Critical Patient eHealth Monitoring System using Wearable Sensors

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***Abstract*—Patient monitoring has advanced over the years, from bed side monitors in the hospital, to wearable devices that can monitor patients and communicate their data remotely to medical servers over wireless networks. It is a process that involves monitoring major vital signs of a patient, to check if their health is normal or deteriorating within a period of time. In a remote situation, vital signs information, can help health care providers to easily send help to patients when their health is at immediate risk. The problem with this kind of remote monitoring system is that most times the patients must be within a specified location to either monitor their health or receive emergency help. This paper presents a potential solution in the form of a global vital sign monitoring system and consists of two components to demonstrate the functionality; a wearable wireless monitoring device that records the temperature and pulse rate of the patient wearing it and a web application, which allows the patient and the emergency response unit to interact together over cellular network.**

***Index Terms*—eHealth, Patient Monitoring, Smart Health, Wearable Sensors.**

I. INTRODUCTION

Patient health monitoring is a very important process which helps doctors and other medical workers to offer various assistance, such as emergency services to patients when their health is deteriorating etc. Without constant health monitoring, doctors may not be able to diagnose some sicknesses on time which may lead to the patients being in various critical conditions [1]. Over the years a number of systems have been developed to cater for some of the issues related to health monitoring, however the aspect of continuous remote health monitoring of patients when they leave their homes temporarily for either a long or short period of time or permanently has not been greatly considered. This aspect can be really critical, because the patient's registered hospital may not be able to reach the patient, during an emergency in such situations. This can lead to the patient getting into very serious conditions or led to death in extreme cases. Thus there is a need for a system to cater for this kind of health monitoring in remote situations. If such a system is put in place, patients can move freely while their health, will still be continuously monitored wherever they go and get the required help where ever they might be in the event of a medical emergency.

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Health monitoring using a wireless sensor network, is a wireless based biomedical monitoring system, which constantly monitors vital signs of a patient such as their body temperature, heart rate, blood pressure, ECG etc. and provides the data to a health-care provider to either assist in health diagnosis or check for health improvements of patients. Recently, there have been various research carried out on how health services can reach the masses, and also increase the interactivity between patients and doctors within and outside the hospital [2]. With every research, new methods, techniques are proposed and some implemented, with the aim of improving the way a patient's health can be easily monitored either within or outside the hospital.

According to [3], constant medical check ups can be very helpful in various cases such as early detection of sicknesses, faster diagnosis during emergency cases and much more. Due to terminal illness or a particular medical issue, some people need to constantly monitor their health and visit the hospital regularly for constant check ups. Thus this becomes very stressful, expensive and time consuming for them. With the newly available technologies, a doctor can monitor his patient's health remotely by the use of wireless sensors [4]. Although these existing systems help in cost reduction and quality health services [5], there are still threats to confidentiality, integrity and availability of the data retrieved by these sensors. As stated in [6], there is also need for interoperability to enable data gathered to be used, fully or partly across multiple health platforms and portability of these health monitoring sensors, to enable large amount of data to be constantly collected without affecting an individual's daily activities. By doing this, health data analysis becomes easier and diagnosis is more precise [7]. However, some systems have tried to address some of these needs, but each of them still lack in one way or the other, thus leading to quest of a hybrid health monitoring system that will have all these functions in its architecture and be able to work independently rendering emergency assistance to patients wherever they may be and irrespective of the hospital they are registered to. This system will work with hospitals, by providing them with basic health details of a patient thus enabling them to provide a quick and accurate diagnosis.

The rest of the paper is as follows. Section II surveys previous literature - it discusses the basic concept of health monitoring, including the types and ways in which patients' health have been monitored over the past years. In this section, various wearable health sensors are discussed and a comparison is performed based on the various communication

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technologies that can be used in eHealth monitoring. Finally, major related works of this research are critically discussed and reviewed. Section III introduces the system's architecture and Section IV looks at the initial results of the system and it discusses the testing of the prototype. Finally, the benefits and weaknesses of the proposed system, are discussed and the paper concluded in Section V.

II. Related Work

A. Patient health monitoring

Patient health monitoring is the continuous observation of conditions or several medical parameters (vital signs) of a patient over time by a doctor or nurse. Most often this is carried out manually, using various devices to monitor the vital signs of patients. These devices can be thermometers for checking a patient's temperature, sphygmomanometers for checking blood pressure, manually counting pulse to determine the respiratory rate, etc. Since this requires a health practitioner to check from one patient to the other, there can be a high tendency of inaccurate data records and it can be time consuming which makes this not feasible in a scenario where a large number of patients need to be monitored. Recently, the health monitoring process has become automated by the use of sensors and various management systems, to continuously check the patient's health without any physical assistance from the health practitioners. This has led to the remote patient health monitoring, whereby no further assistance from a health practitioner is required.

B. Remote Patient Health Monitoring

Remote patient health monitoring is a type of ambulatory health-care, that involves the use of body sensors to measure various human vital signs such as temperature, heart rate, oxygen level, etc. and transmitting them in real-time to a remote server where further analysis can take place. Following analysis, a response can be sent back to the patient by the medical practitioners at the health care unit in the case of emergencies or health advice [8]. According to [2], patient health monitoring system using wireless sensor networks is an innovative idea, which helps to generate prediction on patient's health condition based different vital signs and their medical history. Most importantly, it offers pervasive monitoring of patients, as the wireless sensors transmit their data to the monitoring server using various wireless communication technologies such as cellular, Wi-Fi etc. which are widely available at homes, offices and other social places [4].

C. Requirements for Remote Medical Sensors

Below are requirements that remote monitoring systems should satisfy. These include wear-ability, reliability and security.

- ***Wear-ability:*** This is a key requirement for remote medical sensors, as clinical sensors tend to be obtrusive and can limit movement of patients. Therefore, in remote monitoring, small sized sensors should not affect mobility.
- ***Reliable Communication:*** Remote monitoring requires a reliable always-on communication channel to ensure that sensor data arrives at the remote processing server in the minimum amount of time.
- ***Security:*** In remote monitoring, security is paramount: personal data will be transmitted, so to ensure the privacy of the patient and authenticity of data, several mechanisms have to be put in place [9]. This can range from secured network communication to encryption of transmitted data to avoid malicious interception [10].

D. Review of Current Remote Health Monitoring Systems

This section will review related health monitoring systems and review their strengths and weaknesses.

Manjushree et al[8] proposed a remote monitoring system, that involves the use of sensors to monitor certain body parameters, which are then communicated to a hospital, doctor or medical server. The system monitors the temperature, oxygen level and heart rate of the patient and alerts the hospital via Text messaging using only the mobile network(GSM).

In Otto[11] a wireless body area network (WBAN) implementation is presented. The proposed WBAN makes use intelligent physiological sensor, a personal acting as a server and a network supervisor. It explores "practical implementation challenges and presents original solutions for time synchronization, event management, and for dynamic reallocation of on- chip resources for maximum efficiency".

In Abidoye et al[12], medical sensors were used to "collect physiological data from patients and transmits them to Intelligent Personal Digital Assistant (IPDA) using ZigBee/IEEE802.15.4 standard and to the medical server using 3G communications". They introduced priority scheduling and data compression in the system in order to increase the transmission rate of critical signals which in turns improves the bandwidth utilization.

Mohammed et al[13] proposes a glove system. The glove can be used by people with disabilities in order to interact with the environment such as enabling patients to open and close appliance by measuring the acceleration and movement of the hand. In Ayu et al[1] a system that can measure temperature, oxygen in the blood and heartbeat continuously was proposed. This system only transfers the sensor data to a local server via ZigBee and uses the GSM to send SMS when there is an emergency. This system will fail when the patient's server goes down. Also the patient is confined to a particular building, so once the device is out of range, sensor data will automatically stop logging.

In the paper by Abo-Zahhad et al[14], they implemented a system which continuously collects and evaluates multiple vital signs. In emergency cases it uses a cellular connection to a medical center, while it transfers raw data by the Internet when acting normal. The system can continuously monitor four physiological signs, ECG, SpO2, temperature, and blood pressure. It transfers the sensor data to an intelligent data analysis scheme which detects abnormal conditions and explores chronic diseases

In Anudeep et al[4], the paper proposed and implemented a mechanism for the estimation of "elderly well-being condition

based on usage of house-hold appliances connected through various sensing units". In Kakria at al[15], they proposed and implemented a real-time heart monitoring system. The proposed system was developed with cost in mind, usability, accuracy, and data security. It was developed to facilitate remote cardiac patients monitoring only.

1) Strengths of the Reviewed Systems: Below are the major strengths of the reviewed systems:

- Vital Signs can be monitored remotely.
- Most are cost effective and can be implemented with ease in reality.
- They eliminate the use of cables transmitting data from monitoring devices placed on the patient.
- They help to constantly monitor several patients at the same time.

2) Weaknesses of the Reviewed Systems: Below are the major weaknesses of the reviewed systems;

- Dependent on only one particular hospital.
- No patient authentication when health monitoring commences.
- No Redundancies in the systems, as the all have just one means of alerting during an emergency.
- No location tracking of patients when an emergency occurs, so if the patient is not in the registered residence address at the time of emergency, the hospital may most times not be able to reach the patient.
- Also false negatives and false positives in the systems, as they throw alert when an emergency occurs.

This may be an issue where the system generates false alerts due to maybe weather change or other environmental factors.

However, some systems have tried to address some of these weaknesses, but they are still lacking in one way or another. Thus leading to quest of a hybrid health monitoring system that will continuously monitor and send vital signs data to a remote server, authenticate the patient that is being monitored, ensure the confidentiality and integrity of data, use of portable or wearable sensors to ensure continuous monitoring without affecting the patient's daily routines and also make analyzed data available to be used on other platforms in cases where the patient is not within the location of his or her healthcare service provider or in cases of emergency.

III. Prototype

The prototype aims at providing individuals of various adult age groups the ability to continuously monitor their vital signs (temperature and pulse), using wearable health sensors with an in-built cellular module, wherever they might be in the world at any particular time, named here as a Global Health Service (GHS). The system will work independently from any hospital i.e. the system will act as an intermediary between a patient and any health-care provider. This will help the patient to get medical help in whichever location around the world that an emergency occurs. During monitoring, patients can login via a web application to view and manage a more detailed report of their individual vital signs, that the smart wearable device has been logging on the server. The smart wearable device will authenticate and then continuously monitor, the

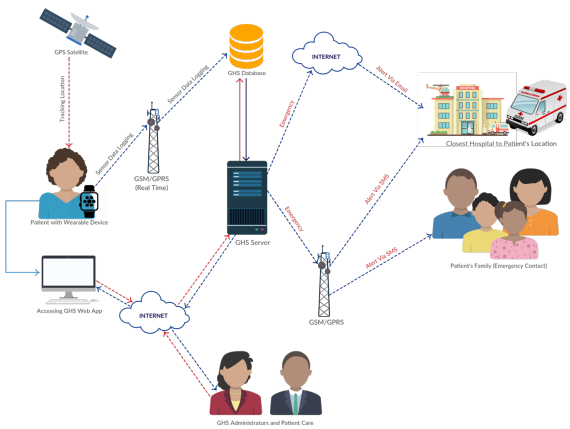

Fig. 1. System Architecture.

temperature, pulse and GPS coordinates of the patient that the device was assigned to. The device will then use its in-built cellular module to log this information, on a remote database which stores the data. The database will work in conjunction with the web application to provide a GUI dashboard to registered patients. The main part of this system is the emergency management, this includes the various algorithms used to detect and distinguish between health emergencies and environmental factor change. The system will notify a patient's emergency contact when any of the vital signs is going out of range, this will be done to prevent the system from throwing unnecessary emergency alerts to health-care providers. The system only raises an alert to health-care providers when the vital signs have gone completely out of range before the situation becomes worst. During such emergencies, the patient's location coordinates will be used to locate the nearest health-care provider, retrieve their emergency contact and notify them along with the patient's stored emergency contacts, of the patient's emergency including the location of the patient. The emergency alert sent to the health-care provider, will consist of a link which leads to a page on the GHS web application which summarizes the patient details, medical conditions and overview of the vital signs monitored for the past one hour before the emergency occurred. This will help reduce the time it takes for a health-care provider to diagnose and identify the health condition of the patient.

A. System

The GHS architecture consists of three major tiers in the health monitoring process; the patient with the monitoring mobile unit (device), the GHS remote server (processing and intermediary unit) and the emergency response unit which consists of the contacted hospital and the patient's emergency contacts. From Figure 1, it can be seen that there are two major communication network links used in the system; the GSM/GPRS (mobile network) and the Internet. The mobile network is used to transfer data in real-time within critical sections of the system (monitoring unit), while the Internet is used by the patient, GHS admin to access mostly the web

application that resides on the remote server. Below, each of the units of the system is explained in details.

1) Monitoring Mobile Unit: This is the first unit in the system architecture, it consists of the patient and the monitoring device. The device is proposed to be mobile, wearable, wireless and also to function without the need of an extra device i.e. the device will authenticate, monitor the patient's temperature, pulse, track the current location and transfer these data to the GHS remote server single handedly. The device will use its inbuilt cellular module to transfer data, allowing the patient to monitor his or her vital signs wherever there is mobile network signal. Since mobile networks are now available in over 151 countries around the world [16], the device will continue to monitor the patient even when the patient is going a long distance, or even traveling as it will automatically begin roaming in a new country. However, the device will require the patient to often subscribe for mobile data through its network provider, to enable it to access the GPRS for data transfer. In cases where there is no mobile data connection and there is an emergency, the device will notify only the patient's emergency contacts via SMS. A GPS is used by the device to get the current location of the patient when monitoring, which will be used by the GHS server to find the closest hospital to alert if an emergency occurs. A patient can also access the GHS remote server, from anywhere in the world and with any device that has an Internet connection via the GHS web application. This application will help patients view the logs of their vital signs, in a processed format that is easy to understand and manage. Thus enabling them to carry their health data along with them wherever they go. The patient can also use the web application to communicate with the GHS administrators and receive feedback, in case of any issues faced with the use of the system.

2) Processing and Intermediary Unit: This is the second unit of the system, it consists of GHS web & database server and the GHS administrators & patient care. This unit serves as an intermediary between a patient unit and the emergency response unit. Here, the patient's vital sign data is stored in a database and web application that resides on the server retrieves this data and processes it into meaningful information, which is passed through various logics and algorithms to detect if the patient's health is deteriorating. The application will check for irregularities in the data logged and only notify the patient's emergency contact, if the vital sign data is going out of range so as to avoid sending unnecessary alerts to hospitals. If the health condition doesn't improve within a specified amount of time then it declares the patient is having an emergency, and uses the current location coordinates of the patient to search for the closest hospital within the area. Once a hospital has been located, it will retrieve the hospital's emergency contacts and alert both the hospital and patient's emergency contacts via SMS and email of the patient's condition. The alert messages will include a link to an auto generated report that contains a summary of the patient's details and health records, that will help the emergency response team diagnose faster when the patient is found. Also, the GHS administrators will resolve any issues logged by the patient through the web application and send back a feedback on the issue. In summary, this tier helps to provide medical response to patient wherever and whenever they need it, unlike the traditional health monitoring system that is based on only one particular hospital that the patient is registered to and usually found at a particular location.

3) Emergency Response Unit: This is the third unit of the system, it consists of the patient's emergency contacts and the closest hospital to the patient's location at the time of an emergency. This unit will find and help a patient during an emergency and with the link to a summarized report of the patient's health, the time it takes to diagnose the patient health issue will be minimal. They are notified via email and SMS, so which ever one is seen first, they get the details of the patient's condition.

However, the link to the generated report will expire within 30 minutes from the time it was sent to ensure that the patient's data is not misused after the emergency. None of the entities in this unit need not be registered to the GHS to be able to help the patient. However, the patient is expected to provide details of his or her emergency contact during the time of registration on the GHS.

IV. SYSTEM TESTING AND RESULTS

The image below in Figure 2 shows the complete device prototype. For the device to detect emergencies, the following analysis algorithm is used by the device according to vital signs ranges defined in [17], to compare the data that is gotten from the sensors. Although this may vary with age and gender of the patient in a clinical setting. However, this device can only be used by adults above the age of 18 for the results to be accurate.

- High Temperature alert is thrown if the patient body temperature is above 45 °C.
- Low Temperature alert is thrown if the patient body temperature is below 33 °C.
- High Pulse alert is thrown if the patient Breath per Minute is higher than 110 BPM.
- Low Pulse alert is thrown if the patient Breath per Minute is lower than 50 BPM.

Fig. 2. Final Prototype of Vital Sign Monitoring Device.

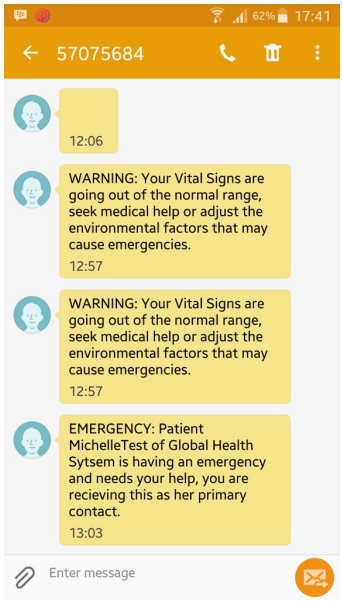

Fig. 3. Warning and Emergency Messages

(a) (b) (c)

Fig. 4. Connection Status

The results of the system testing are briefly discussed in this section; they include the messages that will be received from the system via SMS and Email, and also the report auto generated when the link is viewed by the contacted hospital. For the purpose of this research, no hospital was contacted but a predefined number and email was just used during the testing to prove the system works. The screenshots of the results can be viewed in the Figures 3, 4 and 5. Figure 3 shows the SMS messages sent by the system as Warning or Emergency notifications. Figure 4a shows the notification displayed to the user when the connection to the server has failed, Figure 4b show the message displayed to the user in case the device is not connected to the server and Figure 4c shows the message when the device is connected to the server.

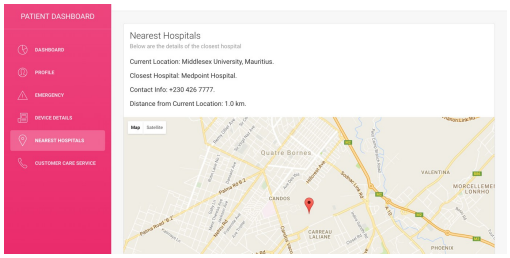

Fig. 5. Patient View of the Closest Hospital

A. Comparison of major related works

Table I contains a brief comparison of the developed global health system and major related health monitoring systems.

TABLE I
COMPARISON OF RELATED WORKS TO DEVELOPED SYSTEM

Criteria	GHS	Abo-Zahhad et al.[14]	Prohaska et al.[3]
Remote Vital Sign Monitoring	Yes: Temperature and Pulse	Yes: ECG, SpO2, temperature, and blood pressure	Yes: Heart Rate
Communicate to Various Hospitals	Yes	No	No
Location Tracking	Yes	No	Yes
Independent Monitoring Device	Yes	No	No
Patient Device Authentication	Yes	No	No
Web User Interface	Yes	No: Desktop Application	Yes
Communication Technology	GSM/GPRS and Internet	GSM/GPRS and Internet	GSM/GPRS

B. Benefits and Weaknesses of the GHS

At the end of this research, various benefits and weaknesses of the system have been noted and are listed below respectively.

1) Benefits: There are several benefits that can be derived from the use of the global health system, and they are listed below;

- Long term health monitoring.
- Comfortable and wearable device for vital sign monitoring, which makes it easier for the patient to move around without hurdles.
- Global emergency alert system.
- Authentication of patients, to avoid another person's health data from being stored under the registered patient's account if the device is worn.
- Faster diagnosis of patients when an emergency occurs, as the hospital is presented with a short history of vital sign data and medical conditions.
- Secured data transfer to the server from the monitoring device.
- Easy to use web interface to view health records.
- No skill is required to use the system.

2) Weaknesses: Some weaknesses or shortcomings of the system are listed below;

- Authentication and vital signs monitoring of patients using fingerprint and the wrist respectively, may not be possible for people with disabilities such as amputated fingers or arms.
- The monitoring device cannot function in areas with no mobile network.
- There is no medical consultation unit where patients can communicate with doctors or nurses if they need to discuss a medical situation.
- The patient getting help solely depends on the hospital and emergency contacts responding to the alert and finding the patient

V. CONCLUSION

In conclusion, this paper has discussed and reviewed the concept of health monitoring and how the process has evolved over the years due to technology advancement. The main aim of health monitoring is to help patients know and find help they need their health is deteriorating. Various types of health monitoring such as in-patient and remote monitoring, were discussed and compared to give the reader an insight on what each type does, with the focus point being the remote monitoring which this research aims to improve. The remote patient monitoring has been adopted by many people because it has proved to be useful and effective, as it allows monitoring outside the hospital. Due to this reason more research has been carried out to continuously improve the process, helping people carry out their daily activities while their health is being monitored at the same time.

The developed system consists of two major prototypes; a wearable wireless monitoring device that records the temperature and pulse rate of the patient wearing it and a web application, that allows the patient and the emergency response unit (hospitals) to interact together among other features. This system allows health monitoring wherever a person might be around the world, because the device uses a cellular module that provides mobile network, so when the person moves from one location to another, the connection is not lost and vital signs data are continuously logged on the server. It can also help registered patients request for emergency help anywhere, by using the person's current location to search for the nearest health-care provider that can offer an emergency response to the patient.

A. RECOMMENDATIONS FOR FUTURE WORK

Various ways or things that can be added to improve are as follows:

- The monitoring device can be made to also store data off-line.
- Advanced maps can be created to get more detailed info about medical centers, in situations where the closest hospital is really far, pharmacy or even police emergency can be called.
- A mobile app can be developed and included in the system.
- More sensors that record vital signs such as blood pressure and respiratory rate, can be included within the wearable device.
- A medical consultation unit can be added to the system where the patient is able to communicate live with a doctor and receive a prescription.

REFERENCES

[1] N. N. F. Ayu and C. Hamid, "Health care monitoring using wireless sensor network (H-Caring)," p. 66, Jun. 2012. [Online]. Available: http://umpir.ump.edu.my/6320/

[2] M. P. Agrawal, S. P. Hingway, and B. P. Dharaskar, "Innovative approach for wireless health monitoring system using Client-Server architecture," *ijettjournal.org*, 2013. [Online]. Available: https://www.ijettjournal.org/volume-4/issue-5/IJETT-V4I5P6.pdf

[3] T. R. Prohaska, E. A. Leventhal, H. Leventhal, and M. L. Keller, "Health practices and illness cognition in young, middle aged, and elderly adults," *Journal of gerontology*, vol. 40, no. 5, pp. 569–578, Sep. 1985. [Online]. Available: https://www.ncbi.nlm.nih.gov/pubmed/4031405

[4] K. Anudeep and S. Srinivas, "Health monitoring system of elderly using wireless sensor network," *ijcat.com*, 2015. [Online]. Available: http://www.ijcat.com/archives/volume4/issue3/ijcatr04031005.pdf

[5] Y. Bai, L. Dai, and J. Li, "Issues and challenges in securing ehealth systems," *International Journal of E-Health and Medical Communications (IJEHMC)*, vol. 5, no. 1, pp. 1–19, 1 Jan. 2014. [Online]. Available: http://www.igi-global.com/article/issues-and-challenges-in-securing-ehealth-systems/109863

[6] L. Gatzoulis and I. Iakovidis, "Wearable and portable ehealth systems," *IEEE engineering in medicine and biology magazine: the quarterly magazine of the Engineering in Medicine & Biology Society*, vol. 26, no. 5, pp. 51–56, 2007. [Online]. Available: http://dx.doi.org/10.1109/EMB.2007.901787

[7] X. Bellekens, K. Nieradzinska, A. Bellekens, P. Seeam, A. Hamilton, and A. Seeam, "A study on situational awareness security and privacy of wearable health monitoring devices," *International Journal On Cyber Situational Awareness (IJCSA)*, vol. 1, no. 1, 2016.

[8] S. A. Manjushree and Y. M. Rajashri, "Remote health monitoring of elderly using GSM," *IJIRTS*, 2014. [Online]. Available: http://ijirts.org/volume2issue4/IJIRTSV2I4035.pdf

[9] X. Bellekens, A. Hamilton, P. Seeam, K. Nieradzinska, Q. Franssen, and A. Seeam, "Pervasive ehealth services a security and privacy risk awareness survey," in *Cyber Situational Awareness, Data Analytics And Assessment (CyberSA), 2016 International Conference On*. IEEE, 2016, pp. 1–4.

[10] X. Bellekens, A. Seeam, K. Nieradzinska, C. Tachtatzis, A. Cleary, R. Atkinson, and I. Andonovic, "Cyber-physical-security model for safety-critical iot infrastructures," in *Wireless World Research Forum (WWRF)*, 2015.

[11] C. Otto, "An implementation of a wireless body area network for ambulatory health monitoring," Ph.D. dissertation, The University of Alabama in Huntsville, 2006. [Online]. Available: http://www.ece.uah.edu/~milenka/docs/ChrisOtto.thesis.pdf

[12] A. P. Abidoye, N. A. Azeez, A. O. Adesina, K. K. Agbele, and H. O. Nyongesa, "Using wearable sensors for remote healthcare monitoring system," *Journal of Sensor Technology*, vol. 01, no. 02, pp. 22–28, 2011. [Online]. Available: http://www.scirp.org/journal/PaperDownload.aspx?DOI=10.4236/jst.2011.12004

[13] A. Mohammed, A. Seeam, X. Bellekens, K. Nieradzinska, and V. Ramsurrun, "Gesture based iot light control for smart clothing," in *Emerging Technologies and Innovative Business Practices for the Transformation of Societies (EmergiTech), IEEE International Conference on*. IEEE, 2016, pp. 139–142.

[14] M. Abo-Zahhad, S. M. Ahmed, and O. Elnahas, "A wireless emergency telemedicine system for patients monitoring and diagnosis," *International journal of telemedicine and applications*, vol. 2014, p. 380787, 6 May 2014. [Online]. Available: http://dx.doi.org/10.1155/2014/380787

[15] P. Kakria, N. K. Tripathi, and P. Kitipawang, "A Real-Time health monitoring system for remote cardiac patients using smartphone and wearable sensors," *International journal of telemedicine and applications*, vol. 2015, p. 373474, 15 Dec. 2015. [Online]. Available: http://dx.doi.org/10.1155/2015/373474

[16] GSMA, "The mobile economy 2016," GSM Association, Tech. Rep., 2016. [Online]. Available: https://www.gsmaintelligence.com/research/?file=97928efe09cdba2864cdcf1ad1a2f58c&download

[17] E. Charbek, "Normal vital signs," http://emedicine.medscape.com/article/2172054-overview, 2015, accessed: 2016-12-12. [Online]. Available: http://emedicine.medscape.com/article/2172054-overview