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Analysing The Use Of A Smartwatch As A Medical Diagnostic Device And Methods Of Data Communication For Remote Health Monitoring

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***Abstract*— The Increase in the number of developers and designers in the smart device industry has resulted in embedding of different sensors, processors, and memories in small-size electronic devices such as a smartwatch. Smartwatches are the latest devices that have been developed for use for the purpose of real time healthcare monitoring of patients by healthcare givers.**

This paper analyses the use of a smartwatch as a medical diagnostic device for vital signs monitoring and the different methods of data communication used when it is employed for remote healthcare monitoring. It gives details on the accuracy of the smartwatch sensors by comparing the diagnostic medical measuring devises to smartwatch sensors by examining the difference on the results of vital signs such as blood pressure, heart rate and blood oxygen that has been done and validated. Moreover, it provides an understanding of any differences of what happen if all personal healthcare vital signs are taken from the wrist using embedded smartwatch sensors and when they are taken from different parts of the human body using the diagnostic medical devices. It also gives an explanation on different types of sensors that are embedded in a smartwatch and their work for personal healthcare monitoring.

Furthermore, it explains the different communication protocols that may be used by the smartwatch to send information to the healthcare givers. To further understand, analyze and test the accuracy and reliability of the smartwatch, Appium mobile application testing tools are employed to test the important features of the smartwatch such as the sensors, battery life and notifications.

Keywords—smartwatch, smartphone, sensors, diagnostic medical devices and communication

I. INTRODUCTION

Smartwatches and smartphones technologies have evolved, they are now embedded with multiple sensors that are changing the way patients are monitored as well as providing real time communication to their healthcare givers. Due to real time control of communication, different set of healthcare applications have been developed which are able to provide interactivity between healthcare givers and patients.

With smartwatches now greatly advanced with different sensors integrated and easy data transmission, they are being used for healthcare monitoring[1][2]. Sensors have been in use for monitoring of vital signs for patients and personal healthcare purpose for some time, as bedside monitors for hospitals and remote healthcare monitoring[3][4].

Recent technological advancement has allowed a move from the use of sensor nodes that can be strategically placed on different parts of the human body creating a cluster called wireless body area network (WBAN) or body sensor networks (BSN) that can be used to collect patient's vital signs to an easily worn device (smartwatch) embedded with multiple sensors and collecting all patient's vital signs from the wrist.

Sensors provide awareness to people on their health status at all times which are used by healthcare professionals in the early diagnosis and prevention of disease[5]. This has therefore resulted in an increased demand of Sensors for health monitoring purpose.

Most smartwatches requires to work in conjunction with the smartphone of the user for them to transfer information remotely. Communication is a vital component in remote healthcare monitoring, therefore, understanding the geographical and coverage area is important for a successful remote monitoring system. Several data communication protocols can be used to transmit data remotely. Communication methods that are employed in remote

healthcare monitoring includes bluetooth, ZigBee, WiFi and cellular networks.
As smart devices increase, so is the increased demand to ascertain their reliability and accuracy. A number of testing tools such as Appium, Robotium, Selendroid and Monkeyrunner etc. have also been developed to check the reliability and accuracy of these devices[6].

II. RELATED WORKS

This work discuses technical aspects of the Smartwatch, sensors and data communication with respect to healthcare monitoring. It also looks at different types of smartwatch embedded sensors and methods of how collected data is transferred to the health caregiver remotely. It further discuss testing tool employed to test important features of the smartwatch.
There are several articles and papers published related to smartwatch, sensor use for healthcare monitoring purpose [7][8][9]. Few years ago, smartwatches where limited in their functionality with little or no sensors related to health monitoring. However, recently smartwatches have immensely improve with a lot of sensor for personal healthcare monitoring as seen in [10] and [1] all these works show how smartwatch sensors have emerged and integrated in healthcare monitoring.
Furthermore, [11][12][13] provides related work on how information collected from smartwatch sensors is transmitted to healthcare professionals for the early diagnosis and prevention of disease. They also provide details of different wireless technologies that can be used to transmit collected data such as Bluetooth and WiFi etc.
For testing tools, [6] and [14] provide related work in relation to testing tools that can be used to check the reliability and accuracy of the smartwatches.

III. SMARTWATCH

A smartwatch is like a wearable computer that we carry with us everywhere we go, it has computational power that can connect to other devices via short range wireless connectivity (Bluetooth), it collects personal data through a range of sensors and can store and transmit data, it has an integrated clock and more important it provides alert notifications[2]. Most smartwatches don't work independently they require to be connected to a smartphone via bluetooth, they are smartphone companions. However, with the improved technology (Internet of Things (IoT)), there are smartwatches which are able to work independently and performs all tasks just like smartphone. Since smartwatches are convenient to wear, have long battery life, have different sensors meant for medical diagnostic with the capability to collect data in a continuous manner and able to continuously and autonomously transmit vital signs data remotely, is the reason smartwatches are the best healthcare monitoring devices of vital signs. Further, there are other benefit of smartwatches to the users and can carry out many different tasks in different areas such as navigation, text messaging, weather, time, calendar, communication, games, fitness and notifications.

IV. SENSORS

A sensor is converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument[15]. There are several types of sensors which are used for different purposes. However, in this paper, the focus is on the vital sign monitoring sensors for personal healthcare. Therefore, understanding what is required of these sensors (good and bad) is very cardinal.
A good sensor should be Sensitive to only the measured property. The output should be linearly proportional to the measured value or a simple function of the measured value. Therefore, sensitivity of the sensor is the minimum input of the physical parameter that will create detectable output change. Graphically and mathematically, sensitivity is expressed as shown in figure 4.0 and equation (i) respectively.

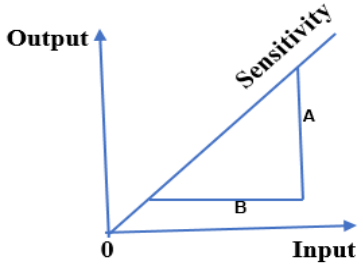

Figure 1.0 Graphical representation of sensitivity

$$\text{Sensitivity} = \frac{\mathbf{A\ (Output)}}{\mathbf{B\ (Input)}} \qquad \text{(i)}$$

When a sensor's output signal changes independent of the measured property it is considered a bad sensor. Bad sensors have noise due random deviation of the signal over time. However, errors due to change or drift (Systematic errors) can often be corrected using calibration. For noise or random errors, errors can be filtered out using signal processing techniques, although they are slow.

V. EMBEDDED SMARTWATCH SENSORS AND THEIR USE FOR PERSON HEALTHCARE MONITORING

Smartwatches are not only embedded with healthcare sensors, they are also embedded with other different sensors such as pedometer sensor for calculating your step count on a daily basis, sleep monitor sensor to monitor your sleeping pattern, GPS and tracking sensors to detect how much you are running and the position of your smartwatch etc[16].The template is used to format your paper and style the text. All margins, column widths, line spaces,

and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

A. Blood pressure (BP) sensor

Blood Pressure (BP) is one of the important vital signs that requires continuous monitoring in personal healthcare monitoring. It is defined as the pressure exerted by the circulating blood on the walls of blood vessels and is expressed as the ratio of the systolic pressure over diastolic pressure.

Blood Pressure Sensor is used to measure the blood pressure using the non-invasive method. It uses a pressure sensor to detect the blood pressure. Different types of sensors are used to detect blood pressure, but the commonly used are the piezoelectric sensors and accelerometer sensors.

B. Optical heart rate sensors

Heart rate measurement is a basic and important issue for either medical diagnosis or daily health monitoring, as issues relating to the heart are more serious and in case of medical emergencies, a proper doctor or healthcare provider should be consulted.
A smartwatch optical heart rate sensor helps in monitoring your flow of blood from your heart by calculating the heart beats per minute when the blood from your heart flows. The blood flow reaches your artery and is reflected on your wrist. Thereafter, the speed of the blood flow is monitored on your wrist to give you an accurate measurement.

C. Body temperature sensors

Body temperature is one of the most important crucial readings that healthcare givers continuously monitor on patients. The body temperature sensor is used to measure the body temperature, it emit light that penetrates the skin and allows the smartwatch to detect the blood flow which is then used to analyze how fast your heart is beating. A real time non-intrusive body temperature sensor for temperature monitoring is the latest emerging technology in both electronics and computer world, and plays the important role in providing of personal healthcare.

D. Electroencephalography (ECG) sensor, Electroencephalography (EEG) sensor and Electromyography (EMG) sensors

ECG, EEG and EMG sensors are used to measure heart, brain and muscle activity (respectively) over time by measuring electric potentials on the surface of living tissue. This is done through nervous stimuli and muscle contractions that can be detected by measuring the ionic current flow in the body. To achieve or accomplish this, a biopotential electrode is used. A biopotential electrode is a transducer that senses ion distribution on the surface of tissue, and converts the ion current to electron current. The cations are discharged into the electrolyte, and the electrons carry charge through the lead wires. The difference between ECG, EEG and EMG is that they each of these vary in amplitude and bandwidth measurements.

E. Blood Oxygen sensor

Oxygen saturation (SpO2) is one of the vital signs that also requires continuous monitoring in personal healthcare especially for humans with respiratory problems. Blood oxygen sensor are used to measure the blood oxygen saturation. Pulse oximeter is used to detect the blood oxygen saturation using probe that can be inserted either on the finger or ear. It has light emitting diodes (LEDs) which shine two types of red light through the tissue. The sensor on the other side of the tissue picks up the light that is transferred through the tissues of arterial blood in the peripheral circulation.

VI. SMARTWATCH TECHNICAL ANALYSIS

As developers and user of the smartwatches for person healthcare monitoring increases, it is very important to understand and analyze the medical and technical aspects of the smartwatch. There are several testing tools that are used to analyze the medical and technical aspects of the smartwatch and the following are the focus Areas for Testing and analyzing Smartwatches;

A. Notifications

Smartwatch Notifications should be accurate, quick, multilingual, and enable the user to take appropriate action. Therefore, testing tools are employed to test the notifications with different lengths, sizes, and types of data and validate the visibility of notifications on these quality parameters.

B. Sensors

Smartwatch sensors should always give accurate result are because they directly impact the user experience and the demand of a device in the market. So, test the smartwatch sensors in all possible physical and scientific conditions is cardinal.

C. Battery Life

A smartwatch battery is an important component of the watch, without it a smartwatch cannot work. It is therefore important that the smartwatch battery life must last longer. Since a smartwatch is a wearable device, it constantly consume battery via sensors, app notifications, and connectivity with the cell phone, it is important to check the battery consumption frequency separately for every sensor and application through testing.

VII. SMARTWATCH TESTING TOOLS

Android and IOS mobile application testing tools are used in testing of mobile device such as smartphones and smartwatches to ensure they meet the required specification, Quality goals or the set standards as per user requirement[6]. This paper discuss Appium for Android and IOS mobile application testing, a simple and easy to use testing tool that help to check if the smartwatches are meeting the set standards especially that they are being used to perform an important task of personal healthcare monitoring.

VIII. APPIUM MOBILE APPLICATION TESTING TOOL

Appium is an open source automation testing framework that covers automation testing across all three types of mobile applications which are the native, web and hybrid, all you just need is to start the Appium server and connect it to a mobile device or emulator to develop and run the automation tests[6][14]. It has several benefits which includes; allowing a single tool work on mobile and smartwatch in parallel to test different scenarios, it is an easy-to-use in which Selenium API is used for Automation testing and it does not need to modify applications for testing. Tests can run on physical devices only locally, while in Cloud they can run only on simulator/emulator.

Appium uses the Selenium Web Drivers to execute scripts. And being an open source cross platform tool, scripts can be written in Java, Ruby, C, Python, Perl which gives the programmers the liberty to use any language. The following are the Mobile application testing stages;

a. Documentation Testing; a non-functional type of software testing which is the necessary preparatory stage of the mobile application testing process.

b. Functional testing; an important test which is a method of verifying the applications features against the requirement specifications. Both native and web-based Mobile Applications can be functionally tested by different scenarios.

c. Usability testing; this test is carried out mainly by users. It is a method used for the evaluation of user-oriented interaction design of an application. This help to provide the direct input from actual user on how they will use the system.

d. UI (User Interface) testing; also known as GUI testing, is the process that requires testing the visual elements of an application to determine whether they accurately meet their expected performance and functionality. This test help to validate that the UI functions are free from any defects by testing all visual indicators and graphical icons which including menus, radio buttons, text boxes, checkboxes, toolbars, colors and fonts etc.

e. Compatibility (Configuration) testing; with the increase in the number of mobile manufacturing companies in recent years, mobile manufacturing companies are manufacturing a lot of different mobile devices. Because of this verity of mobile devices such as smartphones, smartwatches and bracelets, performing compatibility testing for Mobile Application is very important although it is a challenging problem due to the huge number of different mobile devices with various platforms which upgrade very often as well as the complexity in Mobile Application compatibility testing and its cost.

f. Performance testing; performance and stability testing have prime significance in mobile testing and these depend upon a number of different factors such as the server utilization, time required to load on a device, condition of the network and response of application.

g. Security testing; this test helps to check and ensure that there are no any loop-holes in the application which may result in loss of data by exploiting the application to identify vulnerabilities which may cause unauthorized access to the personal data.

h. Recovery testing; is a software testing technique which verifies the ability of the software to recover from failures like software/hardware crashes, network failures etc. The purpose of Recovery Testing is to determine whether software operations can be continued after disaster or integrity loss.

i. Interoperability Testing; is non-functional testing done to attain and maintain an applications interoperability characteristics. The test is done in order to guarantee the end-to-end interaction between two systems based on the predefined protocols and standards. This test is also used to authenticate the data loss, improper and defective operations, and defective interaction between two systems.

IX. COMPARISON BETWEEN SMARTWATCH SENSORS AND MEDICAL DIAGNOSTIC DEVICES.

With the rapid increase on new consumer health devices being developed to easily monitor vital signs continuously in real time such as a smartwatch. There is need for many of these vital sign measuring devices to be formally tested and studied in a clinical setting. However, they have already spread widely throughout the consumer market, as a result, there is a need to investigate the accuracy and precision of temperature, heart rate, blood pressure, and blood oxygen through comparing of results between the smartwatch and medical diagnostic devices that are used in hospitals.

In order to make this comparison, it is also important to understand how results or measurements are obtained or taken from these devices.

A. Taking of results using a smartwatch.

The embedded smartwatch sensors collects all vital signs results from a person through the wrist and the results are instantly displayed on the smartwatch digital display and the companion smartphone as soon as testing is being done. Figure 8.1 shows the position on the wrist where a smartwatch should be worn when collecting vital signs results.

Figure 2.0 correct positioning of a wrist worn smartwatch

B. Taking results using ordinary medical diagnostic devices

Different medical diagnostic devices are used to physically collect vital sign results by health professionals such as a temperature thermometer to measure human body temperature, Pulse Oximeters to measure heart rate and Oxygen saturation, sphygmomanometer to measure blood pressure etc. However, with improved technology all these devices are integrated into one diagnostic machine which is able to perform and collect all vital signs result. All you need to do is to specify on the diagnostic machine what measurement is being done.

When these devices are used, there is a standard way of collect vital signs, that's by inserting the measuring nodes on the specified position as shown in figure 8.1. This is similar to the way sensors are positioned when Wireless Body Area Networks (WBAN) or Wireless Sensor Networks (WSN) systems are employed. Figure 8.1 shows the specified position used when physically collecting vital signs by healthcare professionals.

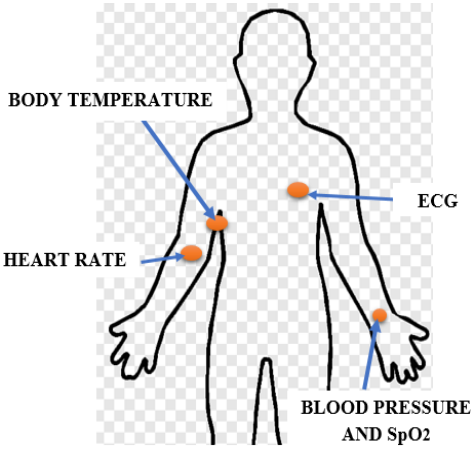

Figure 3.0 Measuring positions for vital signs

X. SMARTWATCH ACCURACY VALIDATIONS

For further investigations on the accuracy of smartwatch sensor measurements, few studies have been done to validate the measurements obtained from the wrist-worn smartwatches in comparison with certified medical devices. One of the study that has been done is determines the accuracy of vital signs measurements by a Smartwatch and a Portable Health Device: Validation Study[17].The other study done was on wearable devices for remote vital signs monitoring in the outpatient setting: an overview of the field which also provides information on the accuracy of the wristband which have similar sensors as the smartwatch[18]. Furthermore, other studies looked at assessing whether smartwatches are useful complements to certified medical devices for assessing PM2.5 health impacts. Smartwatches and medical devices were used to measure heart rate (HR) for 7 and 2 days consecutively, respectively, for 49 subjects in 2020 in Taiwan, results showed a difference of only <10%[19]. These provides detailed information on the accuracy of the smartwatch for use in monitoring of vital signs for patients and personal healthcare.

XI. METHODS OF DATA COMMUNICATION FOR REMOTE HEALTH MONITORING

Several communication protocols are used to transmit information encoded from the smartwatch sensors for remote healthcare monitoring of vital signs. As smartwatches are employed for personal health care, it is of great importance to look at the different method that can be employed to transmit encoded information. Most smartwatches requires to connect to a smartphone through bluetooth for them to operate. Once connected to each other through bluetooth, the two operates in unizon. However, the two devices should be in the range of not more than 10m apart within which bluetooth operates[20][21]. From, the

smartphone other different methods such as Wi-Fi, ZigBee and cellular networks can be used to transfer information remotely.

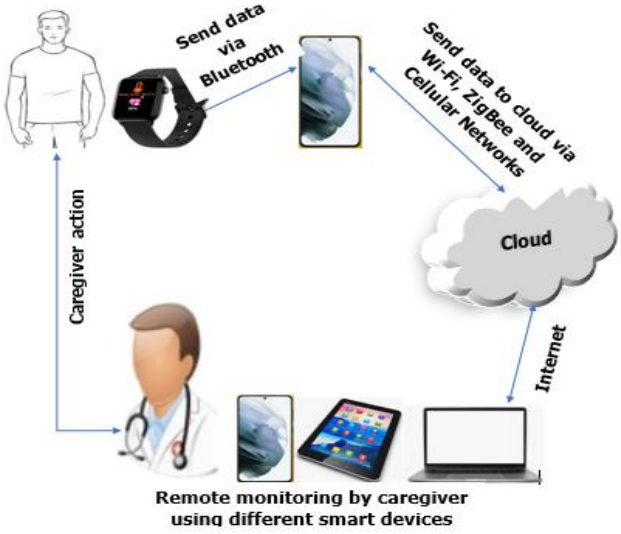

Figure 4. Data transmission for remote healthcare monitoring

A. *Bluetooth Technology*

Bluetooth (IEEE 802.15.1) is a wireless radio system solution with low-energy consumption that is designed for short range and cheap devices replacing the cable system on handheld devices and computer peripherals. It communicates on a frequency of 2.4 GHz ISM band. Bluetooth uses spread-spectrum to transmit data automatically and its applications includes cordless mouse, keyboards, joysticks, printers, Fitness band, a beacon (advertising its location), smartwatches and health monitors etc.

B. *Wi-Fi Technology*

WLANs are the most popular means of access to the Internet. The proliferation of mobile devices equipped with Wi-Fi interfaces, such as smart phones, laptops, and personal mobile multimedia devices, has heightened this trend.
Wireless Fidelity (Wi-Fi) includes IEEE 802.11a/b/g standards for wireless Local Area Networks (WLAN). It allows users to surf the Internet at broadband speeds when connected to an access point (AP) or in ad hoc mode. The IEEE 802.11 architecture consists of several components that interact to provide a wireless LAN that supports station mobility transparently to upper layers The basic cell of an IEEE 802.11 LAN is called a basic service set (BSS), which is a set of mobile or fixed stations.

C. *Cellular Network*

A Cellular network or Mobile network is a radio network distributed over land areas called cells, each served by at least one fixed-location transceiver, known as a cell site or base station. Cellular phones work much the same way as do the other wireless devices, Signals carrying voice, text, and digital data are transmitted via radio waves from one device to another. However, in cellular networks, the data is not transmitted to a central hub in a small network of devices like in a Wi-Fi network or direct from device to device when using Bluetooth but through a global network of transmitters and receivers.

D. *ZigBee Technology(IEEE 802.15.4)*

Defines specifications for a low rate Wireless Personal Area Networks (WPAN) for supporting simple devices that consume minimal power and typically operate in the personal operating space of 10 m. ZigBee provides self-organised, multi-hop, and reliable mesh networking with long battery lifetime .ZigBee is a low-cost, low-power, wireless mesh networking proprietary standard. It basically uses digital radios to allow devices to communicate with one another. A typical ZigBee network consists of several types of devices and must contain a network coordinator. Finally, ZigBee supports several topologies which include star, mesh, and cluster tree.

- *Comparison of Wireless Standards*

Table 1:Comparison of Wireless Standards[20][21].

Parameter	Bluetooth	WiFi	ZigBee	4G
Network	PAN	LAN	PAN	MAN
Topology	Star	Star	Mesh, Star, tree	Mesh
Power	Low	Low-High	Very low	High
Range	<100m	Up to 100m	10-20m	Where signal reach
Application	Network for data exchange headset	Any device with cellular connectivity	Sensor networks industrial automation	Use in WiFi, ADSL,Broadband, Digital TV and Radio
Data Rate	2.1 Mbps	Up to 1.3Gbp	250Kbps	Up to 1Gbps
Network size	Small	Medium	Very large	Very large

XII. CONCLUSION

As the use of smartwatches for personal healthcare monitoring to observe vital signs in real time increases, it is important to analyse and check if they are reliable and accurate. With so many different types of diseases and increase in the number of patients around the world, avoiding unexpected health problems by obtaining higher accuracy and reliable

personal healthcare monitoring devices is of great importance.

finally, mobile application testing tools and techniques have become an important part of the technology as well as the technology users. these tools, help to understand, analyze and test the accuracy and reliability of the smartwatch by providing checks to the unit, system, functionality and performance level testing.

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