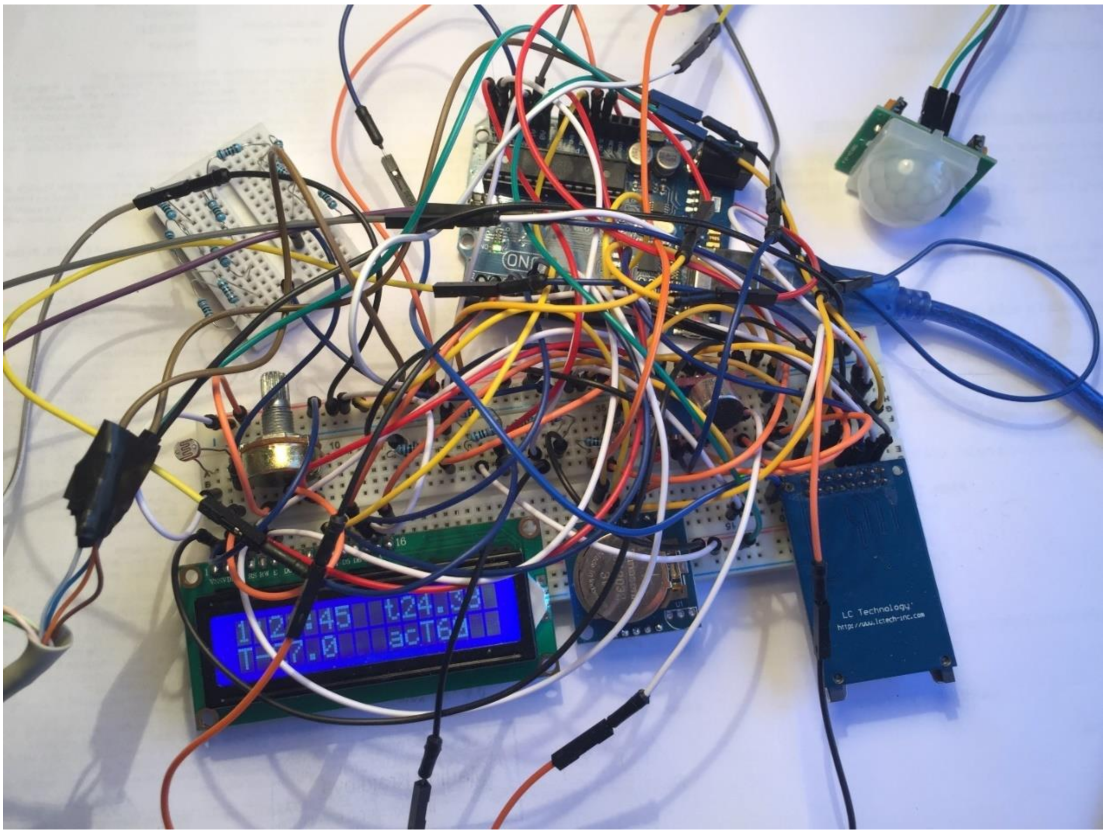

Figure 15: The actual scheme of the developed system for parameters' registration

Figure 16: Arduino UNO board

5.1. The Protocol and method of study

There were two healthy men aged from 19 to 23 years old who involved the study. Studies were conducted under the conditions of dormitory rooms from 22 till 6 o'clock. The purpose was to to research the basic parameters of healthy sleep. Temperature sensor based on DS18B20 chip and MPU 6050 3D-accelerometer were attached to the leg (Figure 17) and to the wrist of nondominant hand (Figure 18), respectively.

Figure 17: Mounting a temperature sensor

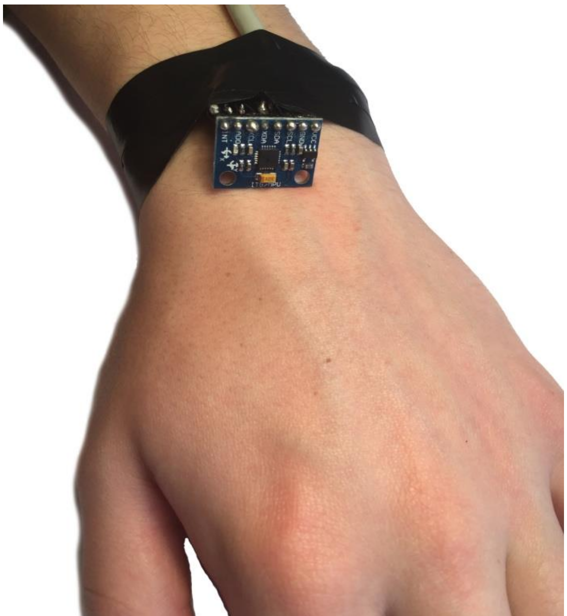

Figure 18: Mounting a 3D-accelerometer

Moreover, at a height of 0.5 meters above the bed, the infrared motion detector which detected the presence of a studied person in his line of sight was fasted.

Environmental requirements: the absence of other moving objects in the zone of action of the infrared sensor, except the studied person.

Temperature sensor (DS18B20) and a microphone were installed in the room to simulate the effect of ambient temperature and noise level. Spectrum of temperature variations comprise harmonic frequencies in the range of 0,003÷0,006 Hz, therefore, the registration period of reading the temperature sensor should be between 3 ÷ 5 min and analog input sampling frequency for reading noise magnitude must not be less than 5kHz.

In the first stage of monitoring tested persons were asked to sleep in a free position in a dark and sound isolated room. This period (Stage 1) was corresponded to the functional state « lying position». The duration of this state of the studied men was determined randomly before the desire to get out of bed appeared.

In the second stage of monitoring tested persons were asked to sleep in a free position «lying position» in bright conditions but also in sound isolated room.

In the third stage of monitoring tested persons were asked to sleep in a free position «lying position» in a dark room but with the presence of moderate noise.

In the fourth stage of the study tested persons were asked to perform mechanical movements without sleeping (typing on the computer) while being in the functional state of rest in a position «sitting on a chair».

All stages were monitored for hand movements with 3D-accelerometer which software allowed me to determine the mobility of the sensor with a frequency of 5 points per second and then convert the data into conventional motion unit. Sensors' location, as well as the identification of sleep, was correspond with current recommendations of the American Academy of Sleep Medicine.

5.2. Calibration of light and noise sensors using the VOLTCRAFT DT-8820 device

Multimeter DT-8820 is a multifunctional digital device of a 4-in-1 type. It executes a complete and accurate analysis of the environment: it determines the level of noise, lighting, humidity and temperature. The large-screen model with display measurements in following units: Lux, °C, %RH, dB; over-range and battery discharge indicators. Automatically deactivated after non-working period is more than 10 min [19].

Since the study was conducted in three phases, each the noise and lighting levels were changed in each subsequent stage. And wherein the system recorded readings from these sensors in relative units then to formalize the obtained results a conversion into a single measurement system was made, namely in dB and Lux using a DT-8820 device.

In the first step, using a DT-8820 multimeter the lowest noise level was determined. It was 28.6 dB (accuracy of the instrument in terms of noise when 94 dB is ± 3,5 dB; resolution is 0.1 dB) and the illumination at 0 Lux (accuracy of the instrument in terms of lightening when +10 °C is ± 5%;).

During the second stage a device showed noise level of 28.6 dB and the illumination level has increased to 112 Lux.

During the third stage, a noise level was equal to 62.5 dB and Illumination was 0 Lux.

Comparing measured values, we can find dependence between them and specify it in Table 1:

Value	**Readings of the developed scheme**	**Multimeter DT-8820**
Noise	508 units	28,6 dB
	522 units	62,5 dB
Illumination	250 units	0 Lux
	750 units	112 Lux

Table 1: The adjustment constants for the developed system

Figure 19: DT-8820 device (1 - sensitive microphone, 2 - photodetector device)

5.3. Filtration using wavelet transform

Wavelet analysis is one of the most promising data analysis techniques nowadays, its tools are used in a great variety of spheres of intellectual activity. Its main distinctive and useful feature for the analysis of dynamic processes of the property is as follows. Unlike traditional Fourier series which is used in spectral analysis, wavelet analysis allows to decompose the frequency spectrum over time and to detect moments of rising and falling of various cycles in dynamics. Also, it allows to decompose time series into levels and to determine the detail of each level dynamics; identify the frequency characteristics of the time series which precede in time the unexpected and segregate "bursts" in the dynamics, etc.

The wavelet transform is a tool for multiresolution analysis: with its help a signal is represented as a set of approximation and details, distinguishing the approximation of the original signal. This representation allows to filter out small changes in the signal, focusing on the study of its global features or consider its "small details", indistinguishable against the background of "large-scale" changes.

Moreover, since noise is usually being represented as a minor frequency ("small-scale") signal changes, wavelet transform can be used for purification of the noise signal by removing therefrom such "minor" parts.

Let’s consider the application of the wavelet transform for the noise registration in the room. The noise level value was received at the microphone, which fixed it at certain points in time.

Wavelets are created using special basic functions that define their kind and properties. The basic functions can be functions of different shapes which provides an easy representation of signals with diverse local peculiarities. Among the many types of wavelets, the following need to be mentioned: Daubechies wavelet [18-20], Meyer wavelet [21], Mallat wavelet [22-24], Morlet wavelet [25], Haar wavelet [26] etc.

The basis of the continuous wavelet transform is the use of two continuous functions which are also integrable over the whole-time axis:

1. wavelet function $\psi(t)$ with zero mean value, determining signal details and generating detailing coefficients;
2. scaling function $\varphi(t)$ with a single value of the integral determining a rough approximation of the signal and generating approximation coefficients (this feature is not inherent to all wavelets, only orthogonal).

Wavelet function $\psi(t)$ is generated on a base (parent) function $\psi_0(t)$ which determines the type of a wavelet [27].

One of the fundamental ideas of the signal wavelet transformation is a signal decomposition into two components - rough (approximating) and specifying (detailing) - followed by the process which fragmentize them in case of change the decomposition level of a signal. This is possible in both the time and frequency domain representation of the signal wavelets.

This basis can be orthogonal (that significantly facilitates the analysis, enables the signals reconstruction and allows to implement algorithms for fast wavelet-transformation) and not orthogonal - there is a number of wavelets that do not have the property of orthogonality [27].

Daubechies wavelet was selected as the tool of orthogonal wavelet transform. It is shown on Figure 20. This wavelet is the most discovered wavelet and the most convenient in computations. The use of wavelet which order is less than 10 seems to be sufficient to solve the overwhelming majority of tasks, connected with the digital signal processing. This wavelet (as orthogonal) has both the approximating and detailing components.

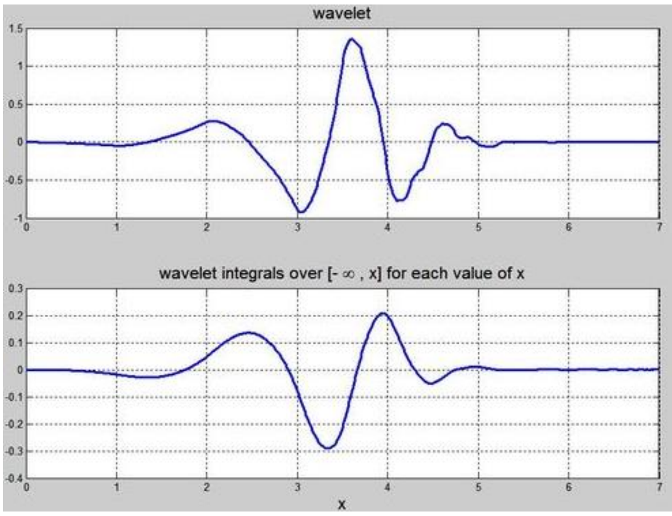

Figure 20: 4th order Daubechies wavelet (upper), the scaling function (lower)

In accordance with the frequency approach the frequency domain is divided into two parts - low and high frequency parts. Mainly two filters are used for the separation of these components - low frequency filter H_1 high-frequency H_0. Signal goes to filters, then using the decimation operation ↓2 (halving the number of frequency components) approximation coefficients can be obtained at the output of the low pass filter and detailing coefficients can also be obtained at the output of the high pass filter.

The depth of decomposition determines the scale of eliminated parts: the higher this value is, the larger signal changes will be discarded. For sufficiently large values of decomposition (the depth of 7-9) not only a signal clearing from the noise is implemented, but also its anti-aliasing (the signal peaks are “clipped”). But we must remember that the use of too depth level of decomposition can lead to errors (a signal is shorter than the length of the filter).

We get a full set of approximating and detailing coefficients as a result of the decomposition, up to the decomposition level. Using the obtained set of coefficients, we can create a wavelet spectrogram of considered signal, e.g., to evaluate its characteristics. Decomposition into components according to any of the discrete wavelet is carried out according to the following formulas:

$$s_{j+1,k} = \sqrt{2}\sum_i h_i s(j, 2k+i), \tag{1}$$

$$d_{j+1,k} = \sqrt{2}\sum_i g_i s(j, 2k+i), \tag{2}$$

in which $s_{j,k}$, $d_{j,k}$ are the approximation and specification coefficients, j – decomposition level number, k – the serial number of the coefficients, h, g vectors are the scaling and wavelet filters coefficients.

Using wavelet transformation, we decompose signal into the frequency components and select the appropriate trend value overall the noise in the room [Figure 21].

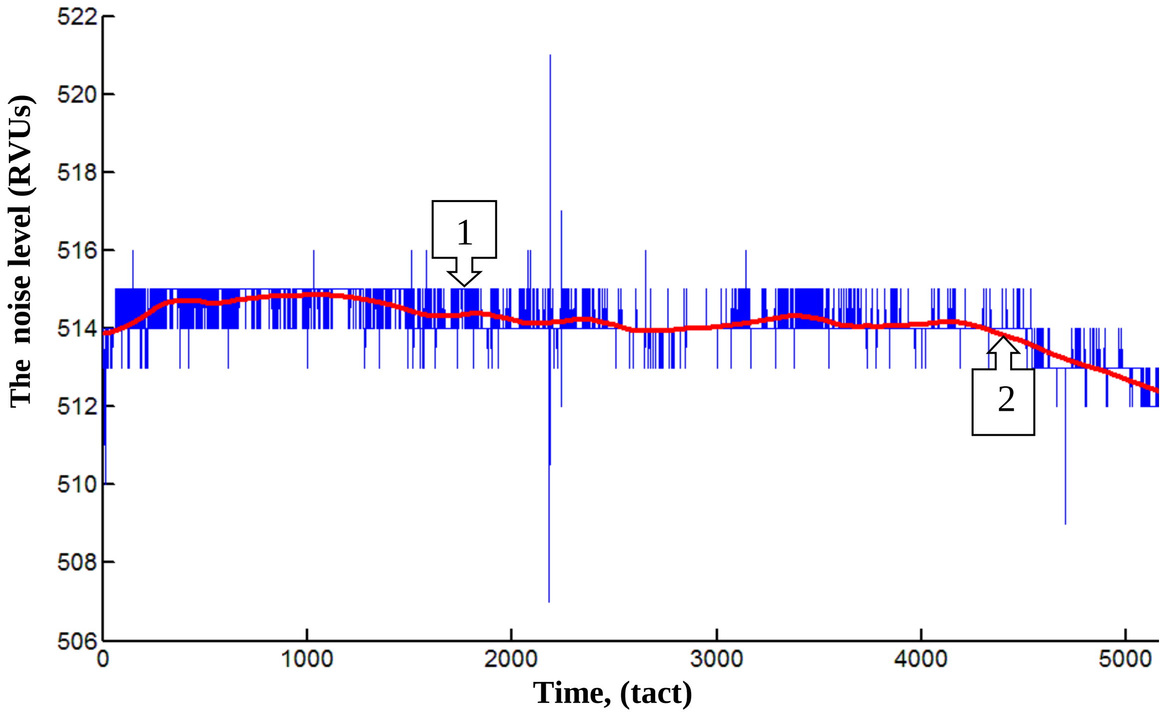

Figure 21: The relative noise value in the room: 1 - original noise signal (blue colour of the line), 2 - trend which corresponds to the value of the total noise (red colour of the line)

Also with the help of wavelet transform the overall lighting trend in the room can be highlighted [Figure 22].

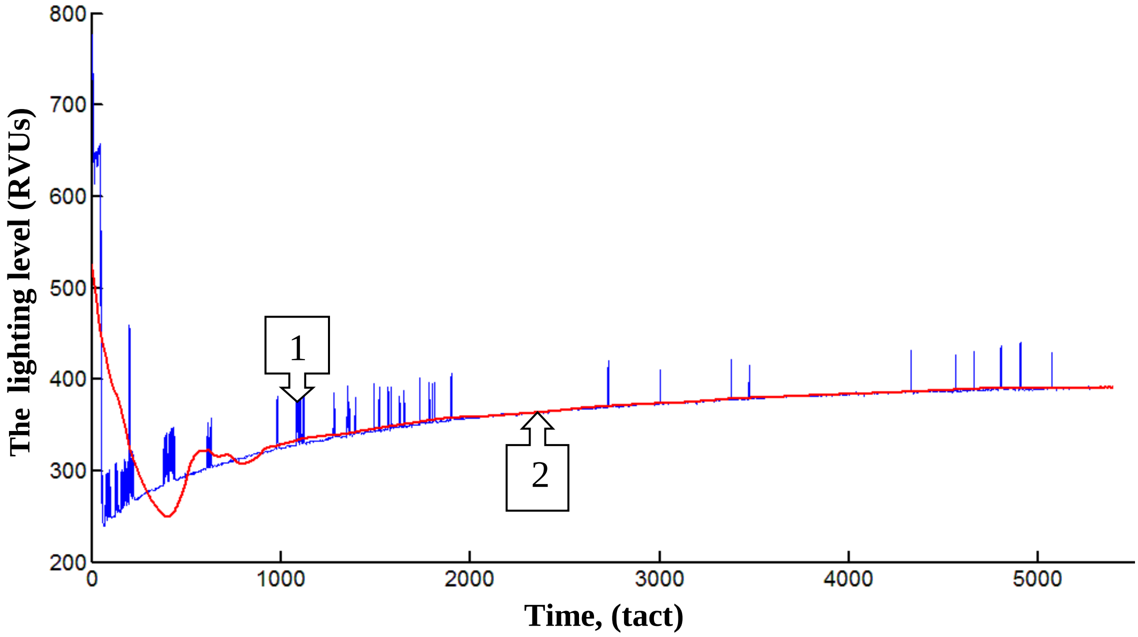

Figure 22: The relative lighting value in the room: 1 – the initial value (blue colour of the line), 2 - trend which corresponds to the value of the total lighting (red colour of the line)

As a result of wavelet transformation we obtain the full set of approximating and detailing coefficients, up to the level of decomposition. Using the obtained set of coefficients, we can create a wavelet spectrogram of considered signal to discover its features. Figure 21 and Figure 22 show us the noise filtering result and noisy luminance signal in the room using a smooth wavelet (4th order Daubechies wavelet, 3 levels of decomposition). A midrange component of the wavelet decomposition of the time series is obtained which describes a rate of specification $w_i(t)$ for $i=3$. These levels of decomposition more clearly reflect the sound and light vibrations in the room caused by various factors and mechanisms allowing to analyse the transfer dependency with significantly higher quality.

5.4. Statistical processing of experimental data

Statistical analysis began with an evaluation of the empirical distribution curves indicators and corresponding histograms to establish normal distribution. Normality test was also carried out by means of the Kolmogorov criterion. Since the received data was not normally distributed (the empirical distribution was not parametric) then nonparametric criteria were used which not depending on the form of the distribution. A non-parametric Mann-Whitney test was used to identify similarities, differences between the two empirical distributions and to evaluate the reliability of differences in the compared samples. This criterion is used to evaluate differences between two independent samples by the level of chosen sign which was quantitatively measured on the scale of intervals. Criterion value determines if there is enough small area of crossing values between the two rows. The smaller the area of the intersecting values, the greater the differences between the samples and the more likely that the differences are significant. The Fishers Criterium was used for comparison of two samples by the frequency of occurrence of the effect of interest (Fisher's angular transformation). This test evaluates the accuracy of the differences between percentages of two samples in which the effect of interest was detected.

The Analysis of Variance method (ANOVA) was used for evaluation the structure dynamics of a night's sleep during the periods of study.

Spearman’s rank was used in the statistical analysis of the dynamics of quantitative indicators. The accuracy of the results was evaluated by the level of significance $p < 0,05$.

Statistical analysis of the study results was performed using $Statistica$ program. Qualitative characteristics were described by means of absolute and relative (%) indicators. Quantitative - using the median and 95% confidence interval.

The following parameters were used in the analysis of hand motor activity:

- general motor activity during the night;
- the fraction of time with high motor activity relative with respect to the total time (%);
- the fraction of time with average locomotor activity with respect to the total time (%);
- the fraction of time with low physical activity with respect to the total time (%).

Considering the possible change in the parameters of sleep during the first night due to getting used to the presence of the attached sensors and the feeling of conducting the research I used data from the 2nd measurement night when processing the results.

Statistically significant differences in the results between the 1st and 2nd night were not found (Table 2).

	1st night	2nd night	P
Night sleep	25,9 [28,8; 36,6]	28,3 [31,8; 43,1]	0,534
High physical activity (%)	0,3 [0,6; 1,1]	0,2 [0,7; 1,7]	0,723
Average physical activity (%)	2,9 [3,0; 4,4]	3,3 [3,8; 5,8]	0,089
Low physical activity (%)	96,4 [94,7; 96,2]	94,0[92,8; 95,2]	0,478

Table 2: The results of processing the analysis during the 1st and 2nd nights

Differences in the motor activity values between the two subjects were not found: the first tested person - 25,7 [24,7; 26,0], the first tested person - 25,8 [24,6; 27,9], respectively $p>0,05$.

5.5. The results of physical activity studies

The visual observation protocol was created for each step of measuring where the data from a 3D-accelerometer [Figure 23] and the temperature of the tested person's body [Figure 24] were displayed. The duration of the 1st stage which was determined by the tested persons individually was up to three hours (180 minutes in average).

From Figure 23 it can be differentiated that a maximum total duration of sleep was 83 minutes. It draws attention the fact that the time is very short during which young healthy tested persons are beginning to feel the fatigue at night time. And the fact that even with attached sensors all surveyed fell asleep without any worries. It follows from the presented data fatigue and want to sleep of healthy young men may come in the first 20 minutes at night.

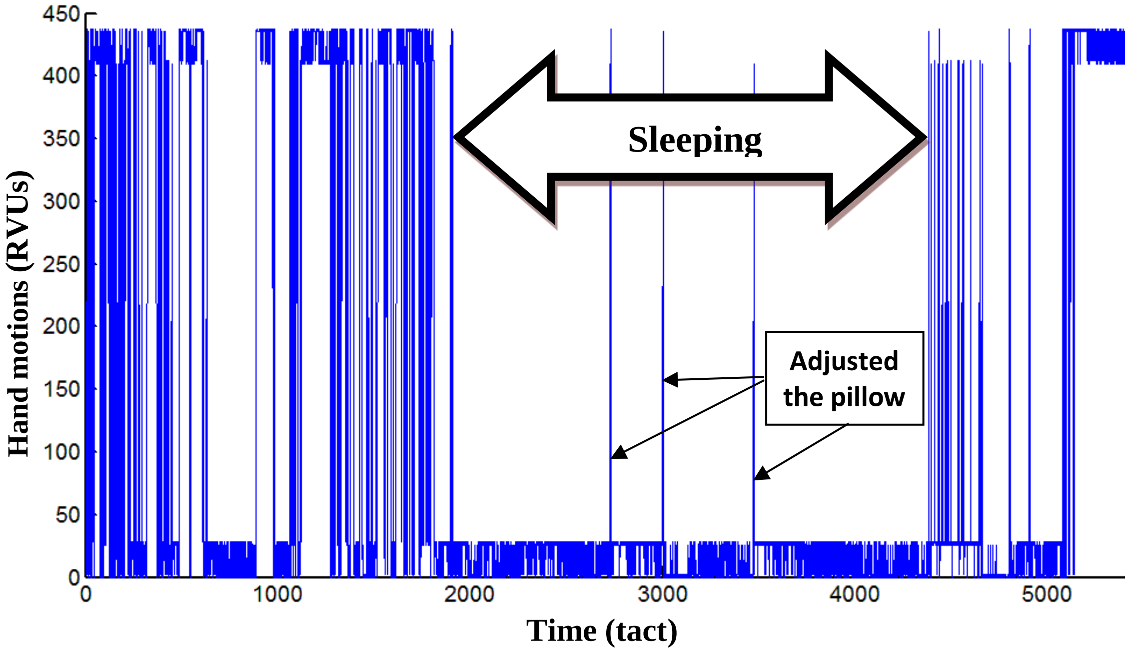

Figure 23: 3D-accelerometer data

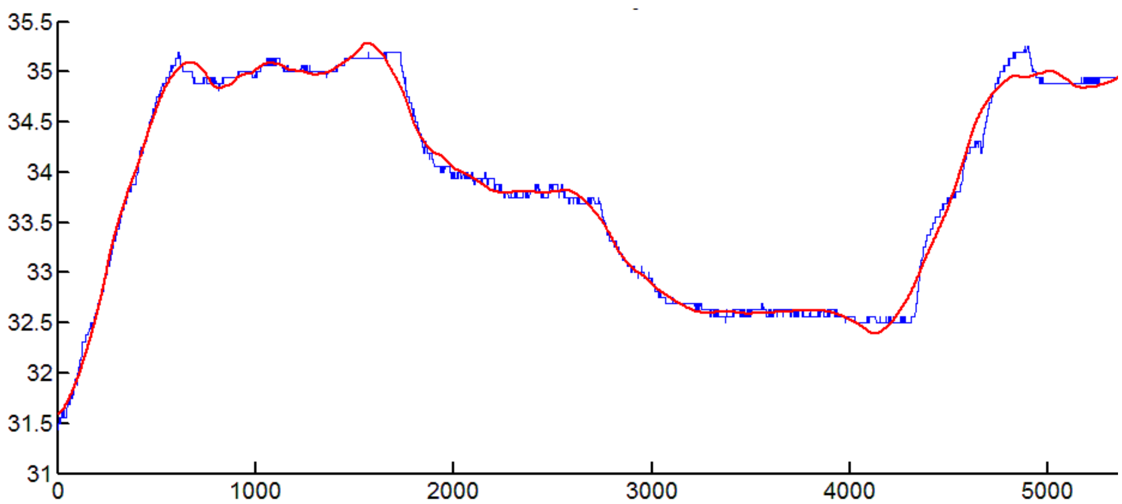

Figure 24: Body temperature

Analytical confirmation of the onset of sleep can be also monitored on the Figure 24 wherein comparing the time-domain from the Figure 23 the body temperature continues to drop for a period of sleep. Around the beginning of the awakening the body temperature of the tested person falls by 2.5 degrees Celsius below the temperature that was in the state of wakefulness. Thus, the metabolic rate also decreases. At this time, the tested person feels itself more tired because a low temperature is equal to the low level of epinephrine.

Low body temperature increases the likelihood of a good night's sleep and allows the body to rest and recover. When the body temperature begins to rise, it is more difficult for a person to remain in a state of deep sleep, which corresponds to the awakening.

Sometimes occasional sleep disturbances may occur due to the presence of a hypersensitivity towards external stimuli, such as increase or decrease in ambient temperature. During my measurements, the room temperature decreased from 25.63 to 25.2 degrees Celsius corresponding to an average temperature value of 25 C^0 (Figure 25). Therefore, the statistical impact of room temperature on the sleep after the correlation analysis by the method of Spearman is insignificant (p = 0,001).

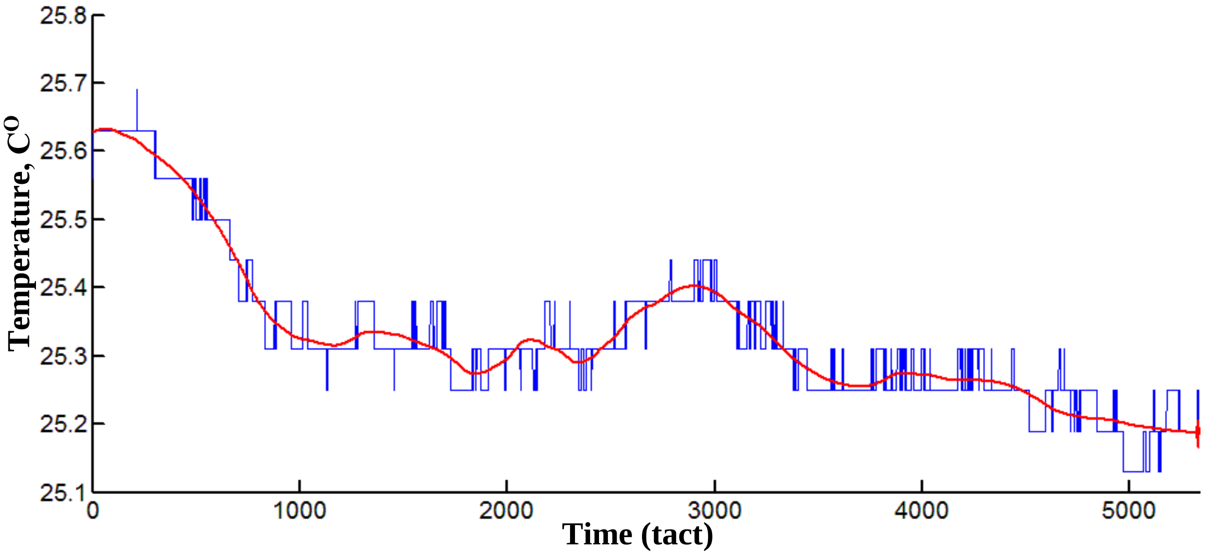

Figure 25: The temperature changes in the room

Statistical analysis showed significant dynamics of 3D-accelerometer parameters at different stages at different stages of monitoring (Figure 26). When in a "sitting" position the motor activity in the right wrist was 1150±2900 units, in the comfortable "lying" position during a sleep all the tested persons have actigraphy index ranged between 60 and 290 units.

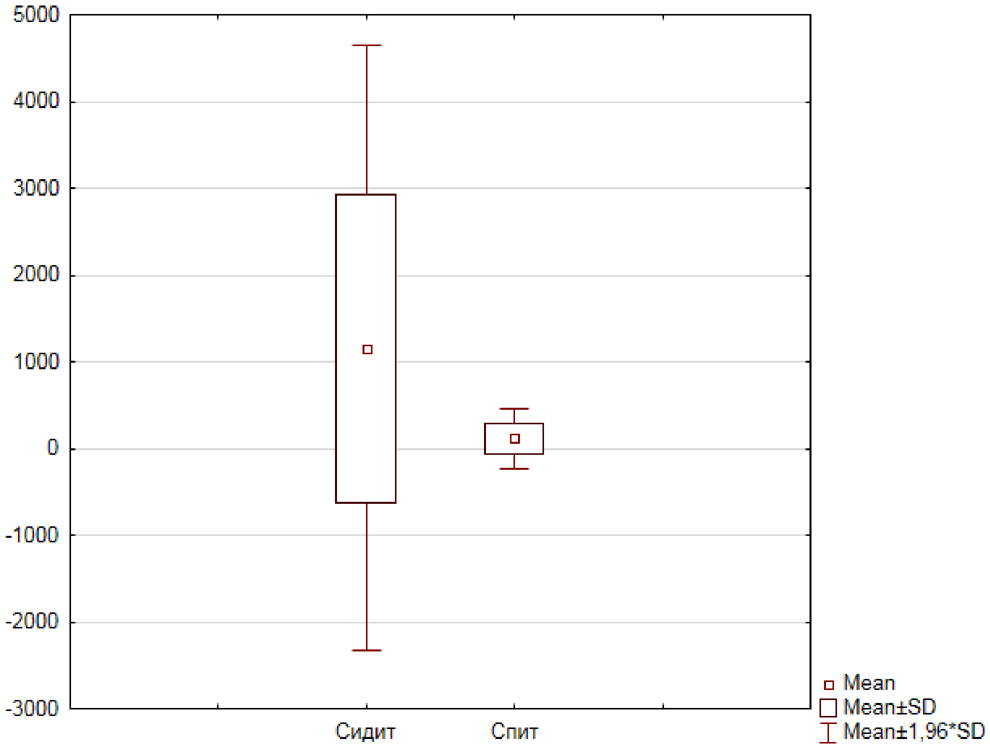

Figure 26: A graphical comparison of the mean values of the 3D-accelerometer indicators at various stages of a research

It was even in those cases where there was a gradual shift of the coordinates because of the gradual reduction of tone muscle arm where a 3D-accelerometer sensor was mounted. Obviously, there are time periods in actogram when the mobility can be below than 200 units during wakefulness.

Determination of the interconnectedness between the parameters of a 3D-accelerometer and the parameters of an infrared radiation sensor [Figure 27] was performed using the Spearman correlation analysis method. Non-parametric correlation analysis option was selected because of the distribution of parameters of 3D-accelerometer which differs from the normal. The analysis revealed a statistically significant ($p<0.05$) difference between two dependencies at the level of 0,116 units, obtained at the beginning and end of the sample. The static difference can be characterized as a negligible error in the middle of the time series indicating the immobility of a tested person or a deep state of sleep.

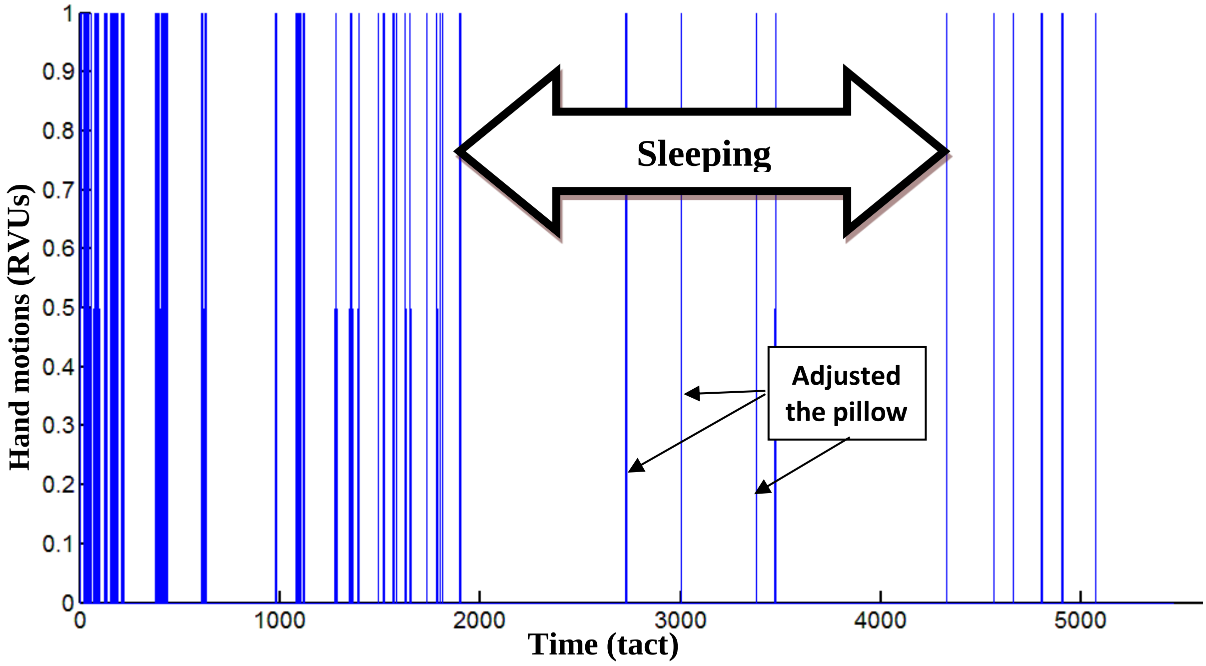

Figure 27: Triggering an infrared motion sensor

When comparing with the help of The Analysis of Variance method (ANOVA)

There were not any statistically significant differences or trends received when comparing by The Analysis of Variance method (ANOVA) for repeated measurements of parameters of nocturnal sleep patterns with a normal distribution or converted to a normal distribution.

5.6. Sleep changes in conditions of high ambient light and noise

There were 2nd and 3rd stages of the experiment conducted similarly to the 1st stage. The correlation analysis of indicators of a night's sleep of the 1st stage was conducted with a night's sleep and an increased brightness and noise. The noise magnitude was increased from 28 dB (a quiet city apartment) to 62 dB (the level corresponds to the normal human conversation) and the illumination was increased from 0 to 112 Lux.

As seen in Table 3, a night sleep is positively correlated with the duration of sleep (at trends) as well as is negatively correlated with sleep efficiency at the trend level.

Indicator	Spearman's Rank correlation		P
	Stage 2	Stage 3	
Night sleep	0.478	0.127	<0.01>
Sleep efficiency, %	- 0.279	- 0.491	trend
The duration of falling asleep, min	0.314	0,249	trend

Table 3: Correlation of anxiety as a result of the experiment of both the 2nd and 3rd stages with indicators of a night sleep structure using the Spearman's method

Thus, the correlation analysis shows us the prevailing light influence on sleep quality in addition to the expected connection between a higher level of anxiety phase from the 2nd experiment and the 3rd stage with a longer time of falling asleep and lower sleep efficiency.

The data from a 3D-accelerometer measured with increased illumination is shown in Figure 28.

Thus, the duration of sleep and sleep efficiency deteriorated compared to the measurement during the 1st stage which in its turn confirms the conducted statistical Spearman's correlation analysis.

A similar proof is shown in Figure 29, only with an increased noise level which corresponds to the 3rd stage. The total duration of sleep and the efficiency have significantly reduced at the same time.

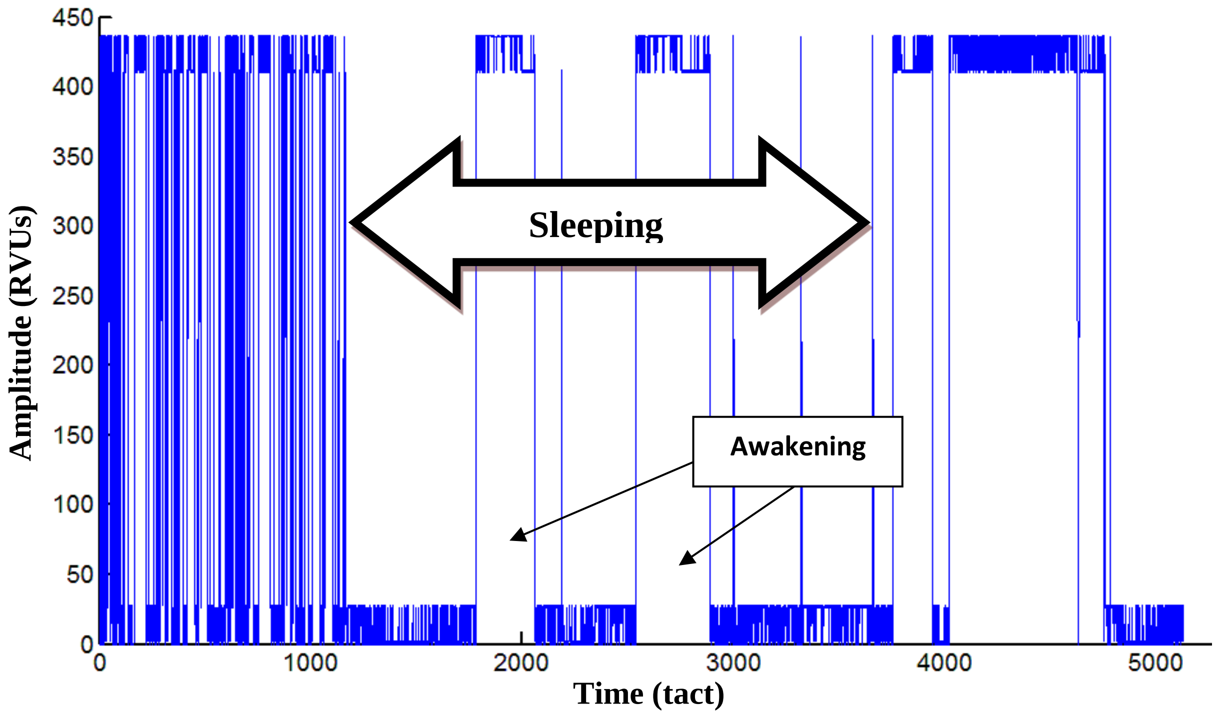

Figure 28: 3D-accelerometer's readings with increased illumination

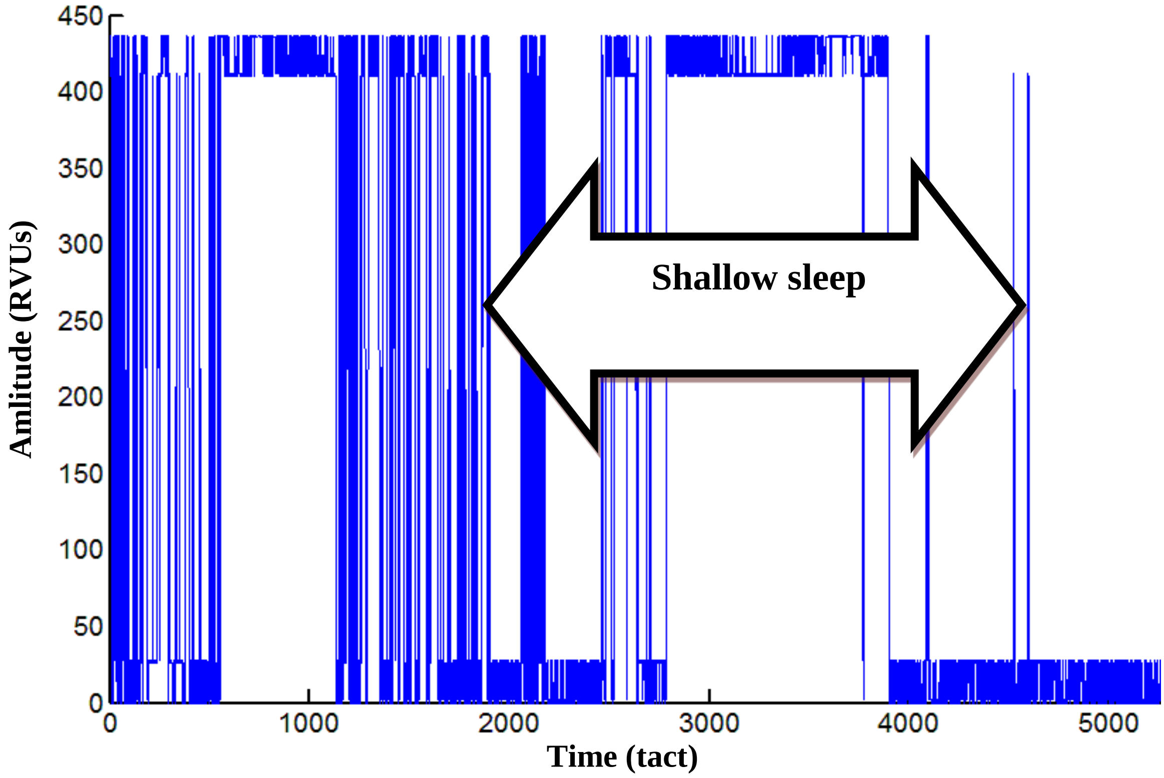

Figure 29: 3D-accelerometer's readings with increased noise

Thus, despite the apparent differences in the results obtained by measuring at 112 Lux illumination level and 28dB noise level the structure of a night's sleep between the two tested persons is on the border of statistical error.

CHAPTER 6

Results

Thus, despite the significant number of publications devoted to the problems of registration of sleep disorders and creating a system with a minimum number of sensors that need to be mounted on patients, a number of issues still have not been solved yet. There is no consensus on the meaning and methods of use of actigraphy in the diagnosis of sleep disorders. Features of physical activity according to age, physical, neurological and psychiatric status and the association of these characteristics with the quality of sleep also did not find a sufficient description in the literature. All of the above leads to the relevance of the study and its prospects.

CHAPTER 7

Conclusion

The developed software and hardware monitoring system allows to detect sleep pattern and the main factors of influence on the duration of sleep and a man's sleep comfort with a minimal number of connected sensors.

The application of the method of a continuous registration of motor activity (actigraphy) allows to identify those with the presence of sleep disorders, it is based on the nature of the distribution of physical activity in the daily cycle.

Both tested men had no differences in the level of daily physical activity during the night time and in the sitting position. It was detected that the sitting position has 10 times higher level of physical activity compared with the supine position.

As a result of conducted study and research, the way to justify and proof the obtained judgements is to increase the number of tested people and to include polysomnography into the experimental studies.

CHAPTER 8

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Appendix A

Contents on the CD:

1. This bachelor thesis in PDF.
2. Program in Matlab: wavelet analysis.
3. Programs in Arduino with description file “look.txt”.
4. Files with measured data in CSV format.
5. Additional images.