Mobile sensors and sensor networks for health care

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I. Introduction

Due to the major technology development in the last decade, smartphones have become more than just communication devices. This small pocket computers are indispensable for living in the modern world, offering real-time transport schedules and directions by tracking the user's location; supporting the user with calendars, to-do lists and reminders; informing about the weather, news or anything else, based on user's preferences and interests; containing pictures, messages and other personal data. According to GSMA, more than 5 billion people were using mobile phones in 2017 [1]. Due to the affordable prices, huge popularity, the habit of carrying the phones everywhere and the amount of personal data inside the phones, they have become of great interest for researchers in the healthcare field, emerging into a new research field called Mobile Health (mHealth) [2]. Modern smartphones are equipped with a wealth of sensors and apps, which use the sensor data, for reacting to the user's body and environment. Sensor data collected by smartphones can be used for monitoring the user's health, give recommendations for improving it and even preventing possible health issues. The sensors which are embedded into our smartphones can be subdivided into environmental sensors, as camera, microphone and barometer, and position and orientation sensors, as accelerometer, gyroscope, and magnetometer. [3, p.1-2].

In this paper you will find an overview about the basic functionality of the most important mobile sensors, android apps which use the sensor data and whether they are capable of improving the user's health in everyday life. All apps presented in this paper can be downloaded for free in the Google Play store. There's no advertisement involved. All apps which appear in this paper are selected because of the relatively good rating and reviews in comparison to other similar apps.

II. Environmental sensors

Camera

The camera is an indispensable sensor in every modern phone. Similarly to the human eyes, the camera sensors measure the light, which hits them through the lens and the image sensor creates an inverted digital picture of the environment [4]. Besides taking photos and recording videos, the camera can be used for several health applications.

One obvious way of using the camera in healthcare is having a video consultation with a doctor. There are various apps which offer a great network of medical professionals, the majority of those apps being available only in the USA and Canada. The app "Doctor On Demand" facilitates live video visits with certified physicians and psychologists, who are available online seven days a week and can consult anyone for a fixed cost, regardless of insurance. Some examples of what they treat are urgent care, cold, flu, allergies, depression, anxiety, skin and eye issues [5].

Teledermatology is a great solution in case of a skin problem, when it's not possible to contact a doctor directly. One of the existing solutions is provided by ClickMedix, consisting of: a mobile application, a data collection center and professionals in dermatology. Before using the Clickmedix service, the patient should be registered in the system and instructed on how to make the photos of the skin correctly [3, p.3].

The smartphone camera turnes to be useful in cardiology as well. There are two ways of measuring the heart rate. The first method consists of turning the flash light on and asking the user to keep a finger on the camera and stand still. When the light goes through the skin, the camera captures the color changes, which was proven to be a very accurate way of measuring the heart rate [6]. Many fitness and health apps use this method to calculate the heart rate during a workout, in order to detect if the exercises had the needed intensity for achieving health benefits, or if the exercise was too intense, thereby warning the user and giving personalized recommendations [7]. In the second method, the heart rate is detected by measuring the amount of light reflected from the face. Every time the heart beats, more blood rushes to the face, causing the face vessels to expand and thereby resulting in a decrease in the amount of light reflected from the face [SOURCE!!!!!].

The digital camera of the smartphone can be used for measuring the intensity of the ambient light and thereby adjusting the brightness of the screen. This feature is mainly designed for saving the battery power, but it's also contributing to the health of the eyes of the user [8, p.5].

In the near future, the extended camera resolution will make it possible to analyse blood cells and microorganism morphology, which will make local and immediate analysis and early disease prevention possible, not to mention the time and effort which don't have to be spent for going to the doctor [3, p.3]. There are several research projects working in achieving this goal. A group of researchers managed to develop a software which can detect skin cancer, by using a phone with a high resolution camera and a neural network trained on pictures of healthy and infected skin [9]. The android app "Medgic - AI for Skin" uses similar Artificial Intelligence algorithms, which take as input a photo of the unhealthy skin and after scanning it and asking the user a few questions, it can detect the skin disease or give recommendations [10].

Microphone

Each phone without exception contains a microphone - a sound sensor used for communication, which detects the sounds of the environment and measures their loudness. All smartphones are equipped with an electret microphone, because it doesn't require any additional battery power, due to its own fixed electric charge [11]. When the air goes through the capsule, an electret diaphragm moves back and forth, creating a voltage difference, which is captured by an amplifier module and transformed into digital sound [11]. Besides making and receiving calls, the microphone is used by a big variety of applications which can track the well-being of the user by recording his/her voice or the surrounding noises.

Many research studies are focused on integrating the microphone into healthcare applications. For instance, a team of researchers designed a software which uses the microphone, to detect if a person, who suffers from asthma and other respiratory disease, is using the inhaler in a right way, thereby helping the user to avoid common mistakes [12]. Another study, focused on the same target group, shows that the smartphone microphone is accurate enough to support people who use inhalers [13].

Another group of researchers developed an interactive voice response diary for patients with non-dystrophic myotonia based on the smartphone microphone [3, p. 2]. Patients with myotonic disorder sufer from the slow relaxation of muscles after contraction, which may cause a difficulty to move [14].. In order to use the proposed method, the patients have to call to the data collection service and talk about their health, thereby allowing the automated voice response system to classify the symptoms in 4 categories: muscle stiffness, weakness, pain and tiredness. This method leads to the reduction of the number of the doctor visits because the assessment can be done automatically and allows monitoring such patients without hospitalization [14].

There's a variety of sleep tracking apps, which use the microphone in order to detect different noises while the user is sleeping. A recent study showed that the smartphone microphone can identify apnea and abnormal breathing, while the user is sleeping [15]. The app "Sleep as Android" detects noises higher than the manually chosen threshold by the user, which can show whether the user is snoring (tagged with #snore), talking or laughing during the night. It creates noise statistics, which can also reveal if the bedroom noise is influencing the quality of sleep [16].

The vocal analysis app "MIMOSYS: Vocal analysis app for mental health", developed by the University of Tokyo, tracks the user's mental health, while the user is talking on the phone, reads something out loud or during a conversation with someone else and creates statistics about his/her mental state [17].

Barometer

The digital barometer consists of a pressure sensor, often located in the GPS units of the phone, used for measuring the atmospheric pressure [18]. Although the primary use of the barometer in a smartphone is calculating the altitude and thereby increasing the accuracy of the location detected by the GPS, it can also be very useful for people who go hiking or for those who suffer of barometric pressure headaches and migraines [18].

The app "Atmospheric Pressure Barometer" does accurate height measurements, offers information about the temperature outside, the speed of the wind, humidity and visibility. By monitoring the atmospheric pressure, the user can be prepared for pressure jumps, headaches, migraine and malaise [19].

Jeff Masters, the director of meteorology at Weather Underground, once shared another perspective on builtin barometers in smartphones in the interview with Dan Nosowitz: "It would also be cool if you could share your pressure readings with a bunch of other smartphone users to get a super-dense picture of the pressure changes due to an approaching thunderstorm, cold front, or hurricane" [18].

III. Orientation sensors

Accelerometer

An accelerometer determines movement and exact orientation along the three axes and as result adjusts the screen into portrait or landscape mode [3, p.2]. The most commonly used accelerometer is the piezoelectric effect, made of microscopic crystal structures, which create voltage by sensing movement and acceleration, and thereby determining the velocity and orientation of the phone [20].

The app ”Sleep as Android”, mentioned in the paragraph about microphones, also uses the accelerometer in order to calculate if the user is in a deep sleep or not, which leads to finding the best moment for the alarm to wake the user up in the optimal sleep phase [16].

There’s a huge variety of sports apps, which use the accelerometer for tracking the workouts and the activity of the user during the day. A recent study, performed on office-based employees, showed that the inbuilt phone accelerometer can accurately detect the activity of the user in real-life conditions [21].

The app ”Nike+” tracks the speed and the distance while the user is running. It also offers personalised coaching based on goal setting, motivates the user to work out and supports him/her during the run [22].

The step counting apps, also called pedometers, use the built-in accelerometer of the smartphones as well [23, p.1]. Based on the user’s body parameters and the body-mass index (BMI), these apps are capable of measuring burnt calories and the changing BMI, as well as the time and the distance of the walk or run [23, p.3]. The app ”Pedometer - Step Counter Free & Calorie Burner” is tracking the user’s activity and clearly displays it in graphs. Having the overview of the daily activity can raise awareness, in case the user is living a sedentary lifestyle [24].

Gyroscope

While the accelerometer is used for detecting the orientation, the gyroscope detects the rotation of the device [25]. By working together, this two sensors can detect the movements of the phone in six directions: right, left, up, down, forward and backward [26]. The primary use of the gyroscopic sensors is the detection of gestures, when the user holds the smartphone in his/her hands [26].

A study focused on elderly and chronic patients, showed that the accelerometer, gyroscope and the magnetometer of a phone can be used for accurate mobility assessment [27]. These three sensors are used by the majority of activity tracking apps, which were already mentioned in the paragraph about accelerometers.

IV. The CodeBlue Framework

V. Security

Besides great advantages and opportunities for mobile health, the development of secure sensor networks is quite challenging, because of their limited memory and low computational power. This subsection discusses the possible security attacks, which can put the patients’ personal data in danger and eventually cause medical complications.

Monitoring and Eavesdropping on Patient Vital Signs

In this attack an adversary can discover the patient information from communication channels, by picking up the messages from the network, which may reveal the patient’s physical location, message-ID, timestamps and other relevant information [28, p.67]. . As a result the attacker can physically harm the patient, because of knowing his/her real time location [28, p.67].

Threats to Information When in Transit

An attacker can capture and alter the physiological data from the wireless channels, while it’s being sent to a doctor or to a server. There are two types of transit attacks: interception, illegal access of the sensor node data like cryptographic keys, sensor ID’s, type etc. and message modi

cation, capturing the patient wireless channels and extract and modify the patient medical data. As a result the attacher may trigger a false alarm, or on the contrary, fool an alarm system and put the patient’s life in danger [28, p.67].

Routing Threats in WSNs, multi-hop environment

As previously discussed in the CodeBlue section, the multi-hop environment is

Masquerade and Replay Threats

Activity Tracking Threats

Conclusion

In this paper different inbuilt smartphone sensors were described, as well as their ability to track and improve the user’s health. Although the accuracy of some sensors is yet to be proven, smartphones have a big potential to change the healthcare system, decrease the service costs and make it available for everyone, because of the their increasing availability and affordable prices [3, p.5].

Smartphone applications are capable not only of tracking the user’s body and the environment, but also persuading the user to make positive behavioural changes, making it easier to follow healthcare routines and become aware of possible health issues, but it's still the user's responsibility to take care of his/her body and environment, no matter how good technologies evolve [29, p. 148].

REFERENCES

[1] "Global mobile trends 2017," 2014. $https://www.gsmaintelligence.com/research/?file=3df1b7d57b1e63a0cbc3d585feb82dc2\&download$, visited in February 2019.

[2] Wikipedia contributors, "Mhealth — Wikipedia, the free encyclopedia," 2018. [Online; visited in January 2019].

[3] E. Stankevich, I. Paramonov, and I. Timofeev, "Mobile phone sensors in health applications," in *Open Innovations Association (FRUCT), 2012 12th Conference of*, pp. 1–6, IEEE, 2012.

[4] H. J. Kamps, "What's the difference between a camera and a human eye?," *medium.com/photography-secrets/whats-the-difference-between-a-camera-and-a-human-eye-a006a795b09f*, 2017. visited in January 2019.

[5] "Doctor on demand," $https://www.doctorondemand.com/$, visited in February 2019.

[6] B. P. Yan, C. K. Chan, and Li, "Resting and postexercise heart rate detection from fingertip and facial photoplethysmography using a smartphone camera: a validation study," *JMIR mHealth and uHealth*, 2017. $https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5368348/$, visited in January 2019.

[7] "Samsung heart rate sensor," *https://www.samsung.com/us/heartratesensor/*, 2018. visited in January 2019.

[8] J.-M. Gutierrez-Martinez and Castillo-Martinez, "Smartphones as a light measurement tool: Case of study," *Applied Sciences*, vol. 7, no. 6, p. 616, 2017.

[9] A. Bourouis, A. Zerdazi, and Feham, "M-health: skin disease analysis system using smartphone's camera," *Procedia Computer Science*, vol. 19, pp. 1116–1120, 2013.

[10] "Medgic - ai for skin," $https://www.medgic.co/$, visited in February 2019.

[11] Hard Copy arduino, "Electret microphones," *http://www.openmusiclabs.com/learning/sensors/electret-microphones/*, 2015. visited in January 2019.

[12] S. Nousias, A. S. Lalos, and Arvanitis, "An mhealth system for monitoring medication adherence in obstructive respiratory diseases using content based audio classification," *IEEE Access*, vol. 6, pp. 11871–11882, 2018.

[13] O. Saukh, "Capturing inhalation efficiency with acoustic sensors in mobile phones," in *Proceedings of the 7th International Workshop on Real-World Embedded Wireless Systems and Networks*, pp. 19–24, ACM, 2018.

[14] R. R. B. B. L. H. J. G. J. M. Statland, Y. Wang, "An interactive voice response diary for patients with non-dystrophic myotonia," *Muscle Nerve*, vol. 44, no. 3035, 2011.

[15] P. N. Narayan, Sanjiv Shivdare, "Noncontact identification of sleep-disturbed breathing from smartphone-recorded sounds validated by polysomnography," *Sleep and Breathing*, pp. 1–11, 2018.

[16] "Sleep as android," $https://sleep.urbandroid.org/$, visited in February 2019.

[17] "Mimosys: Vocal analysis app for mental health," $https://play.google.com/store/apps/details?id=com.medical_pst.mimosys_release2\&hl=en$, visited in February 2019.

[18] D. Nosowitz, "So, um, why does the new google phone have a barometer in it?," *Popular Science*, 2011. https://www.popsci.com/gadgets/article/2011-10/so-um-why-does-new-google-phone-have-barometer-it.

[19] "Atmospheric pressure barometer," $https://play.google.com/store/apps/details?id=com.exatools.barometerandaltimeter$, visited in February 2019.

[20] R. Goodrich, "Accelerometers: What they are & how they work," *LiveScience*, 2013. https://www.livescience.com/40102-accelerometers.html.

[21] J. Bort-Roig, A. Puig-Ribera, and Contreras, "Monitoring sedentary patterns in office employees: validity of an m-health tool (walk@ work-app) for occupational health," *Gaceta sanitaria*, vol. 32, no. 6, pp. 563–566, 2018.

[22] "Nike+," $https://www.nike.com/us/en_us/c/nike-plus/running-app-gps$, visited in February 2019.

[23] J. Wise and N. Hongu, "Pedometer, accelerometer, and mobile technology for promoting physical activity," *College of Agricultural Life Sciences, University of Arizona. Retrieved September*, 2015.

[24] "Pedometer - step counter free & calorie burner," $https://play.google.com/store/apps/details?id=pedometer.stepcounter.calorieburner.pedometerforwalking\&hl=en$, visited in February 2019.

[25] gsmarena, "Sensors - definition," *https://www.gsmarena.com/glossary.php3?term=sensors*. visited in January 2019.

[26] P. Gujarati, "Overview of sensors used in smartphones and tablets," *https://www.techulator.com/ resources/9421-Overview-sensors-used-smartphones-tablets.aspx*, 2013. visited in January 2019.

[27] P. Madhushri, A. Dzhagaryan, E. Jovanov, and A. Milenkovic, "An mhealth tool suite for mobility assessment," *Information*, vol. 7, no. 3, p. 47, 2016.

[28] P. Kumar and H.-J. Lee, "Security issues in healthcare applications using wireless medical sensor networks: A survey," *sensors*, vol. 12, no. 1, pp. 55–91, 2011.

[29] N. D. Lane, E. Miluzzo, and Lu, "A survey of mobile phone sensing," *IEEE Communications magazine*, vol. 48, no. 9, 2010.