Survey about the Accuracy of Wearable devices as Heart Rate Monitor, Fitness Tracker and Sleep Assessment.

Arij Alfaidi
Department of Computer science
University of Colorado Colorado Springs

Abstract—Mobile health applications have become an integral part of human life and is useful in continuously monitoring various health related parameters. These applications are installed in the smart phones to keep track of the health conditions. Smart phones need various sensing devices and accessories and cannot work on its own to perform the monitoring activity. The sensing devices are extra attachments and are tedious to carry along when the user moves from one place to another. This issue can be resolved by using wearable devices. The wearable devices are designed in a way to accommodate all the sensing mechanism and at the same time are comfortable for the user to move along. These devices are being widely accepted by the users due to their cheap price and effectiveness.

This work presents the details of the wearable devices and its effects on the mobile health applications. The paper explained the functioning of the wearable devices which are divided into three main categories heart rate monitoring, Fitness tracker and sleep assessments. How these devices are working are explained to have a full idea about the accuracy of the wearable devices when compared to other similar products. There should be more studies about how accurate these devices to get benefit of these wearable devices in mHealth system as a way for enhancing the user health life.

keywords: Wearable devices, Sleep assessment,Heart rate monitor, Fitness tracker.

I. INTRODUCTION

In the contemporary world, a lot of technological inventions are being developed at a fast rate. In this regard, many businesses are using technological development to improve their functions and operations for achieving the required levels of output. Many people can afford to manage their social and private lives using different technologies like personal digital assistants among others [1]. Technology has improved the way information is developed and shared. The development of the Smartphone seems to have a big impact on the social and economic dimensions of life. With these smart devices, people can manage their emails and social networking at their convenience. Developers have focused on creating many essential functions that people often seek. Thousands of mobile applications are influencing business practices, governance, and investment. In this regard, Smartphones have made a huge impact on the healthcare industry as well. Wearable devices at present have inbuilt sensors to monitor critical human body parameters such as heart rate, pulse rate, body temperatures, and others. Maintaining normal human health among the busy schedule is a major concern in the present situation. A lot of health and Fitness applications are being downloaded by users on a daily basis. To be able to manage your health from your phone is a promising idea. Smartphones with wearable devices use its inbuilt sensors for monitoring purpose. Wearable devices have sophisticated sensing mechanisms and it utilizes the smartphone processing capability to provide more reliable and meaningful results. We have a lot of mobile health applications on the smartphone that has been developed a lot using wearable devices with their wireless sensors. these devices can collect many essential health data that we could not measure it before unless in hospitals. For instance, we can measure Calories Burned, Sleep, Blood sugar, Cholesterol, Medications, Nutrition, Heart Rate, Weight, and Fitness. Also, we can save these measurements on our smartphones to keep track of our health life [3].

A. Background

Wearable devices are the miniature electronic devices with embedded electronics that are wearable like clothes and they get adjusted to the human body without causing much discomfort [4]. They generally acquire information on different health-related parameters and transmit them to a location for further processing. Wearable health devices in recent times have gathered the attention of lot many developers and researchers. The changing lifestyles and increased workloads have led to many health-related issues. There is a considerable increase in the people of old ages. Statistics show that the seniors population will increase considerably over the years 2012 to 2050. It is estimated that by the year 2050 people above the age 65 years will be around 83.7 million [1]. This population is almost doubled that of the year 2012. Finding a way to help people managing their health life without much hospital interventions and other individual assistance is essential. Wearable sensors can become a good companion for such people. Wearable devices are available for different segments and can be categorized into four broad segments depending upon their applications usability [2].

- Fitness and Wellness
- Medical and Healthcare
- Entertainment and Connectivity
- Industrial and Military
The demands for the wearable devices are on the increasing trend. Fig 1 shows the demand trends in the past few years. Researches show that (15 percent) users in the United States currently uses wearable technology, including Smartwatches or fitness bands. While 19 million fitness devices are sold in 2017 that number is expected to grow to 110 million in 2018. As shown on the figure 1. The comfort provided by these devices has made them popular over the years. There is a further scope of improvements and work is being undertaken in these areas. The need for continued monitoring is one reason for the increased in the demand of these devices [5], [6].

The general architecture of the wearable health system is shown in Fig 2. The user will wear the device having a sensor and its associated accessories. Sensors will be in the wearable device that the user wears, these sensors measure health data based on the user or application request. This setup will continuously monitor the parameters and acquire data pertaining to critical information. Depending upon the application these acquired data will be transferred to the user interface, medical/research center or other concerned agencies. The data will be saved on the user device or on a cloud system. These medical centers will provide feedback to the user based on the measurement captured by these devices [7], [8].

B. Sensors in Wearables

Wearable medical devices are designed as per the applications and have built-in sensor according to the requirements. The user has to choose the one that suits their requirements. Each sensor measures different health data. Wearable sensors can be employed in almost all parts of the body. The user can wear them like any other device and become comfortable. The user can use them as shoes that will contain sensors to sense the position and movement. They can also be used as a band or a wristwatch. In addition to displaying the time, they will also capture various information from the human body. These sensors can also be used as an attachment in waist, wrist, chest or any other part of the human body. These sensors can give various information such as heartbeat rate, blood pressure, muscle activity, heart activity, lungs functioning, blood flow, blood volume, pulse rate, brain activity, and many others. Table 1 can show different type of sensors measuring different Physical data [9].

<table>
<thead>
<tr>
<th>Type of sensor</th>
<th>Type of Bio-signal</th>
<th>Description</th>
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<tbody>
<tr>
<td>Skin/Chest electrodes</td>
<td>ECG</td>
<td>It captures the heart functioning at different phases of a heartbeat.</td>
</tr>
<tr>
<td>Pulse</td>
<td>Heart rate</td>
<td>It measures the heart rate.</td>
</tr>
<tr>
<td>Oximeter/skin electrodes</td>
<td>Heart sounds</td>
<td>The microphone captures the acoustics signal generated during the heartbeat.</td>
</tr>
<tr>
<td>Phoniatric radiograph</td>
<td></td>
<td>Useful to estimating smooth functioning of the heart in systolic and sys-</td>
</tr>
<tr>
<td>Arm cuff-based monitor</td>
<td>Blood pressure</td>
<td>Force exerted by circulating blood on the walls of blood vessels.</td>
</tr>
<tr>
<td>skin patch</td>
<td>Body and Skin tem-</td>
<td>The ability of the body to radiate the generated heat.</td>
</tr>
<tr>
<td>Pulse Oximeter</td>
<td>Oxygen saturation</td>
<td>The amount of oxygen concentration in the patient blood.</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>Body Movement</td>
<td>Measure electronic force in 3D space. To monitor the movement.</td>
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These sensors when used in mobile healthcare application are useful in developing different tailor-made healthcare and Fitness application. Using these sensors, we can develop and create different medical applications also it opens the door for researches to improve health application to serve different goals as discussed below: [9]


This service allows the user to be monitored round the clock at any location. The patients health is continuously monitored and the data is saved in the user phone. The data is also sent to the medical or research center.
2-Intelligent Emergency Management System.
In addition to health monitoring, these systems have the capability for decision making in a crisis situation. It will measure the critical parameter and alert the hospital or other agencies in the situation of large deviations in the critical parameters. In some situations, patients may not be in a condition to inform hospitals on their own and these applications can be useful in such cases.

3-Health-aware Mobile device.
These applications are more advanced and identify the behavior of the signal movements in neurons for detecting various parameters such as pulse rate, blood pressure, and level of alcohol. The brain has neurons that produce different potentials for different activities. By measuring these potentials we can develop these kinds of applications that help the user to have a more clear idea about his health data.

4-Access to human Emotions and Mental health.
These systems will continuously track human activities such as movements, speaking pattern, location, sleep time and others to estimate the human emotions and mental health conditions. It has a dedicated algorithm that associates different parameters and links them to get human activities at any point in time. These applications will be helpful for people with mental problems to help them improve while they are monitored and checked all the time.

C. Requirements for General mobile healthcare application
[10], [11], [12]
Mobile healthcare application requirements are rapid changes with the user healthcare need. But in general, there are some requirement should be considered in any mobile healthcare application:
1. High level of security that the patient needs to ensure his data are safe and secure by using different security methods for encryption and access control.
2. Demand on a high level of privacy since the health data is very private to the patient. The acquired data must have a rugged storage system to avoid data loss.
3. The patient device (phone, wearable) function, reliability, and usability play an important factor.
4. The highly reliable and usable wireless base that should support prioritized communications with appropriate network resources.
5. The sensing mechanisms are dedicated to a particular application and a huge amount of cost is incurred on its design and development. The break-even point is thus large for the wearable devices.
Meeting the demand and generating appropriate technology is a challenge. In addition, to meet the demand all the aspects such as security, safety and others must not be tampered and kept intact. This raises different challenges facing mobile healthcare with wearable devices.

D. Challenges
The requirements related to mobile healthcare applications are increasing at a faster rate. The requirements are associated with challenges. Researchers are trying hard to develop a more sophisticated system so as to meet the requirements. Some of the challenges associated with wearable devices and health monitoring are as follows

Privacy and Security:
The data acquired by the health care applications are private to the patient and crucial for further diagnosis. The privacy and security of this data is a big challenge. There is continuous research on how secure we can keep the data collected for the mHealth system through wearable devices. To be more specific the security and privacy challenges can be divided into the following four categories and discussed:

- Security of Data sharing: The data collected by the sensors in wearable devices are related to the User physiology, physical activities, social behavior, and many other parameters. These data are stored for later analysis by physician or researchers. So, there arises the question on who and where the data has to be shared and stored. Research shows that users are not fully aware of the information on who has access to their health data. It is the researchers and developers responsibility to explain in an understandable way on how the users health data is stored and shared [13], [14].
- Authentication: Since the data is collected in the user personal phone the application can check for the user authentication before presenting the data. There is a chance of the phone being hacked by somebody. It also raises a new security requirement for developers to suspend the data transfer when the user device is used by someone else, [13] , [15], [16].
- Confidentiality: The information has to be kept secret and the identity of the patient should not be revealed. The health application should ensure to the user that his identity is protected. [17], [18].
- Continues Monitoring: Continuous monitoring and transmission of the data may have more probabilities of data theft and other related issues. The data transmission in such cases has to be well protected. The user must choose based on the situation whether continues monitoring is needed. [18], [2]

II. HEART RATE MONITORING IN WEARABLE DEVICES
There are a lot of wearable devices that measure the heart rate of the user. These devices can be chest-worn devices, wrist-worn devices. The technology used in the most wearable devices is photoplethysmography (PPG) signal and it measures the change in volume to estimate the health conditions. One of another technology that used in Chest worn devices that captures the Electrocardiogram ECG signal to find out the heart functioning [19] [6]. Heartbeat rate varies with the physical activities and these wearable devices gave the user more awareness about their heartbeat rate during different daily activities. The sensors used in these devices are programmed to measure the heartbeat rate read at any time during the day. Here is the explanation of the two methods used in these sensors.
• (PPG) measurement Technique: [20]
  • This technology is based on the simple fact that blood is red in color and it reflects red light and absorbs green light.
  • These sensors use green LED lights combined with light-sensitive photodiodes to sense the amount of blood flowing through for example the user wrist at any time.
  • When the heart beats, the blood is pumped and it flows in the wrist. The green light absorption is greater for increased blood flow and is less between the beats.
  • When this LED lights flashed a lot of times per second, these devices can estimate how many times the heart beats. Furthermore, the heart rate sensor is proposed to stability for low signal levels by rising both LED brightness and sampling rate.

(ECG) measurements Technique: [20], [21], [22]
• When the heart beats, a small electrical signal is sent through the heart muscles causing one heartbeat.
• The device detects this electrical signal (voltage) through the skin. This device has to be in direct contact with the skin to detect the generated signals.
• This electrical signal is picked up by the electrodes in the chest-worn devices then sed to the transmitter in the device.
• This signal then continuously transferred through wireless mode, usually by Bluetooth 4.0 to a receiver.
• The user phone that enables Bluetooth will receive the data read and display it to the user. This method needs a Bluetooth connection transmitter and a receiver.

The sensors being used in heartbeat rate measurement devices have to capture very small signals and has chances of noise affecting the performances. Hence, there is a lot of concern about the accuracy of the measured data. This has got the attention for many kinds of research to measure the accuracy of these devices.

The difference in data accuracy collected by wrist-worn and chest-worn devices is not large. This difference, however, increases while the user in rest and when performing heavy physical activity [7]. In general chest strap is considered more accurate and reliable since it closer to the heart and it cant move while measuring for any amount of physical activities. With respect to the price, both these devices are affordable and effective. The final factor to consider is the battery life of these devices. Chest strap uses traditional batteries that stand for 350 continues hours while some wrist-worn devices such as Apple watch asks for daily charging requirements [23], [24].

Since chest worn devices use traditional ECG technologies it tends to be more accurate [7]. On the other hand, the wrist-worn wearable devices are stylish and are easily wearable. Research is being done to get more accurate information from wrist wearable devices. Table II shows a summary of the activity measurement in some famous wearable devices used in research experiments about how accurate this device as heart rate monitor. [7] [35] [7][8]

Heartbeat rate monitors are available in different types they follow different principles to estimate the rate. The accuracy of these devices is closer when the user is engaged in large physical activities. The rate measured by different monitors for normal or no works has a mismatch. With the advancement in technology, users are looking for accurate, comfortable cost-effective and stylish wearable devices. Research is being carried out to develop more and more effective wearable systems. The developed devices have to be qualified through a series of clinical trials. The accuracy of these devices is limited only to a specific range and are not suitable for all kinds of applications.

Results based on these experiments have many limitations. some of these papers mention it and some generalize their results. that raises different limitation about heart rate monitor devices:
• The result cannot be generalized so More research to evaluate the accuracy are needed.
• Most of the experiments was done on Healthy people so we need more experiments on people with a heart condition to evaluate how accurate these devices.
• In most research, the claim chest strap is the most accurate and stable because it uses ECG method which is not true when the user is doing a heavy activity the amount of sweat in the chest area is more than wrist area so the chance the device is moving is higher.

III. WEARABLE DEVICES AS FITNESS TRACKER

Researches show that one-third of the US population is obese and another one-third are overweight and at high risk for future obesity. Obesity causes a lot of serious medical conditions with time and may lead to death. Statistical data is

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<tr>
<td>Apple Watch</td>
<td>Wrist worn Many Apps for measuring and research purpose. PPG Tech.</td>
<td>Compared to other wrist-worn devices the error rate is less so it considers accurate HR monitor even when the user is resting. [25], [20]</td>
</tr>
<tr>
<td>Fitbit</td>
<td>Worn in wrist Count heart rate based on hourly basis to give the user a more detailed picture. The most popular device used in many types of research for different tasks. PPG Tech.</td>
<td>Reasonable result measuring heart rate, Long Battery life. [26], [27], [20]</td>
</tr>
<tr>
<td>Mio Alpha</td>
<td>Worn in wrist Measure heart rate. The most popular device used in many types of research for different tasks. PPG Tech.</td>
<td>It can be considered a valid HR monitoring technology for use during graded exercise testing. [28], [27]</td>
</tr>
<tr>
<td>Chest strap</td>
<td>Chest worn Measure. The data can be set to any user device receiver that has Bluetooth capability. ECG Technology.</td>
<td>Most accurate heart rate measurement device. [28], [27], [20]</td>
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estimates that 20 percent of US deaths attributed to obesity and physical inactivity [29]. Treatments through direct appointments with specialist and change of healthy diet have helped a lot to reduce weight. The cost of these services are high and need a lot of time. Wearable health device monitors the body conditions and helps reducing obesity and weight reduction [24]. Obesity can be reduced through food control and regular exercise. It involves the burning of calories to reduce weight. The sensors in the wearable device will continuously record the user movement steps and the calories burned. It will then suggest the user on any additional exercise or the food control. It will update the risk level at a continuous time interval and also help the users on dos and donts for reducing weight [29]. In general wearable devices for Fitness, tracking is either wrist-worn or ankle-worn devices. They have sensors to measure heart rate and counts the steps. The technology used in these sensors are: 3-axis accelerometers, which measure speed and direction.

Altimeters to track the elevation of the device.

Using this data, tracking devices make a measurement to detect steps, running distance.

Additional sensors used in more advanced devices include: skin temperature sensors, optical sensors to measure heart rate.

Based on the available information the calories burnt can be calculated. With the user-friendly application on the user personal device the user can regularly monitor his/her improvements [29].

The accuracy of these devices is measured to evaluate how accurate these devices to count the steps also how accurate tracking the movement during different activity. Some of the wearable devices for fitness tracking and how accurate they are based on researches experiments are presented in Table III.

Most of the fitness control devices measure the heartbeat rate and counts the steps. They use this information for estimating the calories burnt. The step counts are measured through the accelerometers. The accelerometers measure the rate of change of the velocity and any rate change is considered as a step. However, in actual practice, humans perform physical activities not only through walking but also through various other ways such as exercise, hand movements, weight lifting, boxing, and many others. In all these cases the step movements are very less and the system may not give the actual information on the calories burnt. These sensors perform better when the user walks at high speeds. Some of the limitations associated with these wearable systems are as follows:

- Step count cannot be always related to the calories burnt.
- Some realistic approach is required to be adopted to estimate the actual work done. [29].
- Power consumption by these devices is large and gets drained when used for longer time periods [21].
- Information on energy input in the body is a kind of user input in most of the applications and the results rely mostly on the user input rather than the realistic situations [29].

### TABLE III

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<tr>
<td>Apple Watch</td>
<td>Wrist worn measures all the way the user move, such as walking the dog, taking the stairs, or playing with your kids. The user has many application and choices.</td>
<td>Estimates of energy expenditure are poor. More accuracy in step counting heavy activity. Battery need to be charged daily. [30]</td>
</tr>
<tr>
<td>Fitbit</td>
<td>Worn in wrist ability to track steps, distance, calories burned, floors climbed.</td>
<td>More accuracy in step counting in speed walking. Reasonable result measuring heart rate and estimate the calories burned. Long battery life [26], [31]</td>
</tr>
<tr>
<td>Jawbone</td>
<td>Worn in wrist the device includes a food-logging feature, which helps improve daily eating habits.</td>
<td>Error rate with step counting is high compared to the other tasks. [26]</td>
</tr>
<tr>
<td>Moov Now</td>
<td>Wrist/Ankle worn The user app gives audio instruction as a private coach. It provides workouts and feedback on those workouts.</td>
<td>Most accurate step count device. Effective to help change eating habits. Effective as a private coach that motivate the user. [32], [31]</td>
</tr>
</tbody>
</table>

- It is hard to obtain the experimental proof for the design.
- Sufficient clinical trials are not carried out before putting the system to use [29], [21].
- Positioning of the wearable device and estimation of the accurate heartbeat rate is a challenging task. For example, the chest strap may get misaligned while running and give incorrect results [21].
- Longer Battery Life: Power sources need rapid peak power and may be subjected to repeated charge and discharge cycles during the use-life of wearable devices. This reduces the life of these systems. Researches should focus on a new method of power saving. [33], [34], [35]
- A lot of people credit the trainer for the positive fitness result. The information as provided by the trainer can be very well provided by the software applications on Smartphone. This will make the entire process as cost effective. There is a need for creating awareness about the products and its benefits. [36].

### IV. SLEEP ASSESSMENTS IN WEARABLE DEVICES

Sleeping is a daily activity that plays a big role in human growth and activeness. Quality of sleep can affect the quality of life in a direct manner. People who do not have sound sleep are subjected to many health-related problems. A lot of sleep-related problems needs to be studied and solved. Examining sleep need the patient to sleep at the clinic for long hours while undergoing monitoring. The wearable device can monitor sleep as a daily activity needed. These devices can give the users a whole picture about their sleep pattern and
sleep times and what is the body functionality at different times during sleep [37].

Wearable devices provide a sleep monitoring system based on actigraphy measuring of the wrist activity. Wrist actigraphy is used for the long-term sleep study and it is popular for its low cost, good portability, and the performance. However the actigraphy can have identified only two states, either the user is sleeping or awake. This technique is more acceptable when compared to Polysomnography (PSG). PSG is a costly affair and contains electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG) and electrocardiogram (ECG) wires when the user is sleep to monitor his sleep cycle which is not as comfortable as wrist-worn sleep trackers. [38].

Many studies show that sleep stages can be classified by sleep-related physiological signals such as blood pressure, heart rates, Galvanic skin response, respiratory rate, and heart-beat rate. Measurement of all these parameters can provide more accurate and quantitative information about sleep. Most of these wearable devices use heart rate variability since the accuracy of measuring heart rate is high and reliable when compared to other parameters [37]. Researches are being made to assess sleep stages at a different time during sleep. It will help people (at different ages) who suffer from sleep-related problems. [39].

The performance of these wearable devices can be carried out through experimental validity. User can have to monitor the sleep using a wrist-worn wearable device as well with a phone Camera to record all sleep cycle duration. Then these data will be saved and the results from both methods the traditional PSG that used in clinics and Actigraphy can be compared. In table IV the most used sleep tracker devices in different experiments and what is the result of their accuracy.

Reading the experiment in research papers about the accuracy of these sleep tracker devices raise many challenges and limitations. Some of them are: [39], [37], [42], [3]

- Actigraphy can only distinguish a transition of wakefulness from sleep and it is not the perfect alternative sleep assessment tool. It requires assistance from other physical parameters to give more meaningful information.
- Sleep requirement largely differs from person to person. One can lead normal health with just 5hrs of sleep per day whereas the other person may require twice as much as of the first person for maintaining normal health. It is thus difficult for the application to arrive at the conclusion.
- The power requirements are large as these devices operate for a longer time period. Short battery life in some devices affects the result.
- Deprivation of sleep does not directly affect human health but triggers various other complications. It is thus difficult to arrive at the conclusions.

V. Conclusion

This paper carried out a detailed review of different aspects of the wearable devices. Three main human activities were presented in detail. The presented activities are heart rate monitoring, Fitness tracking, and sleep assessments. The challenges associated with each of the activities were discussed. It was found that the users are looking for sophisticated, accurate, safe, low cost and a comfortable wearable device to assess the parameters. The design and development of these devices have a lot of challenges such as The power consumption associated with these devices are large and it is urgently required improvement in this area. It is understood that the future of the wearable device is massive and more people are opting for these devices. It makes the user independent and they get the required information without spending much time on it. The discussion presented in this work shows that wearable device will benefit people in a great way by educating the users about their health issues to be more aware and careful. Also, it helps them manage their health without the need for staying at hospitals.

These devices have a large scope for further growth. The demands for this equipment already have exponential growth and are still increasing. These devices can be further improved by integrating and developing a common single device that can measure all the health-related parameters through settings. The user will buy the device and make certain settings to put them to use. Such a device will bring down the cost of healthcare to a large extent. Nanotechnology can be more and more used to further miniaturize the system. The need for future studies and experiments is always in demand in this field while it is growing daily.

REFERENCES


