An IoT system for healthcare in the smart city

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Abstract

Urban lifestyle, stressful work, a large number of daily obligations significantly affect the occurrence of stress. If stress reduction is not addressed, adverse effects on human health may occur. This paper proposes a model of smart healthcare service based on the Internet of Things. The main goal is to develop an IoT system that will enable real time monitoring of citizens' stress in a smart city, during their everyday lives. Users of this system can monitor stress level and receive notifications and recommendation how to low down stress via their mobile phones. Depending of the detected stress level, users of the proposed system can be provided with relaxation materials in the form of short relaxing video or audio contents. After the stress level is normalized, the user receives a notification and can continue with normal activities. Unlike well-known solutions for stress management, this solution is wearable and can provide biofeedback to both, users and therapist or healthcare workers. The proposed IoT system is developed using intelligent devices such as mobile phones, Raspberry Pi microcomputer, Arduino microcontroller, and sensors for monitoring heart rate and skin conductivity. As a support for monitoring stress level a responsive web application is developed. All the measured data are stored in the cloud. Based on obtained and analyzed data, users can manage the stress level and prevent disease. The obtained results could serve as a good basis for adoption and implementation of stress management as a smart city service.

Keywords: smart healthcare, wearables, stress management, heart rate monitoring, smart city.

1. Introduction

The smart city presents applied innovative information and communication technologies (hereinafter: ICT) in the city infrastructure and services in the domain of administration, traffic, education, healthcare, public safety, real estate, energetic and urban environment [1][2]. The urban way of life in big cities significantly affects the health of citizens. Modern cities, whose infrastructure is based on innovative ICT, should pay special attention to the delivery of healthcare services to protect their citizens' health.

Smart cities enable digital services to improve life quality and environmental protection [2][3][4]. The constant influx of the population in the big cities creates problems such as environmental pollution, health problems, difficult traffic flows, and similarly [3]. Lifestyle in a smart city encompasses imbuing of collective awareness of the citizens on accepting and utilizing Internet of Things (hereinafter: IoT) and mobile technologies into different e-services (e-health care, e-administration, e-participation, e-education, etc.) [3]. These technologies enable deploying Wireless Sensors Networks and different types of intelligent devices (sensors, actuators, microcomputers, microcontrollers, modules, etc.) in the smart cities for collecting data and information from the environment such as air quality, allergens, level of noise, and vibrations in traffic [2][5][6].

Intelligent devices can improve life quality especially in the domain of healthcare where citizen physical condition can be monitored in real-time by different wearable devices [7]. Wearable devices in the combination with the smart phones and mHealth application can enable tracking vital parameters such as temperature, heart rate, skin conductivity, SPO2, breathing rate [8].

Smart healthcare promotes interaction between all parties in the healthcare field: citizens, doctors and patients, hospitals, and research institutions [2]. The application of smart healthcare directly effects on [2]:

1. **Assisting diagnosis and treatment**. Technologies such as artificial intelligence, surgical robots, and mixed reality, enable more accurate descriptions of patients' conditions and disease status and define a personalized treatment plan.
2. **Health management.** Wearable smart devices enable real-time self-monitoring of patients/citizens with feedback of health data via mobile healthcare applications or healthcare information platforms. Smart devices such as different wearable sensors, microcomputers, microcontrollers, smart phones, smart watches, and smart bracelets monitor various physiological indicators of patients. Mobile healthcare allows telemedicine services and engaging interaction between doctors, patients, researchers, therapists or healthcare workers.
3. **Disease prevention and risk monitoring.** It enables patients and doctors to monitor disease risk, and conduct targeted prevention based on data collected via wearable devices and smart healthcare applications. These data are stored usually in the cloud and analyzed by big data algorithms and delivered to end-user via short message service.
4. **Virtual assistants.** In smart healthcare, virtual assistants (Microsoft Cortana, Google Assistant, and Apple Siri) enable better communication between patients and doctors and medical institutions. Using speech recognition, big data analysis, and virtual assistants can respond according to users' preferences and help patients to seek the corresponding medical service more accurately.
5. **Smart hospitals.** Smart hospitals rely on the application of automated processes based on IoT to improve services for medical staff, patients, and administrators. The information platform integrates IoT systems implemented in the scope of the

smart hospitals, intelligent buildings, and personnel. These IoT systems can be used for the identification and monitoring of patients in hospitals, the daily management of medical staff, and the tracking work of medical equipment.

The focus of this research is development of model of a smart healthcare service based on the Internet of Things for the domain of disease prevention and risk monitoring. The main goal of the paper is to preview a developed IoT system for stress monitoring in everyday life in a smart city. The proposed system monitors and informs about the detected stress level and recommends relaxation content and provides advice from the healthcare workers via mobile phones.

2. Healthcare services in smart cities

The term smart city has been mentioned more and more frequently around the world in the last decade. That term refers to cities that implement the modern technologies based on Internet connectivity to obtain benefits in different areas of human life. The basis of smart city is a combination of a technology that includes smart phones and sensors connected by high-speed communication networks, specific applications that makes an information from a raw data and usage of information by cities, companies, and the public [9].

Numerous definitions define or describe a smart city as a place with technologies that can make daily commutes faster and less frustrating, a place that delivers a cleaner and more sustainable environment, upgraded water supply. Besides, it delivers more interactive and responsive city administration, safer public spaces and meeting the needs of an aging population, and create a better life for all [10][11]. Although there are currently a number of definitions of a smart city, the most are with limited consideration of healthcare or public health as the basic principle. In terms of healthcare, a smart city is a community where the residents can engage with smart services that are specifically designed to improve their health [12].

Smart city concept and technology innovations have a great potential in improving healthcare services for metropolitan areas, including the interaction between patients and caregivers and better access to medical information and resources. The main goal of public health in the 21st century is to improve health and provide simpler and more efficient access to healthcare and health services. Accordingly, expected public health outcomes are longer life expectancy, reduced morbidity and injury rates, cost rationalization, and high availability of healthcare.

The introduction of modern technologies in the health sector opens new possibilities for creating the goal of public health [13]. Modern technologies that detect and measure certain physical quantities and communicate with the outside world are given the epithet "smart" and their use in healthcare has led to the development of the concept of Smart healthcare [14]. The smart healthcare concept is based on various technologies: mobile devices with mobile wireless communication, sensor technology, networking, big data analytics [15], artificial intelligence (hereinafter: AI), cloud computing, wearable computing and the

Internet of Things [16]. IoT is a key technology in smart cities and synced with AI and Machine Learning algorithms, provides effective diagnosis in the healthcare area.
Implementation of smart cities can have an impact on public health [17] and lower healthcare costs for smart city residents [18]. One of the primary goals of a smart city is to create an environment that provides a high quality of life to its residents [19]. Recently, more and more citizens are migrating to cities and the United Nations forecasts [20] that more than 60% of the population will live in cities by 2050. Life in cities affects the emotional state of citizens and their well-being. The faster pace of life, higher costs of living, pressure at work and deadlines, air pollution, etc. lead to anxiety, and negative emotions, and then to the occurrence of stress in citizens. Furthermore, anxiety and stress affect residents' life satisfaction and their overall emotional well-being.

In the area of stress control, there are numerous sensors that can identify the presence of stress or stressors by measuring various vital parameters on the user's body [21], as well as measuring environmental parameters that can affect the change in the values of vital parameters. Typical physical parameters that can indicate the presence of stress are heart rate, blood pressure, level of blood glucose, skin temperature, sweating [22]–[24]. Many studies deal with the identification of stressors using different sensors, and more often with a combination of different sensors (e.g., pulse sensors, skin conduction sensors (GSR), accelerometer, noise sensor, air humidity, temperature, etc.) [25]. These parameters can be easily measured via wearable devices that can be integrated seamlessly into people's daily lives anytime and anywhere [26]–[28].

In addition to measuring vital parameters, it is often of importance to measure and collect data from the environment, such as air pollution, allergen concentrations, temperature and humidity, noise and other parameters that affect human health [5][6][29][30][31][32]. Changes in the values of environmental parameters can greatly affect the health of citizens, both physical and mental health [33]. For example, the appearance of allergens in the air in combination with high-temperature causes increased sweating, runny nose, sneezing, and so on. This can lead to increased anxiety because for someone is difficult to perform daily activities and has a limited movement.

Services based on sensory measurement of environmental parameters are important in a smart living environment and are an important prerequisite for improving the quality of life. One example is an AI-enabled healthcare monitoring system, proposed for smart cities [34]. Vital parameters are collected from patients equipped with wearable devices. The data is continuously transmitted to the edge node that corresponds to the hospital and the proposed system is useful in pandemic situations like that of COVID-19 [34]. Citizen emotions relate with heart rate and galvanic skin response. The system for emotion analysis was designed, tested and implemented for citizens in different city areas. Feedback consisted of sending differently colored city areas to the user as well as city representatives or healthcare workers [35].

The application of the stress management system is also shown through everyday activities such as learning, i.e. taking exams [14] and visits to the dentist [36]. Both Systems consist of wearable devices that measure vital parameters and, depending on the context, provide feedback in the form of relaxing content or progressive muscle relaxation through a mobile healthcare application.

3. Model of smart healthcare services based on the Internet of Things

In this section, we present a model of smart healthcare services based on the Internet of Things (see Fig 1). The presented model is based on sensing vital parameters from citizens and parameters from an environment, generating a large amount of data that are collected and analyzed. The analyzed data provide information that serves as feedback to citizens or health professionals.

System architecture for smart city healthcare services consists of:

1. **Sensing layer**. The sensing layer implies collecting data from users/citizens via smart devices and sensors, and the environment through various crowdsensing systems (crowdsensing system for measuring noise pollution and vibration in traffic, crowdsensing system for monitoring air quality and allergens, smart system for monitoring microclimate conditions) [6].
2. **Processing layer**. The processing layer gathers and analyzes data, displays processing results on the developed web application for monitoring stress level and send information further to the consumer layer. Processing layer collects large amounts of data from the sensing layer, which requires a powerful architecture to adequately handle the data. For those purposes, processing layer has cloud services for data storage and big data technologies for processing and analysis of gathered data.
3. **User layer**. User/consumer layer where users are notified about their stress level and provided with relaxing content that is sent to their mobile devices. Besides that, healthcare workers are notified about their patient's condition, allowing them to further communicate with them about additional steps for maintaining their stress on a healthy level.

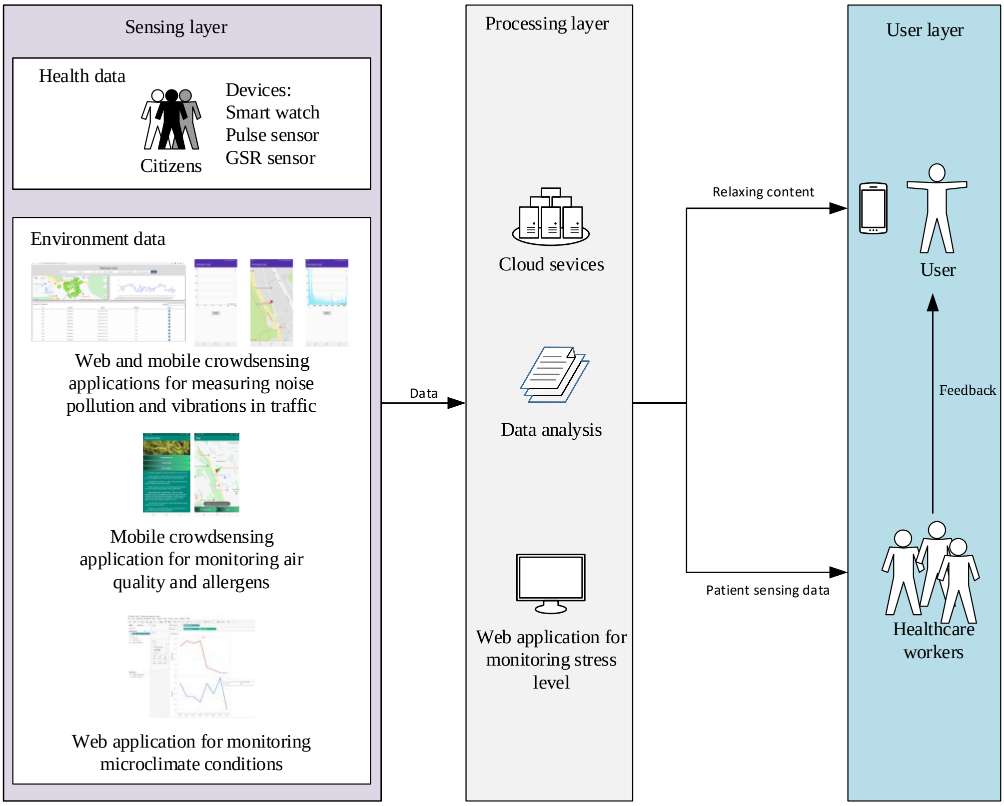

Fig. 1. Model of smart healthcare services based on the Internet of Things

4. IoT system for stress management

This section describes a developed IoT system that enables real-time monitoring of citizens' stress in a smart city, during their everyday activities. The developed IoT system for stress management is composed of hardware components (Fig. 2) and a web application. The proposed system can be carried by the user in its wearable form as well. The system was developed according to the proposed model of smart healthcare. This is just a part of proposed model which has yet to be integrated with crowdsensing system for monitoring air quality and allergies.

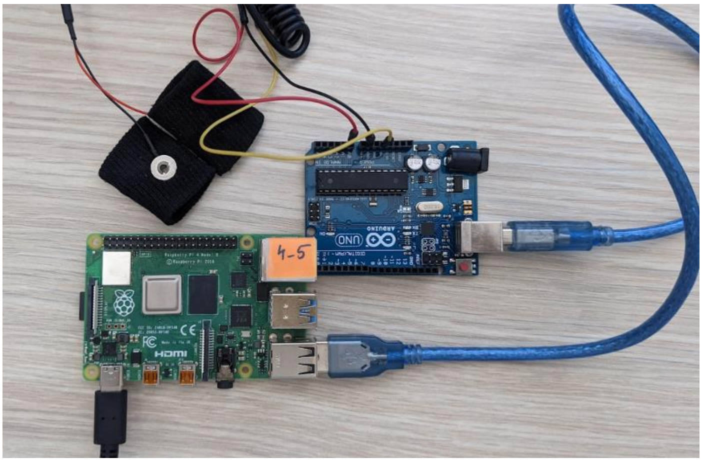

Fig 2. IoT system for stress management

The system consists of a Raspberry Pi microcomputer, Arduino Uno microprocessor, GSR sensor and oximeter. Schematic view of components and their connection is shown in Fig 3. On the far right, we have a heart rate/pulse measuring sensor that should be placed on the user's index finger and is connected to the Arduino via analog pin, as the sensor is providing data in analog form, which is further processed through an algorithm showing relevant heart rate data. Next, we have the GSR sensor for measuring skin conductivity levels. The sensor itself has two attachments (Fig. 2.) that can be placed on the user's fingers, sending data to the GSR chip, which sends data further to the Arduino through an analog pin as well. Arduino and oximeter are connected to Raspberry Pi sending data over serial ports. Data is further processed and visualized on the developed web application for stress monitoring.

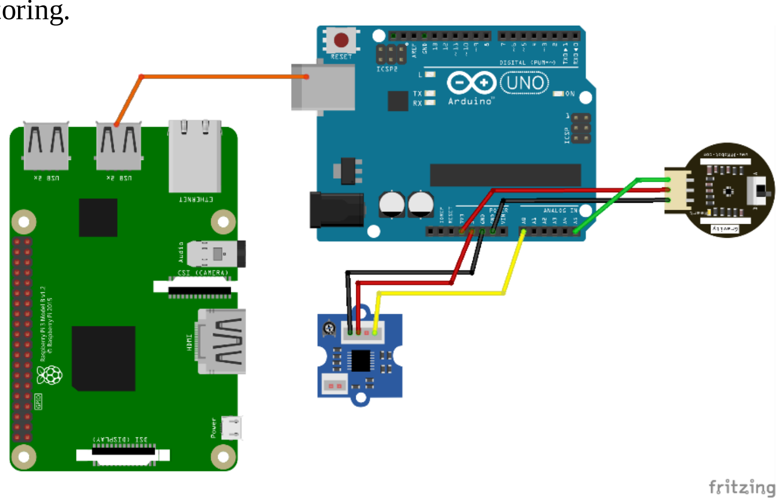

Fig 3. Schematic view of components of a wearable system for stress management

4.1 Web application for stress monitoring

As a support to the proposed IoT system, a web application for stress monitoring was developed (Fig.4). Web application was developed using modern web technologies, like ReactJS JavaScript framework for frontend development, while the backend of the application is developed in Django, Python's framework for robust web applications. Web application allows examiners to manage the collection of health-related data from the examinee and display live feedback to the user. One of the main requirements in the process of developing the web application were responsiveness and user-friendly interface, as the application can be used on any device with ease.

Main functionalities of the web application for stress monitoring are:

1. **Control area** (Fig. 5) has three buttons for loading initial values, starting the live monitoring and stopping after finished examination.
2. **Examinee information** (Fig. 6). The form is used to store personal information about the examinee, required for future research purposes. All participants agree on data processing and no personal data is revealed through research.
3. **Monitoring table** (Fig. 7). This part of the application is split in two:
    a. Starting parameter values where initial values of pulse, SpO2 and GSR are recorded by clicking on the Load ponder values button (Fig. 5);
    b. While the examination is ongoing Monitoring area is showing live information and values after Start monitoring button (Fig. 5) is clicked.

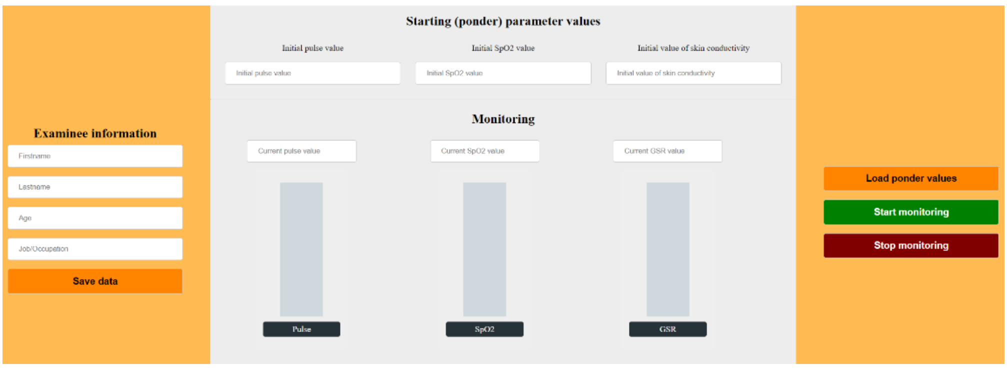

Fig 4. Web application for stress monitoring

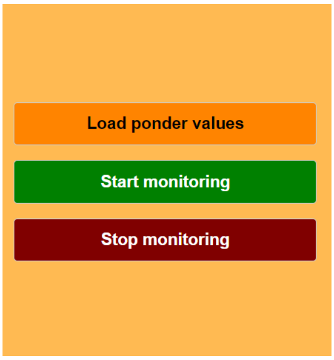

Fig 5. Control area

Fig 6. Examinee information

When monitoring start, bars for pulse, SpO2 and GSR change color and value based on comparison of ponder values, current values and optimal values recommended by health institutions [37][38].

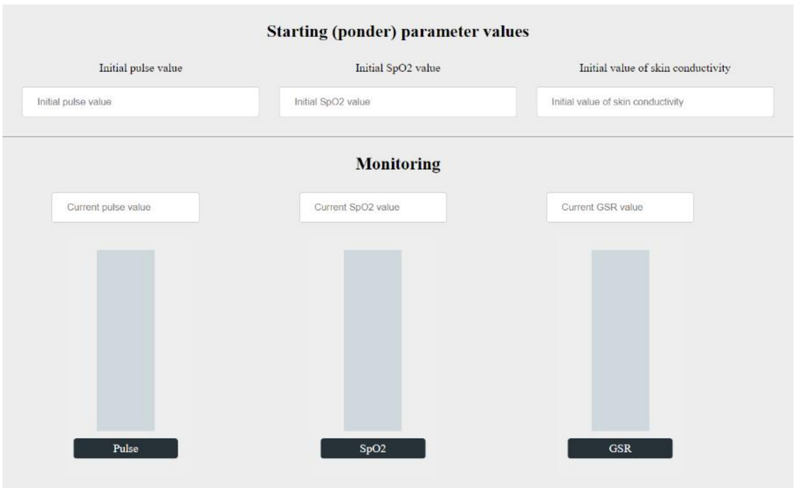

Fig 7. Monitoring table

Skin conduction (GSR) is one of the signals often used in lie detectors, but this parameter is also included in many studies that identify stress. The sensor for SpO2 estimates the amount of oxygen in the blood and represents a non-invasive method. In addition to individual vital parameters like pulse, GSR and SpO2, it is important to measure certain characteristics of the environment, as well as to observe changes in different contexts which may make or influence the occurrence of stress or changes in behavior. Green marks a positive outcome, when user is calm and relaxed, where orange and red indicate some changes in stress level.

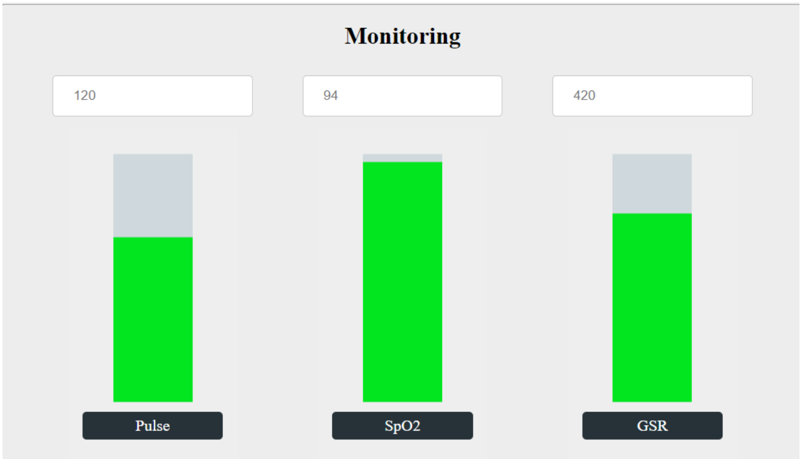

Fig 8. User feedback: measured data do not indicate the presence of stress

Values described in the Fig.8 show that the examinee has high oxygen saturation level and pulse and skin conductivity levels in optimal range, which concludes that examinee is calm, relaxed with no indication of the stress presence. Contrary to previous results, values described in the Fig. 9 show that the examinee has high oxygen saturation level, but elevated pulse and skin conductivity values indicate the presence of sweat, which leads us to conclusion that examinee is under stress.

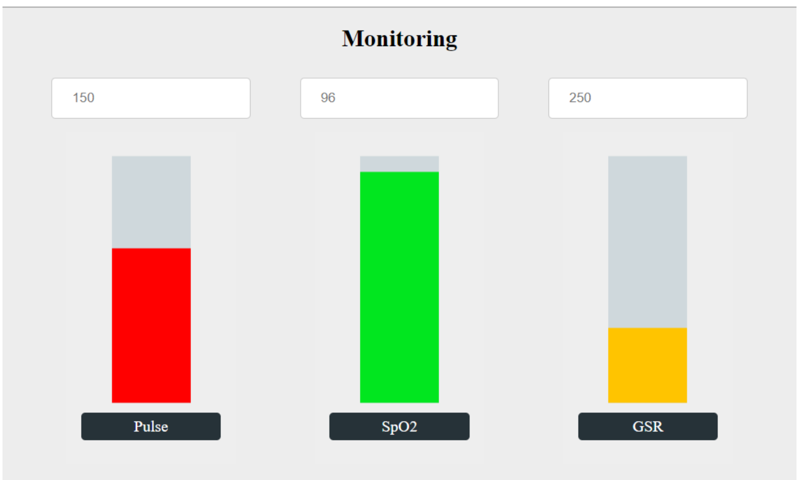

Fig. 9. User feedback: measured data indicate the presence of a stress

When excitement or anxiety is detected, the user is provided with the content through a mobile application, in the form of feedback that helps him to calm and relax (Fig. 10). Delivered contents should have a relaxing effect and that can be funny sports scenes, beautiful nature photos, relaxed natural sounds [39]. In addition, the user can receive biofeedback from the therapist or healthcare worker. This service has not yet been implemented, but it is shown in the proposed model.

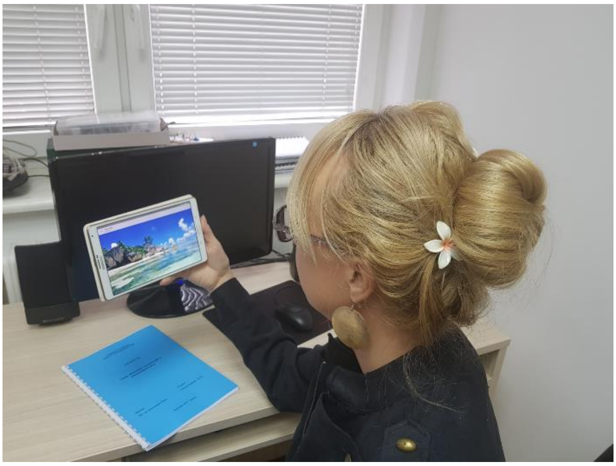

Fig.10. Mobile application with relaxing contents [39]

5. Conclusion

This paper presents an IoT system for real-time monitoring citizens' stress in a smart city. The proposed system was developed at the Faculty of Organizational Sciences, University of Belgrade and integrates three implemented subsystems: crowdsensing system for measuring noise and vibration in traffic, crowdsensing system for measuring the air quality and presence of allergens, and crowdsensing system for measuring microclimate conditions. The main idea of the proposed model of smart healthcare service based on the Internet of Things is to show how parameters from the environment affect stress occurrence. Users of this system can measure stress using a developed wearable system and receive biofeedback via a developed web application. If the stress is detected, users can be provided with relaxation content. The proposed system has some limitations that will be addressed in future work. The method for determining which environmental factors affect the stress occurrence should be defined. Data should be analyzed using big data analytics and used to help therapists or healthcare workers to give specific advice to users. In addition, future work will be directed to the improvement of a web application with new functionalities such as a personalized recommendation from a therapist, a preview of detected stress, and linking to the specific activity or environmental cause.

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