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REZUMAT TEZĂ DE DOCTORAT

Monitoring and improving workers body posture and physiological parameters via an unconventional user interface

Monitorizarea și îmbunătățirea poziției corpului și a parametrilor fiziologici ai angajaților folosind o interfață utilizator neconvențională

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1 Introduction

The development of computer technologies made our jobs easier to conduct, but on the other hand causes new but serious health associated problems. Work at the office typically means to spend particular amount of time sitting in an office chair, which in its turn adds stress to spine. As it is well-known back pain is one of the most common work-related health problem and is mostly caused by particular work activities, such as heavy lifting or sitting in an office. Office work related pain in neck is also very common nowadays and is agreed, that the ethology of neck pain among office workers is a multidimensional and is associated with complex factors with individual, physical and psychosocial components. We will show all components in Virtual Reality environment, and each time when the worker deviate from normal posture program will react in most realistic way.

Virtual reality refers to computer or other hardware-simulated reality that is perceived by humans through senses, including sight, hearing, etc. Virtual reality is replicated in real life.

The term “artificial reality” first introduced by an American computer artist Mayron Krueger has been in use since 1970s. Virtual reality in its modern usage was popularized by Jaron Lanier in 1989. Virtual reality is otherwise known as electronic reality or computer-based model of the reality. One has the feeling of being part of the reality replicated on a computer. The virtual reality developed for training and educational purposes is capable of simulating any situation that takes place in real life.

Different types of communication formats are available in 3D virtual reality, including text, audio and video. Communication via virtual reality becomes more interesting when users thereof use avatars, as well as avatar groups that communicate and cooperate with others(in our case avatar groups can be chair, office table, computer, etc).

Virtual reality is also used for scientific purposes, to represent objects with different sizes. For example, scientists have developed programs that enable to see on the screen how the atoms augmented to giant sizes join together and form chemical compounds. Virtual reality has also penetrated into many other disciplines.

Virtual reality has also positively impacted the educational process. Many education experts have begun reckoning with virtual reality and take urgent actions to use virtual technologies for the benefit of education.

It is not news that spending extended periods of time in front of the computer and doing sedentary work adversely affects human health. However, human health is mostly affected by the negligent attitude of people towards their sitting posture and health. Following our study among more than 300 workers, we found out that most of them had a feeling of discomfort caused by the work they were doing and almost all of the interviewees did nothing to improve the situation.

Virtual reality has poorly penetrated into workplaces so far. As already stated, virtual reality is the human presence in a computer-generated environment in real time.

With a view to helping workers to take care of their health, we have decided to consider human health in the context of virtual reality and to develop such computer-based interfaces that will enable to monitor human health in real time and based on certain physiological parameters help to create a healthier working environment.

2 The research of this thesis

2.1 The addressed issue

Nowadays economy has made serious scientific and technological progress. Our society has been very quick to adopt and apply state-of-the-art computer, as well as mobile technologies as an inseparable part of our everyday life. As said in [Paruyr et al, 2015] innovative technologies have integrated into our lives in a way that most of us do not even realize their being relatively new technologies, and today it is just impossible to imagine everyday life without these technologies. In fact, the IT technologies create lots of conveniences for human life, but at the same time, it can be definitely stated that they also negatively impact physical, mental and psychological state of humans. The medicine and education are the two main disciplines mostly influenced by the technological progress [Konsbruck, 2013].

Where does this progress lead to? What will be the consequences for the society? Here are two main questions that need to be carefully and thoroughly considered. Today almost all office workers, e.g., telephone operators, remote sales specialists, back-office workers among others, spend most of their working day sitting. If we search for the terms “healthy working environment” or “ergonomics” via search engine, we’ll find thousands of related articles, researches and studies. Tens of thousands researchers are concerned in a study of this rather important issue. The comparison of current and 20-year-old working styles reveals that parallel to the upgrade of computer technologies, workers’ sitting time is continuously increasing, which, in its turn, results in the increase of the number of diseases of people leading passive, sedentary lifestyle. Human brain is incapable of concentrating on work for hours and, what’s the most important, working for 8-9 hours daily in a sitting position is harmful for health. It is necessary to have regular breaks (every 30 minutes), to walk away from computer, to have a walk, to talk to colleagues and perform certain physical work/exercises [Parry, 2013]. Prevention or improvement of an unconsciously wrong attitude of humans towards their posture, whether sitting, standing or lying, will help to create a healthier working environment and to increase workers’ productivity. The present research covers the right ways of working.

The results of many researches [Ortiz-Hernandez, 2003][OSHA Ergonomics] have shown that humans are rather poorly “protected” from IT technologies at work. Our study (see Chapter 3) have revealed that most workers do not even realize the scale of damage caused to their health at work, which, in its turn, negatively impacts workers’ productivity. In the scope of study I had face-to-face interviews with over three hundred workers I defined that the huge part of them didn't know the cause of health problems. Worker’s physical and psychological state first of all depends on the worker himself/herself and only then on his/her management. After having been working for over 3 years on this thesis, I found out that most people were not aware of possible damages that could be caused to their health at work. Like robots, they do their job unconsciously, and the organizations they work for are not interested in changing anything in the organization of work at all, so that to give priority to workers’ health issues. By the end of this thesis it would be clear that preventing or improving incorrect postures and physiological other parameters with the help of special programs will lead to less musculoskeletal disorders.

2.2 The importance of this research

This research is of great importance to different concerned parties:

- For the management: workers should be productive at work and satisfied with their job. It is natural that the productivity coefficient of workers satisfied with their job is much higher than that of workers who are not satisfied with their job.
- For workers: work-related stresses should be kept under control. The phenomenon and concept of “stress” has been largely circulated in recent years, causing serious concern for the management. “Stress” is deemed to be one of those most “expensive” risks negatively affecting both workers’ health and organizations’ profit.
- For further development: a work-health balance should be maintained. For most people finding this balance has become extremely difficult. When work takes most of their time, working without breaks and other problems that workers have cause overstress and finally they get sick. One should reasonably make work planning, by learning to say “No”, adopting healthy practices and thus reaching work-health balance.

2.3 Research Goals and Objectives

The present research work represents a study of a method, which helps to reveal early signs of fatigue, sleepiness, tension and incapability to work. If the variables, such as those depending on biological and environmental influence, are studied, it will be possible to reveal the cases of loss of alertness and mental load at their early stage. It is a rather complicated phenomenon and cannot be simply measured using ordinary tools, and based on the results to determine worker’s health status. If all the necessary data is collected in one system and studied and reasonably processed from a medical point of view, we can get a clear picture of worker’s health status in real time. In case of complete study and design of the method, we’ll get a system, which will help to determine whether or not the worker is capable of working or doing other necessary actions at the moment (this system will have a great demand among workers leading sedentary and passive lifestyle).

As necessary parameters for making the analysis of this issue can be, for example, person’s visual behaviour – eye movements, gaze, blink rate, as well as the viewing angle and distance from the computer screen. As for other parameters, e.g., physiological parameters, such as heart work, brain activity, spine position can be considered. Also, it is necessary to study and consider the environmental influence on human body, such as temperature in the workplace and, why not, other factors controlled by workers, such as monitor placement, chair placement in front of the desk, room illumination, etc. In a word, the system will collect and process all the parameters necessary to organize the working process properly.

There are certain measures that could be taken to minimize the scale of damage caused to human health at work, such as doing physical exercises, avoiding same sitting positions, walking away from the workstation on a regular basis, doing special exercises to relieve eye strain, etc. [Dunstan, 2013]. All these actions should be done regularly, so to become an inseparable part of everyday work. However, at work people are sometimes so much engrossed in doing their everyday tasks that they forget about other things (it is not a secret how attractive it is to work with computer or just surf the internet). And so, these are the factors that urge us to create such a system, which will help to monitor the physical state of workers at work. Thanks to that system it will be possible to fix any changes in the physical state of workers and to offer possible solutions, in order to prevent negative consequences.

The global and main objective of this research and of development of a special system is to constantly monitor the physical state of workers without any interference with their life and to evaluate the general state of workers, having spent an extended period of time in an awkward position. The system will collect all the possible biological data via special devices and various sensors. It should be equipped with all necessary devices, in order to enable the system to collect all the biological and non-biological data and to derive a systemized algorithm based on the results of data processing.

The system will collect and process the data and derive a systemized algorithm in real time. The final result that represents a special algorithm will help workers take relevant steps in their workplace, in order to enable them to avoid further serious health problems caused by sedentary, passive workstyle. This system is intended for use in large companies with over 100 workers, as in such companies workers are subject to busy work schedule and it will be possible to get the most accurate picture.

The objectives of this research can be summed up as follows:

1. to show the possible impacts of computer systems and to develop safe work practices among workers via a virtual reality environment;
2. to reveal early signs of fatigue and inability to work through virtual reality;
3. to create a number of virtual reality based programs that can be used to educate workers in implementing safer work practices, as well as to evaluate efficiency of such programs during work.

2.4 Research methods and approaches

The methods and approaches used in this research are mainly for test purposes and by their nature correspond to the domain of human-computer interaction. When measuring any parameter of medical intervention and using the results in any domain, we have relied on professional literature and taken into consideration opinions of different specialists. Brief description of innovative devices used in the system, their manner of operation and the purposes of their use in the system is given below.

Now briefly about Kinect: it is a special tool released by Microsoft Corporation. It is controlled without any physical interaction, using only gestures, and tracks movements of objects and people in three dimensions [MsKinect]. In other words, Kinect enables the user to control it through verbal/oral commands, gestures and through other objects.

There is a great potential all over the world to use Kinect in different domains. For example, it is widely and efficiently used in medicine – in operating rooms, at home or in hospitals for the purposes of physical therapy. As far as the newly-developed system will be used to monitor the physiological state of workers in the working environment, the above-mentioned logical approaches are in direct proportion to all healthcare norms.

In 2014, Microsoft Corporation launched Microsoft Band smart device. Microsoft Band, the first device powered by Microsoft Health, helps to achieve wellness goals by tracking heart rate, body temperature, physical activity, as well as sleep duration and other similar parameters [Agelink, 2001][MsBand]. The device tracks user's movements, considering the distance and speed, measures body temperature, heart rate and calorie burn. One of the more interesting sensors on the Microsoft Band is the UV sensor. It helps to get a snapshot of the current UV level and avoid too much UV exposure, thus enabling users to lead a healthy lifestyle and to work efficiently. It is composed of 10 sensors – an optical sensor to measure heart rate, a triaxial accelerometer/gyroscope, air humidity, GPS, illumination, body temperature, UV sensors, etc.

Microsoft Band has a great capacity to collect the parameters of human physiological and physical activity. It provides many parameters from which the necessary ones will be included in the system. Each parameter necessary to give a solution to the problem in question will be specifically processed and presented in the designed system. The next special feature of Microsoft Band used in the scope of this research measures the physiological phenomenon of variation in the time interval between heartbeats. Small-scale recorders are intended to collect data on heartbeat acceleration rate. Pulse is a numeric average of a person's heart rate during one minute [Agelink, 2001]. 60-80 beats per minute are considered to be an average heart rate, but it does not mean that the time interval between heartbeats makes 1-1.3 seconds: it may range between 0.5-2 seconds [Agelink, 2001]. The factors affecting the heart work may be as follows: age, genetics, body position, time of the day and health status. These are the main factors to pay special attention to. More details will be discussed in the relevant chapters of this thesis.

The level of progress of IT technologies plays a very important role in the lives of both healthy/disabled and old people. People with hearing or visual impairments, as well as with motor disabilities, such as spinal cord injury or dysfunction and other problems, very often face many obstacles in human-computer interaction, which they overcome with great difficulty. People with physical disabilities experience difficulties in using computer accurately and effectively, which usually hinders their integration into the society, as well as limits communication with the world around them without additional aids. Tobii Eye Tracker [TobiiEye] is an ideal solution for people with such disabilities. It helps to work with the computer using eye movements. I have used this device in the designed system, in the following way: using eye behavior we determine some parameters, such as, blink rate, duration, viewing angle and the distance from the monitor.

2.5 Research Delimitation

As already stated in the beginning of this research, we have set ourselves a goal and started looking for possible ways to reach that goal. The first step to take towards reaching our goal is to give the right definition of that goal. And so, the first thing to do is to create a prototype. A demo version was developed and presented in the scope of the testing. Based on the results of pilot test, we got the general picture of what we have and what we had to do to develop it further and to have a more user-friendly interface. This solution was warmly welcomed by many users and we got their positive feedback, as well as suggestions which we took note of. The interview with users is a proven method to find out the factors interacting with human spectrum. Multiple tests of the prototype and discussions with users help to achieve the final result.

In the scope of this research we now have a modern and functional system, which is rather flexible and which uses the latest IT devices and approaches. Considering the highly progressive trends of the IT industry, we should do our best to always maintain all devices and software used to operate this system up to date. The hardware used in the system is intended to evaluate the physiological state of humans.

3 Study of the discomfort for office workers

The present research was carried out using the method of prospective cohort study. Such studies widely vary in terms of size and complexity. A cohort study is mainly used in medicine, social science and business analytics, as well as in other disciplines. In this specific case it is used for health evaluation purposes. A prospective cohort study is a study that follows patients over particular time, by performing permanent or repeated monitoring of risk factors or health status of patients or both of them [Mana, 2008]. A cohort is a group of people sharing a particular characteristic and tracked for a particular period of time.

In the scope of this research work the main objective of cohort study was to get exhaustive quantitative data to help us in decision-making with regard to further development and upgrade of our system. A non-random sample selection method was used to select the participants of the study. Workers having shared the same workplace for the targeted period of time were selected to participate in the study. The use of such method enabled us to have a representative sample of workers from Armenia.

Source data collection was performed in January-February of 2015 and medium-term data collection - in April-June of 2015.

3.1 The target population

The target population was represented by a group of workers, which worked during the 3 years of my research, the period from 2012 to 2015.

The target group members were selected based on the following criteria:

- bank workers, whose work agenda is much stricter as compared with others;
- workers of multinational organizations doing their business based on international standards;
- workers doing part-time active job.

Those eligible for participation had to meet the following criteria:

- to work in the same organization throughout the research period (2012-2015);
- to do different types of job (e.g., active, partly active, sedentary);
- to be a Republic of Armenia citizen;
- to speak Armenian, English;
- to wish to participate in the study.

The exclusion criteria for participation were as follows:

- workers with physiological problems (as the results of study would be drastically impacted);
- workers always doing a physically active job.

We have also excluded workers over age 50, as the likelihood of occurrence of health problems conditioned by age is rather big at that age. Whereas, the main objective of the study carried out by us was to reveal health problems conditioned by poor organization of work.

3.2 Study instrument

The first thing done in the scope of the study was to filter the organizations according to the type of business they do and only after that make final selection of organizations and workers. Following the selection process, we made a phone call to those organizations to verify certain information and only after that meetings were organized to conduct interviews with workers.

EQ-5D-3L instrument applied in the study is a verified, approved and reliable tool used to evaluate the quality of life (QoL) [EuroQOL] of people. The QoL Commission has studied the problem in advance and offered a questionnaire consisting of several questions. Parallel to this questionnaire we also used the Cornell Musculoskeletal Discomfort Questionnaires (CMDQ) developed by Dr. Alan Hedge [Cornell] from Cornell University.

The final questionnaire consisted of the following sections:

- General information about worker
- Job description
- General information about worker's health status
- Environment
- Study of highly vulnerable aspects

3.3 Sample Size calculation

The sample size for our study was calculated with the confidence level of 95%, power 80%, assumed relative risk of 1.7 and expected incidence in unexposed group of 19%, which is based on the results of previously conducted study [Devereux, 2002]. So the needed sample in the scope of this particular study which will best represent Armenian population is 332 [EpiTool].

3.4 Statistical considerations

Before entering the data into the SPSS (Statistical Package for the Social Sciences) database, we reviewed all questionnaires completed by interviewees. At that stage a unique data entry was performed by us with further cleaning, which was rather a time and effort consuming process. During the medium-term evaluation, in order to avoid mistakes and to improve the quality of the database, a double data entry was performed, which took us almost 4 weeks. Data analysis was conducted via the SPSS and STATA software packages.

Categorical variables were presented as counts and percentages compared by *by-item analyses* and continuous variables were presented as means and standard deviation. As far as we have used categorical data we have used bivariate and multivariate logistic regression analysis.

3.5 Study variables

The dependent variable of the study was quality of life of workers divided in the three work categories: active, partly active and sedentary. Based on a few studies of regression analyses the dummy variable was created for this variable. These types of variables (dummy) are used mainly in regression analyses to represent subgroups in a study. The investigator recoded the options of the variable and defines passive as “0” and partly active and active options as “1”, based on other studies being done previously. The independent variables of the study were gender, time of working (months), sought or received medical assistance, changes performed at workplace to improve quality of workplace, variables experiencing ache, pain and discomfort, including options of never, 1-2 times last week, 3-4 times last week, ones every day, several times every day/uncomfortable feeling when experiencing ache, pain and discomfort/ache, pain and discomfort interfering ability to work, with options of slightly, moderately and very. It is worth to mention that for regression analyses score was generated for these variables. For the neck, all options were summed and the maximum value was 8 and minimum 0, for shoulders 16 and 0, for upper back 8 and 0, for upper arm 12 and 0, lower back 8 and 0, forearms 14 and 0, wrist 16 and 0, hip buttocks 7 and 0, thigh 16 and 0, knee 16 and 0, respectively maximum and minimum values.

3.6 Ethical considerations

This study corresponds to local and international ethical standards. All participants were informed about their rights (participation was on a voluntary basis and participants could refuse to further participate in the study and answer the questions; anonymity and confidentiality was fully ensured).

3.7 Results

3.7.1 Administrative data

10 organizations were contacted, of which 4 organizations refused to participate in our study and 6 were included in it. All together in those organizations were 834 employees, of which 590 met our inclusion criteria. So, 485 employees were contacted, from which 112 employees refused to participate, 24 were on vacation and 349 completed our in-depth interviews. After data collection and cleaning, 16 persons' data were excluded from the analysis due to missing values.

So, the final sample available for the analysis was 333, which fully corresponds to the needed sample size calculated previously.

3.7.2 Baseline and procedural characteristics of the patients

Of 333 employees included in the sample 65 (19.52%) had active, 71 (21.32%) partly active and 197 (59.16%) sedentary working conditions. More females were in sedentary group (55.33%) than in the partly active (49.30%) or active (35.38%) groups (p=0.020). Less people were working more than 61 months (approximately 5 years) in each group (29.23% versus 70.77%, 43.66% versus 56.34% and 35.53% versus 64.47%, p=0.210). And in all the groups people were less likely to sought or receive medical assistance.

3.7.3 Quality of life for employees

The by-item analysis of the questionnaire showed significantly worse results for the sedentary group regarding ache, pain or discomfort in neck. And people with active lifestyle had more chances to never experience neck pain (68.25% versus 46.48% or 34.01%, p=0.000). Regarding shoulders, 81.54% of people working with active conditions never experienced shoulders' pain ache or discomfort compared to people from partly active (64.79%) or sedentary group (64.47%) (p=0.011). The groups also differed significantly in the rates of lower backache, pain or discomfort. And employees in the sedentary (75.63%) or at least partly active (66.20%)

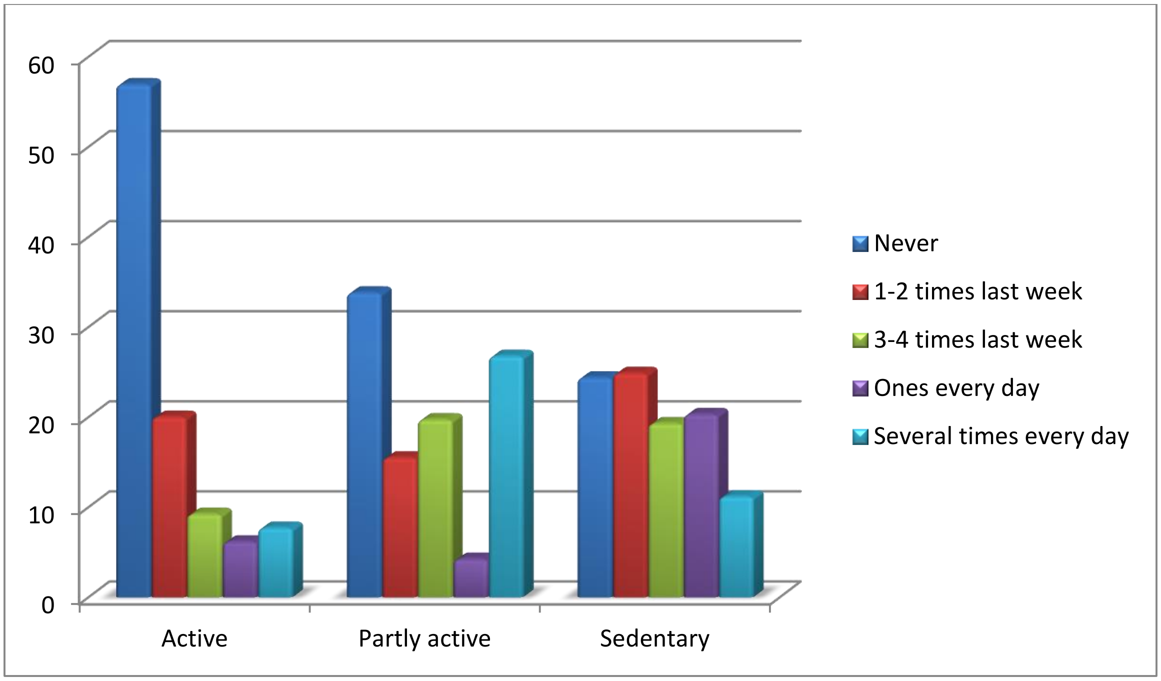
group experienced lower part of back pain, ache or discomfort at least once a week compared to people from active group (43.08%, p=0.000).

There is also significant difference in hip/buttocks, as people from sedentary group had worse results, experiencing ache, pain or discomfort more often than those from partly active or active groups (35.53% versus 21.13% or 4.62%, p=0.000). And it is also worth to mention that people experience pain, ache or discomfort in lower parts of legs more frequently with active work than people with sedentary working conditions (29.23% versus 25.38%, p=0.006). No differences were found regarding shoulders, upper back, upper arms, wrists and thighs.

The most significant differences are found in neck, shoulders, lower part of back, forearms, hip/buttocks and knees. The by-item analysis showed worse results for employees with sedentary working conditions compared to the ones with partly active and active working conditions, showing very uncomfortable feeling in neck (25.89% versus 14.08% or 4.62%, p=0.000), shoulders (15.25% versus 5.63% or 0.00%, p=0.007), lower back (26.40% versus 23.94% or 10.77%, p=0.000) and hip/buttocks (3.55% versus 0.00% or 1.54%, p=0.000). No significant differences were observed regarding the other parts of the body.

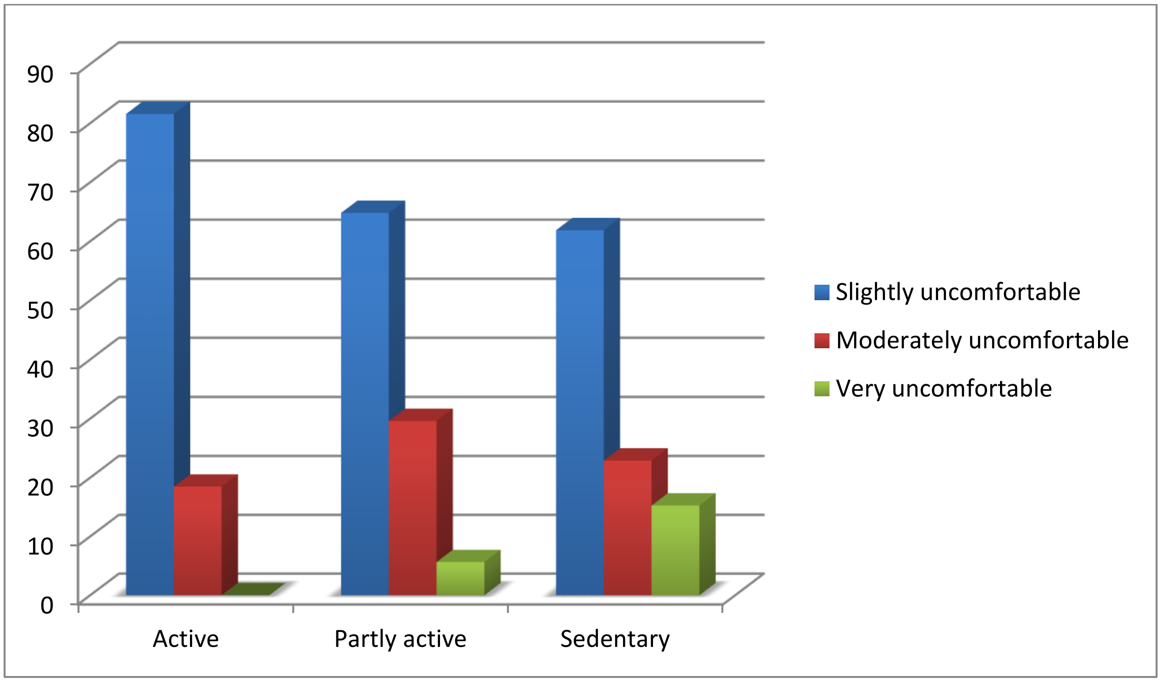
Significant differences were found showing substantially worse results in ability to work when experiencing ache, pain or discomfort in neck, lower part of back, wrists and hip/buttocks. Employees' neck pain, ache or discomfort substantially interfered their ability to work for the ones with sedentary working conditions compared to the ones with active or partly active work (25.89% versus 4.62% or 9.86%, p=0.000). People from sedentary group also had higher chances to have lower part of backache, pain or discomfort that substantially interferes their ability to work if compared to people from partly active or active groups (28.93% versus 15.49% or 7.69%, p=0.000). No significant differences were observed in domains of upper back, upper arms, forearms, thighs or knees.

Chart 1 - Ache, pain and discomfort in the lower back



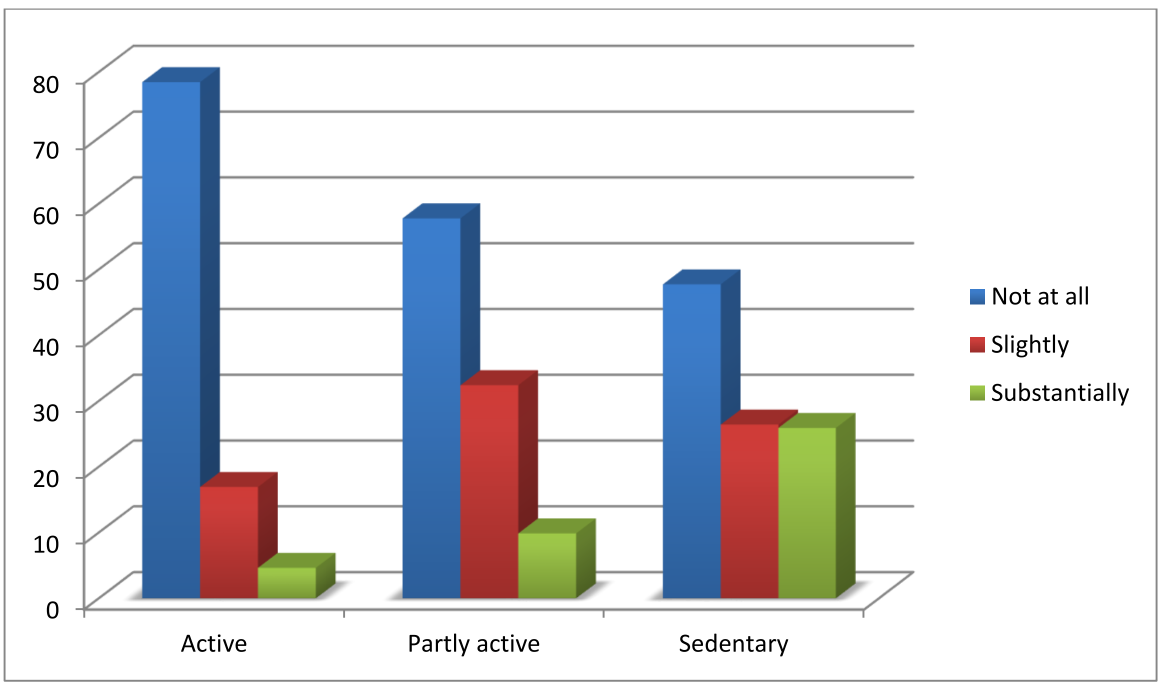
As it is seen from the chart above, active workers experience ache, pain or discomfort in the lower part of the body less than workers from partly active and sedentary groups. It is also obvious, that workers from partly active group experience ache, pain or discomfort more frequently than those from active group.

Chart 2 - Uncomfortable feeling of ache, pain and discomfort in shoulders



As shown on the chart above, the uncomfortable feeling of ache, pain and discomfort is increasing from active lifestyle to sedentary.

Chart 3 - Ache, pain and discomfort in the neck interfering with the ability to work



It is obvious that ache, pain or discomfort in the neck affects the ability to work in different groups of workers doing different jobs and especially workers doing sedentary job, as compared with workers doing active or partly active job.

4 Healthy workplace and Computer Ergonomics

4.1 Why develop a healthy workplace?

As describes in [Joan, 2010], to answer the question “why develop a healthy workplace?”, perhaps another and no less important question should be answered first: why bother with healthy workplaces at all? While it would be logical, if it is self-interest for workers to want to have a healthy workplace, why should employers care?

We can answers to that in several ways. First of all, creating a healthy workplace that does no harm to the mental or physical health, safety or well-being of workers is a moral imperative of our days. In recent years, more attention has been paid to business ethics and the norms deriving therefrom. The second reason that creating healthy workplaces is important is the business argument. It looks at the hard, cold facts of economics and money. Companies do business to make money, and to make money healthy workplaces should be created. These workplaces require workers in order to achieve their goals, and there is a strong business case to be made for ensuring that workers are mentally and physically healthy through health protection and promotion [Joan, 2010].

4.2 What is Ergonomics?

In our everyday life we very often use the term “ergonomics”. The present section describes the ergonomic conditions in the workplace. What is ergonomics and why do we need to have ergonomic conditions in the workplace? Here we will find the answers to these questions. Ergonomics is the science of studying people at work and then designing tasks, jobs, information, tools, equipment, facilities and the working environment so people can be safe and healthy, effective, productive and comfortable [Alexander, 1998]. It is the science of studying general activities of people, means of activity and human-environment interactions. Its main objective is to ensure the productivity, safety and comfortability of production processes, i.e., to create such conditions that will help to reduce fatigue and contribute to health.

The success of every organization depends on human factors. The productivity of organizations highly depends on job satisfaction of workers at workplace. Ergonomics tries to harmonize things that interact with people in terms of people's needs, abilities and limitations. Ergonomics is the scientific discipline concerned with the study of changes of functional state of human body, and the profession that applies theory, principles, data and methods, in order to optimize human well-being [Alexander, 1998].

Working in awkward positions or work overload may cause muscle fatigue/strain. Under such working conditions muscles, tendons, ligaments, nerves and blood vessels can be damaged. They generally affect the back, arms, shoulders and neck. Such injuries are called locomotor disorders. Moreover, sitting at a desk for extended periods of time increases the likelihood of occurrence of muscular injuries. This risk is increasing parallel to the time spent in front of the computer. Very often the reason for muscle strain or discomfort is the awkward position of worker in the workplace (chair placement in front of the desk, uncomfortable office furniture, etc.).

Computer operators may experience both muscle and visual discomfort and strain. Symptoms vary from eye strain, eye burning sensation and blurred images to headache. Depending on the placement of computer, new visual demands, such as illumination and brightness level, can be presented by computer operators.

The present research studies the physical and visual factors, affecting people working with the computer. It focuses on the placement of workstation, computer and its accessories (keyboard, monitor, mouse, etc.), office furniture and other objects, as well as on workplace illumination and design of computer-related tasks.

4.3 Worker fatigue

4.3.1 What is fatigue?

In this subchapter I'd like to give the outline of the main health problems that occur in human-computer interaction, as well as of consequences and progress thereof. The studies of this topic provide deeper understanding of these problems, as well as of their impact on human health. The most important thing to do at this stage is to reveal the critical problems that we'll need for further development of our system prototype, as through that prototype we should monitor workers at work and offer them right solutions from a medical point of view.

Fatigue can be defined as an increasing decline in alertness and ability to work, thus causing sleep. Fatigue is a daily phenomenon and in an ideal world it would not have posed a serious risk to human health and safety. Nonetheless, the society we live in is a living organism, which is in motion 24/7, without week-ends, and, correspondingly, most people are forced to work "non-standard" hours. Hence, this chaos leads to severe fatigue. Shift work, long hours, business trips among others can be a serious cause of fatigue. Other causes of fatigue are medical disorders, such as sleep disorder, drugs, etc.

People are different by their nature and physical and physiological characteristics. For example, the same action done by different people may cause different degrees of fatigue. As far as our research mainly targets office workers doing sedentary jobs, we'll focus on office workers' health problems, as well as on negative impacts suffered by them as a result of fatigue.

Nowadays we spend extended periods of time in front of the computer. Such lifestyle has rather an aggressive and irritative effect on human brain and organism, in general. Let's consider several aspects of computer exposure.

Firstly, it is the unimaginable and large amount of information that our brain has to absorb every second. Humans have never been exposed to such a large amount of information before. In addition, we need to instantly analyse, make decisions and take other necessary actions with regard to the information we receive every second. To do this, our brain loses a lot of energy. That is why, after spending many long and tense hours in front of the computer, whether for learning, working or for other purposes, many people feel tired and exhausted. Secondly, it is the same body position that not only affects our posture, but also our organism. Human spine has several curvatures that normally ensure the good physiological state and wellness of human body. The curvatures of chest and spine are of greater importance [Rudakewych, 2001] and especially these curvatures are affected as a result of spending extended periods of time in front of the computer. Another important problem is the impact of computer on human eyes and sight. Interaction with the computer, whether for learning, working or for other purposes, makes us blink eyes six times less [Bacher, 2004] than necessary. As a consequence, the cornea does not get enough moisture, thus resulting in sight degradation.

As far as today we cannot imagine our everyday life without information technologies, we can say for sure that it exerts positive or negative effect on everybody, whether a child or adult. There will come a time when we'll live in an age richer in information technologies. In the meantime, however, we will have a society with different health problems entailed by negative impact of such technologies.

5 Workers monitoring systems

There are many opinions regarding monitoring of workers' health status at work. However, almost all authors of these opinions have come to the same conclusion that the mentioned domain is rather poorly developed and that it is necessary to control and protect workers' health in the workplace to the greatest degree possible.

In this section I'll present several monitoring systems that already exist and are in use, and through comparison thereof I'll try to clearly showcase the importance and seriousness of the work done. Having studied different research materials and works for already three years in the scope of this research, with difficulty I can bring some examples related to the topic in question, due to the modest quantity of such research works.

Kortuem [Gerd, 2007] defines that ubiquitous tracking and monitoring technologies are now routinely used in industrial environments, but very rarely with the goal to improve occupational health and safety.

The authors of [Parry, 2013] indicate that interrupting sustained sedentary time with short rests result in improved glucose metabolism in overweight individuals and increased energy expenditure, suggesting that relatively small changes in activity level and pattern have the potential to modify adverse health risks.

The authors of [Eleni, 2009] add that first is the issue of privacy: patients, although they may appreciate the increased sense of safety that comes with the monitoring infrastructure, are leery to have their every move monitored.

The paper [Moeslund, 2006] provides an overview of researches done with a view to detecting human body movements and estimating human body postures through video monitoring.

Some other examples of image estimations are described in [Lee, 2006][Zhao, 2007][Loke, 2007][Bernhard, 2013], including the ones based on video monitoring from the same or multiple points, and monitoring using static images.

The paper [Lee, 2006] introduces an algorithm, which based on a static image helps to determine human body posture. Lee and Cohen [Lee, 2006] also states that, if the algorithm detects all body postures, whether sitting or standing, then such algorithm can be useful to detect different sitting postures.

The research described in [Zhao, 2007] aims to create a three-dimensional human body model based on an image sequence taken by one camera.

A most useful and effective method is described in [Loke, 2007], where human body images are received in a three-dimensional space using different video cameras. This monitoring method also detects movements of eyes, hands and fingers.

Schwartz and others [Bernhard, 2013] have introduced the “active chair” solution for workers doing sedentary work. They aimed to evaluate and develop a special device with integrated sensors, which could be used for every office chair.

A common office chair is usually a swivel chair with a set of wheels and four independent, especially designed force transducers for mobility and adjustable height. Force transducers signals are digitized and transmitted through a microcontroller using wireless protocol. Four force sensors are situated in each corner under the chair, thus enabling to compute the coordinates of the center of pressure (COP).

The COP coordinates vary according to the person's posture on the chair, which allows classifying the sitting posture and the time spent in the corresponding position. For further analysis the mean values of the positions are computed and normalized. Additionally, the normalized deviations of the positions from the mean values are computed and provided for further analysis.

Related to the monitoring subject is the driver fatigue detection. The research described in [Rogado, 2009] refers to early detection of the signs of fatigue and sleepiness while driving. It states that the analysis of certain biological and physiological variables may detect the signs of loss of alertness before the driver falls asleep. Thanks to such analysis the system can determine whether or not the driver is able to continue driving. Visual facts, such as, eyes movement, head movement, facial expression, or non-visual facts, such as HRV, ECG, pressure, exercised over the steering wheel, relative humidity, as well as temperature difference between the inside and outside of the vehicle, make possible to estimate in an indirect way the driver's fatigue level. Detection of the signs of fatigue based on a single physiological parameter is impossible, that is why, different devices and various sensors were used to detect the above-mentioned parameters, as well as an algorithm was developed to detect human heart rate variability (HRV).

It is true that the above prototype differs with its usability from the ones used for office workers. However, the mentioned prototype may serve as a basis for a research on workers monitoring.

Very few of the above mentioned solutions are integrated systems that estimate workers' health status and physiological parameters. It testifies to the conviction that workers are poorly protected from modern technologies in the workplace and everyday life.

6 Using Virtual Reality for workers monitoring

6.1 Hardware and Software tools used in the development of the proposed system

Based on the results of all studies we have done and experimental data processed so far, we developed a system for workers monitoring, which uses virtual reality and special devices. The system is described in the next chapter.

In this section we present the hardware and software tools used in the implementation of the system. The devices provide various data necessary to measure both ergonomic conditions and worker’s health status in the workplace. The user’s body is visualized by an avatar in the virtual environment of his/her workplace. For the design and implementation of the virtual environment we used the Unity 3D framework. For monitoring, we used the following tools: Microsoft Kinect V2 for measuring worker’s body posture (neck, shoulders and back); Tobii Eye Tracker for monitoring worker’s eye behavior, as the eyes are especially vulnerable to computer exposure. The necessary parameters for eye behavior monitoring are: eye blink rate (we all know that when tired we keep our eyes closed a bit longer when blinking), distance between the eyes and computer screen, viewing angle and worker’s head motion. The third tool that helped us to have a better and useful system was Microsoft Band. It enables to measure human heart rate at a particular moment of time, as well as physical activity on a daily basis, as physical activity is one of the first prerequisites to creation of healthy work environment.

Experimental results have shown that the system, developed in the scope of this research work, provides recommendations without prejudice to productivity. Moreover, prospective estimations show that it contributes to improvement of worker’s health. Worker’s health status is in direct proportion to the work done by him/her, i.e., the better is worker’s health status, the higher is his/her productivity.

7 Developed Employee Monitoring System

From previous chapters we already know that there are other tracking methods, such as through a standard camera or multiple cameras, in order to receive a more detailed graphical representation of human body. These methods, however, are not very accurate and cannot represent human body while sitting. Considering the aforementioned, we have used Microsoft Kinect in our system with a view to collecting information regarding the ergonomic conditions in the workplace and monitoring worker's posture. Microsoft Kinect provides more precise information regarding the worker's presence in the room, his/her movements and attention. The collected data enable to create the graphical representation of the worker. For any deviations from predefined norms, the system sends a warning to worker in a form of a pop-up window opening on the computer screen, or signal or animation. Also, additional warnings are provided, aimed at reminding the worker to maintain safe distance from the computer screen, or to do eye exercises in order to relieve eye strain, or to take a break. In this proposed system each type of notification warnings are already installed. All data is processed locally, so the privacy of the worker is respected.

7.1 System overview

As understood from different researches, virtual reality is a computer-simulated reality perceived by humans through sight and hearing, e.g., eyes and ears. Virtual reality is represented in real time. Our system is a completely virtual reality based system. Like applications, virtual worlds represent three-dimensional interactive environments with animated characters, called avatars. In this specific case, an avatar is attributed to the worker, through which the worker acts in the virtual reality. The virtual reality may contain different objects, which we can manipulate as we wish. In this case we have created a 3D room model similar to the office room. And when the worker works at his/her desk in the office, the same is done by his/her avatar in the virtual reality. Thus, we aim to create such an environment, which will help workers monitor their own behavior at work and follow predefined health rules and norms. Figure 7.1 showcases the virtual office room and avatar.

Figure 7.1 - Virtual office room and avatar

Our system consists of different types of sensors, designed to monitor workers at work. They are installed at a certain distance from worker and do not interfere with the latter's work (only Microsoft Band is worn around worker's wrist as a wristwatch).

Now, one by one about the data collected by each device, usage thereof in our system and all this represented in a given virtual environment.

7.2 Microsoft Kinect processing

Let's start with Microsoft Kinect. We are already familiar with this device from subchapter 6.2.2. Now about its usage in the system and on how it supports the system performance. In Chapter 4 we have revealed all important points that should be the focus of attention of workers at work. One of the most important points was worker's sitting posture at work (head not tilted back or too forward, or too right, or too left). Another important point was the spine position, which should not be curved (this does not refer to people suffering from scoliosis or with inborn spinal deformity). We all may be tired, or on the contrary, ready to work hard and be highly productive at different times throughout the day. Kinect starts monitoring workers, whether sitting or standing, since the beginning of the working day (let's assume it's 9 a.m).

Now a little about how Kinect identifies people, i.e., about its principle of operation. Prior to the application of the proposed action recognition approach, the depth maps captured by the Kinect sensor are processed by a skeleton-tracking algorithm. It is also used for detecting the performing subject and tracking a set of joints of human body. For determination of body position several actions are taken. First, the Depth Map is considered, followed by development of the skeleton. The first step to take is to send and receive infrared beam. Based on this principle the skeleton image is created, encompassing the head and other parts of human body.

Thanks to Kinect V2, values for 25 joints are received every second. Figure 7.2 showcases the varying distance between the pairs of 25 joints, thus making interaction with virtual reality clearer to the user.

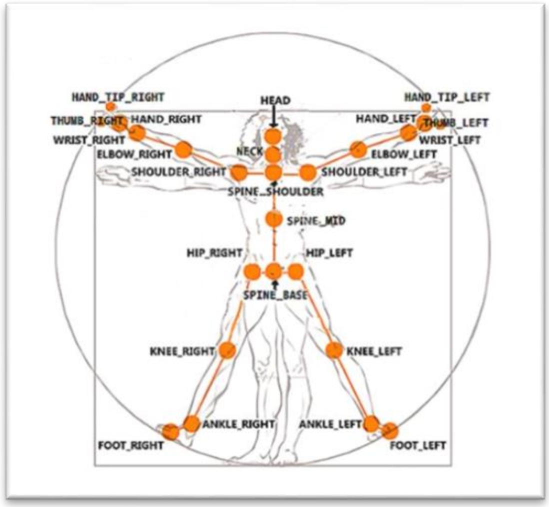


Figure 7.2 - 25 skeleton joints [Microsoft Corp.]

With the help of Vector3 of pairs or triplets we can derive the deviation value thereof.

Kinect v2 provides Vector3 (x, y, z) coordinates of 25 joints showcased in Figure 7.2 in a three-dimensional space. In order to measure the JointType.Neck, we consider X and Z coordinates of Vector3. These coordinates are then filtered and brought to a common unit measure. As worker's neck goes forward, coordinates grow positive (1,2,3,...16,17,…,n) and as the neck goes back, coordinates become negative (-1,-2,-3,…,-16,-17,…,-n). In this specific case (-15; 15) are assumed as normal values. In the event that these values are exceeded, the worker will be notified thereof.

The same principle is applied for determination of JointType.SpineBase value. Here X coordinate of Vector3 should be considered. In this specific case (-15; 15) value will be considered as an acceptable norm, as, in fact, the user cannot tilt his/her spine the way he/she does with his/her neck. Appendix 3 showcases some parts of the programming code.

In order to have a better understanding of the situation, let’s have a look at the skeleton, which showcases the body parts discussed hereinabove (neck and spine). The coordinates of joints in blue allow determining neck position and those of joints in red allow determining spine position.

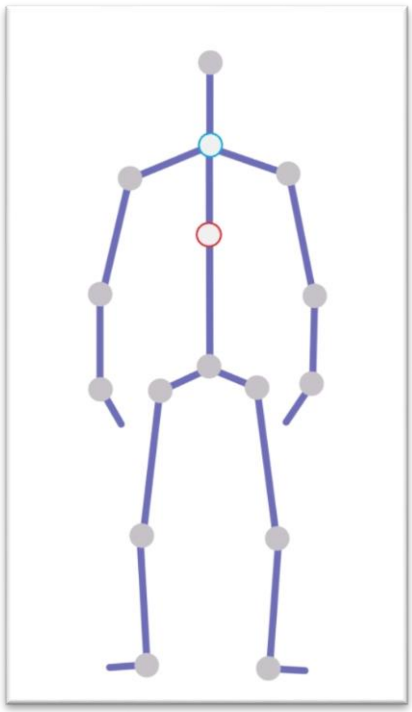


Figure 7.3 - Neck and spinal joints

All data on every single movement is recorded and stored in a corresponding file or database. Regardless of worker’s sitting position, whether right or wrong, he/she can continue working without paying attention to the system. Thus, the system does not interfere with his/her work or personal life. Moreover, this system provides maximum level of confidentiality and does not provide data without user’s approval. Users of our system do not explicitly interact with the system, it is designed to passively compute and present data.

It is assumed that worker’s working day begins as soon as he/she turns on his/her computer, and beginning from that moment our system starts monitoring the worker. Any moment workers can allow deviations from predefined posture norms, but such deviations are not dangerous and cannot be fatal. But if it is done regularly, the system sends a warning and recommends taking corresponding actions. The recommendations may be as follows:

- You hold your neck in an awkward position.
- You hold your spine in an awkward position.

There may be cases when the worker ignores these warnings and continues to work holding the same awkward position. Regardless of the ignored status, the system continues recording the data. In this case as well the computing is made based on algorithm and, if the total number of deviations exceeds the acceptable norm within the last 30 minutes, another type of warning is sent to the user. This type of warning already contains a variable value showing the percentage rate of awkward and normal positions. This refers to human-computer interactions only in real time. Regardless of anything, the system stores all data of monitoring conducted throughout the day in a corresponding .CSV file for further statistical analysis.

The system also envisages graphical representation of monitoring data, which, however, will be presented later, as long as other parameters thereof are not familiar to the audience.

7.3 Tobii Eye Tracker processing

Eye gaze is a potentially powerful tool, if used accurately. Eye movements are also a very important research topic that enables to measure the productivity and potential of user interface as an input device [Duchowski, 2002]. Traditional methods of gaze tracking have used specialized hardware, typically consisting of multiple cameras and/or infrared sensors [Zhu, 2007] [Ning, 2007]. In our proposed system we use Tobii Eye tracker, already discussed in this chapter.

The flexibility of tracking human face in various positions is crucial for our system, as workers do not always look directly at the monitor, especially when busy doing other tasks at the desk. The front facing, built-in device in the user's personal computer extracts eye related attributes of the user, including gaze direction (eye angle from monitor), distance from the screen, eye blink, as well as duration and frequency of blinking.

In our application, we wish to extract the eye behavior of the user, as well as head position and orientation. This is slightly rough approximation, however, using the data extracted from eye tracker we can determine user's coordinates and identify head direction and orientation through analysis. Based on head position and orientation we can find a vector representing the head direction as a proxy for the gaze direction. We then project the estimated gaze vector onto the computer monitor and calculate gaze angle. According to ergonomic rules, user's gaze angle (α) in human-computer interaction should be 15-17 degrees (Figure 7.4).

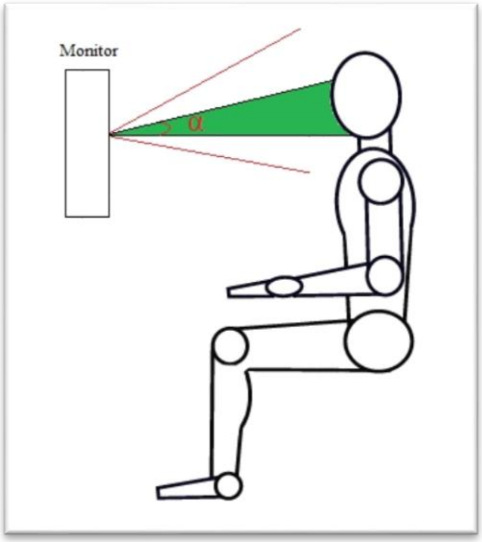


Figure 7.4 - α gaze angle

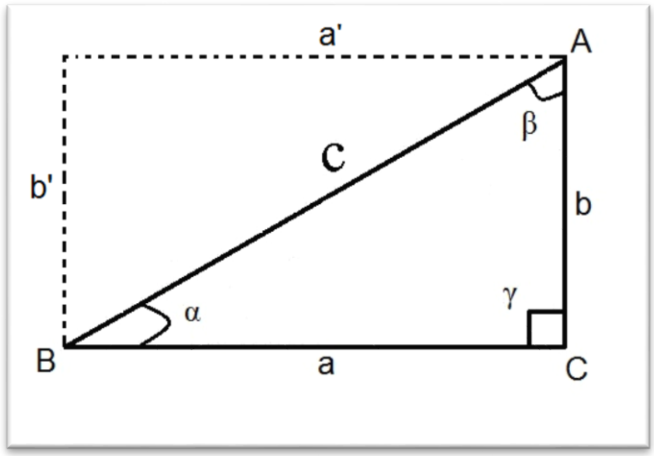


Figure 7.5 - Geometric gaze image

Now let's have a look at how α angle is determined. As already mentioned hereinabove, Tobii Eye Tracker is used to track eye and head movement directions. It is installed on the monitor, right in the center of horizontal axis, so to capture user's gaze, when the latter is looking at the monitor, and provide values (variables). In this specific case, as a necessary value we may need to have the hypotenuse (c) of the triangle showcased in Figure 7.5, which is the distance between user and monitor. Point A is the viewing source point. It's a combined value, as human eyes move parallel to each other and there is no need to determine the angle for each separately. Exceptions are squint-eyed people; in this case quite other logic should be applied to determine gaze angle. The next variable is b', which is the coordinate of the point the worker is looking at.

$$\sin \alpha = \frac{b\prime}{c} \Rightarrow \alpha = arcsin\frac{b\prime}{c}$$

Hence, having this angle we can track gaze angle every second. Should the standard gaze angle be violated, a corresponding warning is sent to worker. Through collection of the data recorded throughout the day or for the given period of time, it'll be possible to perform statistical analysis per worker and provide individual advice.

It is very important to maintain proper distance from the monitor, in order to avoid eye fatigue in the workplace [OSHA, 2012]. Using the data received as a result of face tracking, we can easily determine the distance between user and computer. A user's distance can suggest possible changes to a user's computer viewing habits when compared to ergonomic guidelines. Tobii Eye Tracker identifies user from a distance of 45-75cm. We should send three infrared beams to identify human eyes. If the distance is <45cm or >75cm, the system will be unable to identify human eyes and will send a corresponding warning to user with the following text: "Please keep proper distance from the computer". However, if the user is within the range of 45-75cm, it does not mean that he/she follows the ergonomic rules. According to these rules the proper distance should be 55-65cm. In this case the system double checks the location of worker and if the latter is within the range of 55-65cm, such distance is considered normal and the worker may continue working, but if the distance varies between 45-55cm or 65-75cm, the worker is warned about it. The warning text contains the following information: "The permissible distance is exceeded, please maintain the correct distance". Distance variable helped us to determine gaze angle.

Eye fatigue is a term used to designate a state, which is commonly known as "eye strain", pain in the eyes, weakness or heaviness in the eyes due to hard work.

Common signs and symptoms of eye strain include:

- Pain in the eyes
- Dry eye
- General heightened fatigue
- Feeling of heaviness in the eyes

All these 4 factors can be identified through eye behavior tracking. Tobii Eye Tracker helps to record all data regarding the eyes, e.g., eye blink rate, i.e., how long user keeps his/her eyes closed or open when blinking. A question comes up: how can this tracking method be helpful to us in this specific case? If we pay attention to our eyes behavior during the day, we'll find out that when we are tired our eyes close spontaneously, against our wish; it's a sign of eye fatigue. Measuring the milliseconds between blinking frequency and duration and establishing a logical link with predefined norms, we can identify indicators of fatigue. Absence of blinking or a blink rate decrease may lead to the rupture of the tear film and cause discomfort, eye strain, burning sensation, excessive lacrimation, willingness to keep the eyes closed, pain, keratitis, visual alterations and decrease in vision capability.

The average eye blink rate in humans is 25 times ±5 per minute [Carney, 1982]. Involuntary blinking takes place spontaneously, and as for voluntary blinking, it depends on each person's habits. Blinking is divided into spontaneous, which takes place at constant intervals, and reflex, resultant from external factors in corneal stimulus [Lavezzo, 2007]. Based on study done involuntary blinking lasts from 290 to 750 milliseconds as an average, it is influenced by several conditions, among them the illumination, temperature, air draught speed, ocular pathologies, and attention levels [Dumery, 1997]. The research done in [Dumery, 1997] showed that one blink took 572 ± 25 ms and was accompanied by asymmetric motion with much faster closing action compared with opening action of the eye [Kyung-Ah, 2013].

Now about the solution proposed by us in this respect. Number of worker's eye blinks in 5 minutes is measured. If the average norm is 25±5 per minute, then the number of blinks in 5 minutes will make 125±25. Should this threshold be exceeded by ≤100 and ≥150 respectively, worker will be warned about it, for example, "You've violated the blinking norm", for further consideration. This, however, does not mean that if worker fails to blink, he/she is tired. The system just keeps warning the worker to blink eyes, in order to avoid eye pain or discomfort.

Another question comes up: How to identify fatigue, having these data at our disposal? The answer to this question is rather simple. As far as we have already succeeded in obtaining all data regarding eye behavior, we can measure blink duration (means closing-phase, closed-phase, early opening-phase, late opening-phase collectively) and based on the predefined norm, we can identify whether or not there are deviations from the norm. If, however, there are deviations, the mean value per hour should be calculated and worker should be notified of the result.

7.4 Microsoft Band processing

The last device used in our system is Microsoft Band – the latest thing in personal comfort-saving devices. More details of this and other devices used in our system have already been presented hereinabove. Now about the features of Microsoft Band that we need to know, in order to collect and process the data we are interested in. The role of this device is vital to our system performance, as with Microsoft Band we can collect data on physical activity of humans, e.g., number of steps, travelled distance, etc. Thanks to this device the system not only collects data, but also reminds worker from time to time to do physical activity, in this specific case, to walk. Sleep time should also be considered, as the role of sleep is also vital to worker's productivity at work. Also, two other very important parameters that can be received from Microsoft Band are heart rate and skin temperature.

How the data received from Microsoft Band is processed by the system? Every 60 minutes the system measures the data on physical activity of worker for the last 1 hour received from Microsoft Band. Generally, we compute the number of steps, as not all offices provide the possibility of walking long distances. We could also develop such a system that would force the worker to follow the clearly predefined norms, but we refrained from doing it, as in a fast-paced working environment not all the norms can be respected by all. Unfortunately, this also refers to health norms. The number of steps, however, is not as important, as the fact of tearing the worker away from the computer and making him walk for a while. Thus, we can have our little contribution to human health at work and to help workers respect the ergonomic and health norms fully described in Chapter 4 of this thesis.

So, if the system can tear the worker away from the computer even for a second and make him/her walk, it already means a success. The worker will be notified of any necessary action to be taken via notifications popping up on the computer screen. Regardless of the calculations done by the system, the distance (km) travelled by the worker will also be displayed on the screen.

Just for worker's information, data on worker's sleep duration for the previous night will be displayed on the screen as well.

Two more very important parameters to be dealt with in the scope of this research are heart rate and skin temperature.

It is true that this research refers to information technologies, and notably, virtual reality systems, but it also requires having certain knowledge in medicine. Different studies reveal that heart rate among people vary between 60-80 beats per minute. In this specific case, the system measures heart rate every 30 seconds. If the abovementioned threshold is exceeded, the system sends a warning to the worker and gives corresponding recommendations, such as, "Go outside and breathe some fresh air." But if the deviations from the aforementioned norm are greater, the following recommendation is given: "Consult a doctor". The next parameter directly relating to human health is skin temperature. In normal conditions human skin temperature during the day varies between 36-37°C. Skin temperature does not depend on environmental factors thanks to internal heat generation center that ensures the balance between heat generation and heat transfer. If in unit time skin temperature remains constant high, it means that something is wrong and urgent actions should be taken. Data on skin temperature, exceeding the predefined norm, are available on the computer screen every second via specially designed software. Based on the result, the worker will be recommended by the system to consult a doctor.

In any case, one should always remember that early detection of diseases is the earnest of full recovery. Our system will help to deal with this issue.

7.5 Graphical representation

Throughout the day it is necessary to record and maintain all data on worker’s physiological state for both the workers and for those who’ll need them later for statistical analysis. The system allows creating the graphical representation of all data on worker’s physiological state throughout the working day, e.g., body position, eye behaviour, heart rate, physical activity, etc.

It has been mentioned so many times already in the scope of this research that the system is designed for office workers to monitor their behavior at work. They usually work 8 hours daily and during this period they receive a large amount of information. And as the technologies used by them are capable of transmitting data instantly, it means they may receive thousands of lines of data every second. Conditioned by this, we have grouped all values for every 5 minutes. As a result, if we exclude 1 hour break, we’ll get mean values equivalent to 96 (96x5min=8 hours) and will be able to measure worker’s state throughout the day. The possibility of further data analysis will enable us to determine at what time of the day the worker is overtired and based on that give individual advice.

7.6 Data transferring

The system sends the collected data LIVE, i.e., in real time. But it is not the case with Microsoft Band, which updates data every 30 seconds following data collection. However, we won't be mistaken, if we say that Microsoft Band as well is functioning LIVE, as we do not need to have the data collected by Microsoft Band every second.

In the beginning we store all data in the database, but after receiving first range of data from three devices we saw that it is not effective as millions of data transferring every second and computer capacity goes down. So the structure was changed, and all data the system store in CSV (comma-separated values) files. Such file formats are used to store tabular data, such as a spreadsheet or database. In the experimental part the tabular data will help us analysis the data, and it is easy to imported and exported from programs that store data in tables, such as Microsoft Excel.

The USB standard supporting information exchange between computer and output devices has been widely and successfully applied in computer technologies for already 10 years. Initially, USB 1.0 was widely used, later it was upgraded to USB 3.0. In the scope of this research the latter version is used. These versions of USB standard mainly differ from each other with their speed. USB 3.0 theoretically supports data transfer speed of 5Gbit/sec. In fact, we need such a high speed to receive a large amount of information every second from different devices and to process them accurately in real time. Microsoft Kinect and Tobii Eye Tracker use USB 3.0 for data exchange, and Microsoft Band is connected to the data acquisition module via Bluetooth 4.0 Low Energy, which consumes less energy as compared with Bluetooth devices of previous generations. Like USB 3.0, Bluetooth 4.0 Low Energy is distinguished with high speed.

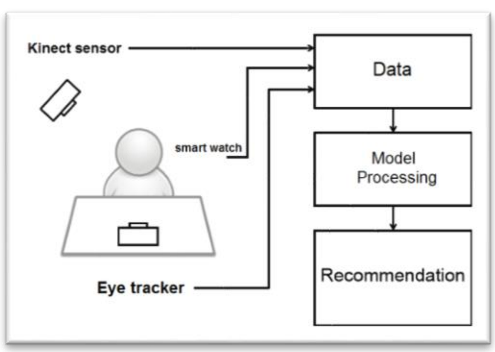


Figure 7.6 - System overview

Figure 7.8 shows the workflow logic overview. The data received from different devices are sent to the model processing module. The latter is responsible for making all logical calculations. It compares the data received from different devices with predefined values entered in the system as normal values. These values are the norms that should be respected in the workplace (sitting posture, distance from the computer, etc.).

8 Experiments and evaluation

This sub-chapter is dedicated to the pilot prototype testing in an organization, where standard hours of work for employees are 8 hours. The experiment was conducted in November 2015. Let's see how it works.

8.1 Technical equipment and design of experiments

The sample group of the experiment consisted of 3 workers (2 females and a male) with an average age of 27, height – 168-175 and weight – 57-75kg. All participants were informed in advance about all details of the experiment, and, of course, they signed a consent form. After having obtained their consent, the whole process was explained to them and they were asked to use the system during normal office hours. As far as not all organizations and their management would allow embedding any software or hardware in their systems, we had to use our own laptop to ensure system performance. With the experiment we had set ourselves a goal to evaluate (i) worker' body posture while doing a sedentary job, as well as (ii) more critical behaviors and when exactly they reach the critical point during office hours.

According to our plan, for the experiment a full working day (09:00–18:00) was provided to each worker, lunch time (13:00–14:00) excepted.

Received data were computed within subsequent time-windows of five minutes. As a result, for standard hours of work, i.e., 8 hours, we received 96 different samples of sedentary behavior of one worker. According to the predefined plan, our experiment consisted of 2 parts: the first part was fully dedicated to the familiarization of workers with the system (1 full day) and the second was fully dedicated to the process of monitoring of workers during office hours.

In order to evaluate our system efficiency, enormous amounts of data were collected. The experiment started in mid-November of 2015, and data collection ended at the end of the same month. It took us much more time to process the collected data and clear useless data. As a result, over 2500 lines of value and date-time pairs were processed.

8.2 Results

Here are presented system experiments and discussion for three employees (User A, User B and User C). Because of time limit and also resources we run the experiments for "neck monitoring" and "eye distance" functionality. And here we will represent some results in graphical mode. In charts you can see user A, user B and user C, with Blue, Red and Green colored accordingly.

A. Neck monitoring

Our developed system is capable of transmitting data instantly, meaning that it may receive thousands of lines of data every second. Conditioned by this, we have grouped all values for every 5 minutes. Especially, the system give as an average value each 5 minutes. As a result, if we exclude 1 hour break, we'll get mean values equivalent to 96 (96x5min=8 hours) and will be able to measure worker's neck state throughout the day. Chart 4 and Chart 5 shows neck monitoring data from three employees. As we know from Chapter 7 the conventional normal coordinates for neck we consider is (-15; 15). See Figure 8.1 for each back and forward posture.
So, if we compare the data from our test users we will see that each user passed the acceptance range of coordinates many times. We can see that with minus value in the graphic are few, and it is normal, because in position of bending back the head worker can't work normally. If we compare all three users we'll see that almost all have the same behavior.

Based on our test results if we compare three users data, we will see that User B for each five minutes average value have more wrong positioning than User A and to User C. But even in that case there are no very precise differences between them. User B has 15 before lunch and 20 after lunch time, User A and User C has 16(12 after lunch) and 15(19 after lunch). Further experiments will allow us more clearly imagine critical hours during full working time.

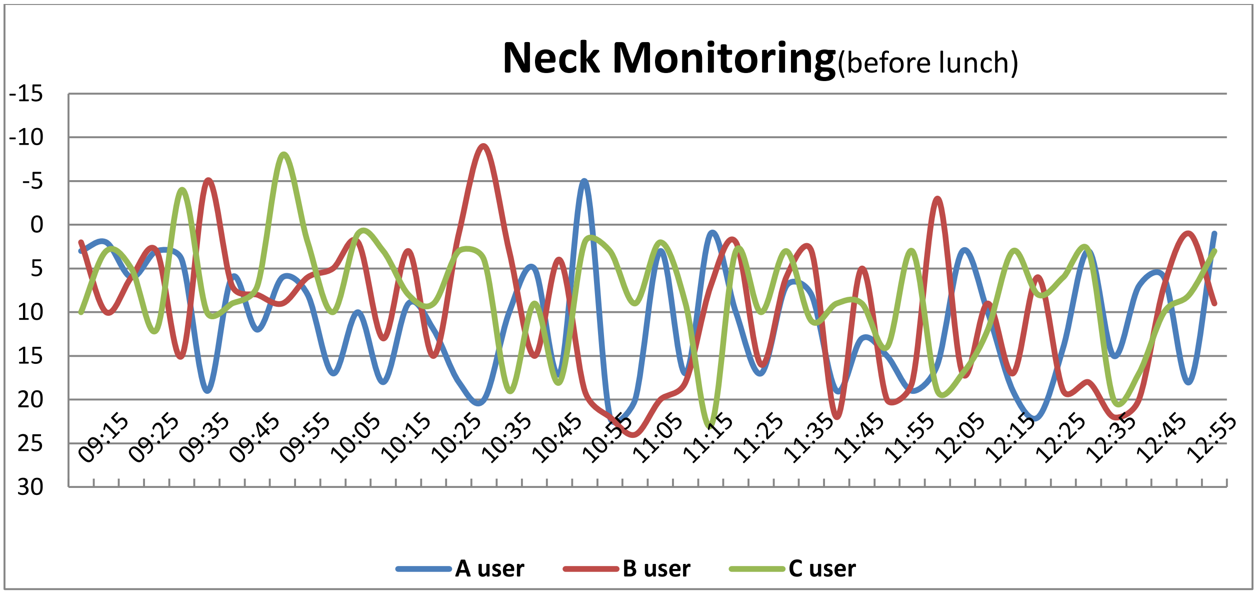


Chart 4 - Neck monitoring before lunchtime (User A, B and C)

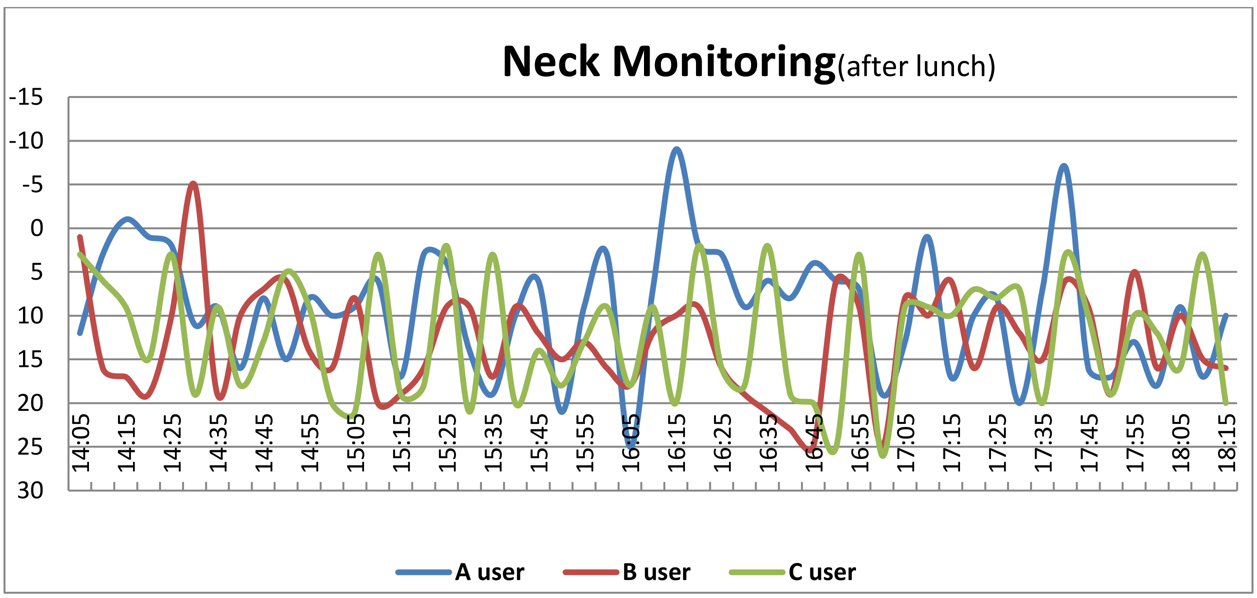


Chart 5 - Neck monitoring after lunchtime (User A, B and C)

B. Screen Distance Analysis

The graphic of the screen viewing distance for our three test users are shown in Chart 6 and Chart 7. Here also we divide all data charts into two parts, before lunchtime and after. The difference in average viewing distance between the users can be explained by User A's and User C's, as only they has 0 value in some place. It means that they go out from front of monitor (and also eye tracker device), and they value was 0. We account the distance when a user's face was in view, and he/she is looking directly at the screen, but when the worker is on the front of office table but not looking thought monitor the eye tracker can't track his/her eyes gaze, so the distribution of viewing distances could be a little bit skewed. As you can see in Chart 6 and Chart 7, zero value was registered for user A and user C. As in this case the test refers to the distance of the employee from the monitor, zero value can be registered in two cases: the employee has either been so close to the monitor that he touched it or the system has not registered employee's look (if the employee has not been in front of the monitor) and has printed the zero value. Taking into consideration also that cases we choose the way to combine the values every 5 minutes.

A user's distance can suggest possible changes to a user's computer viewing habits when compared to ergonomic guidelines. Our system identifies user from a distance of 45-75cm. However, if the user is within the range of 45-75cm, it does not mean that he/she follows the ergonomic rules. According to these rules the proper distance should be 55-65cm. In this case the system double checks the location of worker and if the latter is within the range of 55-65cm, such distance is considered normal and the worker may continue working, but if the distance varies between 45-55cm or 65-75cm, the worker is warned about it.

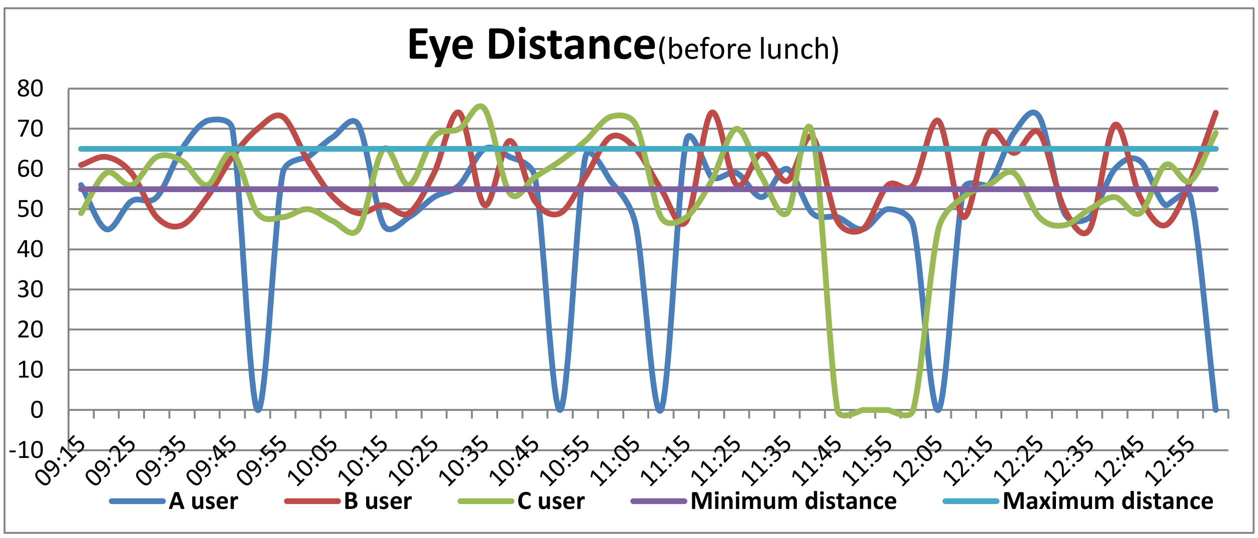


Chart 6 - Eye Distance for three users (User A, B and C)

In Chart 6 and Chart 7 we marked with Purple and Light Blue the normal minimum and maximum range as a normal value. Here is very clean underlined that all three users has the problem with keeping distance when they are in front of the monitor. So continuously using our system will train them keep normal distance without supporting devices.

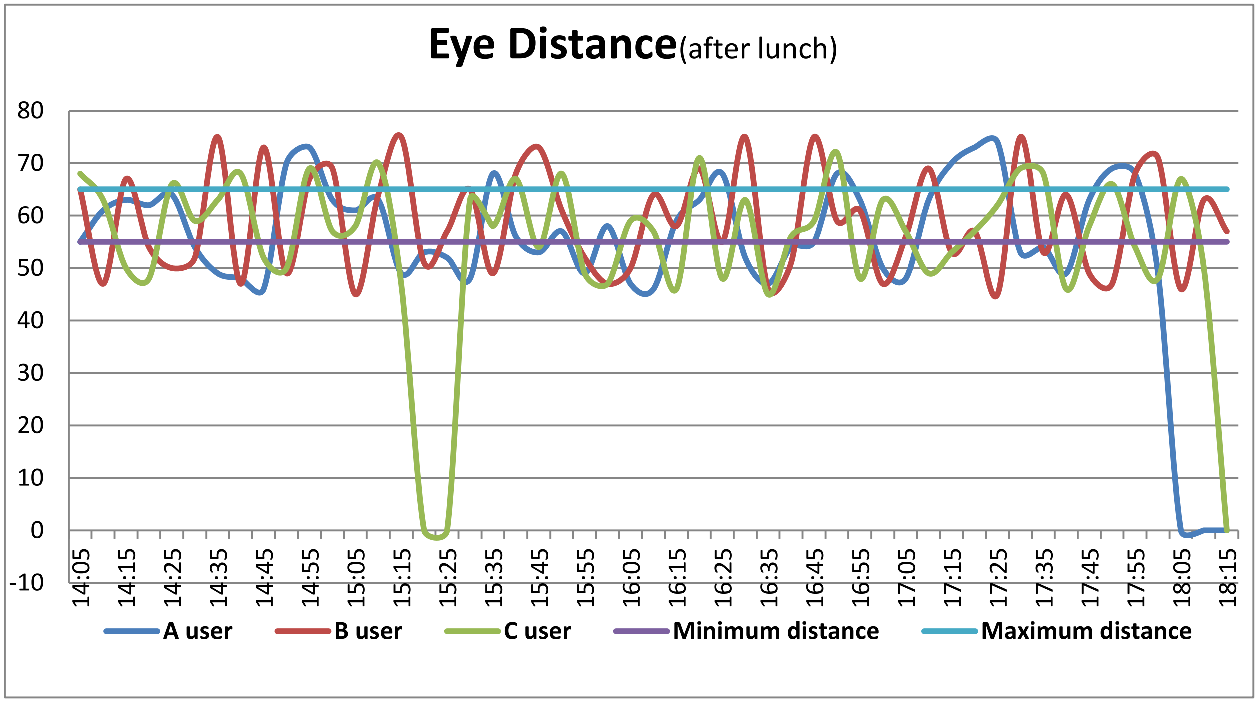


Chart 7 - Eye Distance for three users (User A, B and C)

As a conclusion I can say that we need to test it with up to 10 users and 6-12 months continuously. To record the entry data in the first days and compare them after 12 months. In that case I am almost sure that for some users we will have positive progress. And if we append also some workers who had already work-related musculoskeletal disorders (neck pain, eye strain, etc) we will achieve great results.

9 CONCLUSIONS and FUTURE WORK

9.1 The original contributions of this thesis

The technological development, and particularly the development of computer technologies provided humanity a great range of tools for facilitation and speeding up the accomplishment of daily work tasks and duties. With development of computer technologies we got unique possibilities and advantages in our professional development processes, but unfortunately, with all the range of possibilities and advantages it provided also a variety of disadvantages – serious health associated problems.

A study of the discomfort for office workers was carried out, to prove the existence of a real problem for sedentary workstyles employees. The study was carried of three groups of workstyles - active, partly active and sedentary. As shown on the results, the uncomfortable feeling of ache, pain and discomfort is increasing from active lifestyle to sedentary.

As seen from the previous part of this research, working at the office with advanced computer technological tools, which is doubtlessly the inseparable part of modern working process, affects office workers health extremely negatively, causing a variety of spine, neck and other problems the reasons of which are multidimensional and are associated with complex factors with individual, physical and psychosocial components. In this research, with the help of virtual reality tools, which are largely used nowadays in almost all extra important fields of educational and scientific processes and activities, we have tried to indicate all the negative aspects of sedentary work and to focus our attention on latest developments and studies of this problem. And also, what is more important, with the help of virtual reality, which, as stated above is the human presence in a computer-generated environment in a real life.

As discussed in previous research publications, nowadays almost all office workers spend the most of their working day doing sedentary work – telephone operators, remote sales agents, customer care agents, etc. With advancement of computer technologies time spent by employees in a sitting position continually grows. Thanks to the state-of-the–art technologies it has now become possible to do any type of working activities in a virtual environment thus “impeding” human mobility.

As stated in a Department of Labor Bureau of Labor Statistics, about 1 million of people annually devote time to treatment of musculoskeletal disorders caused by sitting at work.
Various other surveys of ergonomic intervention have been conducted which show that by preventing or improving human unconscious approach to his/her sitting position will help to create a healthier ergonomic environment, as well as will increase work efficiency and, of course decrease time and means for employees spent on treatment of disorders caused by above mentioned factors.

The International Labor Organization (ILO) even proposed to move on four-day workweek in order to improve employees health and somehow decrease the stress, sedentary lifestyle and overworking that inevitably lead to disorders. First tangible symptoms are weakness of fingers, elbows, knees and toes, back pain, uncomfortable postures etc. In our research we discussed methods for preventing such health-harming developments – to do exercises, do not sit in same position for a long period, often walk away from the computer and do eye exercises in order to reduce tension in eye muscles etc. And this should become integral part of a work process.

The present research aims at revealing the problem, offering a solution, conducting testing and proving system efficiency based on testing results.

To summarize, the original contributions of this thesis are:

1. A study of the discomfort for office workers. The study aims at revealing the problem of office workers who spend most working time in office and don't have enough mobility during work. The target population was employees in Armenia and was carried out using the method of prospective cohort study. Statistical considerations, study variables and results are presented in chapter 3 of this thesis. The study and its results were accepted to be publish in [Paruyr, 2016]. Preliminary results of this research were published in [Paruyr et al, 2015].

2. Using Microsoft Kinect V2, Tobii Eye Tracker and Microsoft Band devices for monitoring employee's posture, head position, eyes behavior, as established in the study from chapter 3. The monitored parameters are: head position (especially neck), spine position, distance from monitor, eye blinking parameter, as well as Heart rate variability

and physical activity during day. Details about processing of data from these devices are presented in chapter 7 and will be published in [Paruyr bUPB, 2016]. Preliminary results of this research were published in [Paruyr, 2014] and [Paruyr, 2015]

3. Using Virtual Reality tools for helping office employees to improve their health, based on the data acquired from the above mentioned devices. These contributions are highlighted in chapter 7 and will be published in [Paruyr bUPB, 2016].

4. Development of a system for employees monitoring, using parameters established in chapter 3, and helping them to improve their health, through presentation of the monitored data analysis using virtual reality, voice and text.

5. The experiments and tests of the system prototype, made in an organization with 3 participants. These and their results are described in chapter 8. They will appear in [Paruyr bUPB, 2016].

9.2 Future work

The main issue considered in the present thesis relates to all activity domains, however, it got a solution thanks to IT technologies and advanced solutions that develop and upgrade every second. Hence, parallel to making a step forward, we should focus on development trends and upgrade our system and devices used therein. The main goal we'd set to ourselves in the scope of this research was to monitor human behavior during office hours. Hence, as a step forward, we may consider new parameters for further monitoring, such as physiological and ergonomic parameters.

As a new psychological parameter we may consider the factor of human fatigue revealed through EEG study, as well as changes in the electrical resistance of the skin caused by emotional stress through new sensors. As for new ergonomic parameters, desk placement, chair height, room illumination, air humidity and others can be considered.

Considering the aforementioned development trends, our system should be continually upgraded, in order to keep abreast with those trends, but before adding any new features to the system, we should first of all test it for a long period of time. It means that we should monitor workers' behavior for months long, in order to find out if positive changes are observed in their behavior during office hours or see if workers have given up bad habits and adopted good ones.

Author's publications in connection with this thesis

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