Development of Wearable Solutions for Healthcare: Initial Stages Analysis and Case Study

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Abstract. In the last decade Wearable Health Devices (WHDs) have enabled continuous monitoring of various human vital signs during both everyday routine and emerging situations, such as hospitalization etc. Nowadays most of WHDs are tightly coupled with smartphones, which provide means for gathering, processing, analyzing and saving personal health data for further use. The constant development of new devices and improvement of existing ones enlarge WHDs and mobile applications markets. This pose difficulties for non-technical users to select most fitting solution for their existing problems. In this paper we present an survey of up to date WHDs as well as vital signs that can be monitored using them. Further, we provide list of basic characteristics that have to be analyzed while selecting the appropriate WHD and state upcoming challenges that emerge in wearable devices industry. Additionally, we present the developed glucose rate management applications. This applications aim to help user in managing personal glucose rate, based on gathered and stored data from various WHDs.

Keywords: Wearable health devices, Wrist worn motion trackers, Smart clothing, Glucose rate, Mobile applications, Healthcare monitoring.

1 Introduction

During the last decade, wearable devices have attracted much attention due to high perspectives that it can bring into everyday human lives. The [1] define wearables as electronic devices that detect, analyze and transmit information concerning vital signals, ambient data etc. and are worn close to skin.

Being introduced as a concept in the late 1990s the wearable devices become an emerging technology with estimated growth of the market over the 25.57% within 2020 – 2025 period and growing from $24.640 billion by the end of 2025 [2].

Healthcare quickly became one of the biggest adaptors of wearable devices ides starting with the "patient empowerment" concept. This concept stands for placing the

individual user at the center of the healthcare delivery process and providing clients with ability to manage their own health and interact with care providers. Now, WHDs help to create a synergy between biomedical technologies, micro and nanotechnologies, materials engineering, electronic engineering and information and communication technologies domains.

The use of WHDs allows to extend the period of monitoring various vital signs due to ability to be used outside of clinical environments. This improves the accuracy of medical diagnostics, ensure a better support and speed up the recovering from a medical intervention or body injury. Always targeting the patient body monitoring process WHDs can be applied for medical, activities, fitness, wellness purposes. Based on the highlighted purposes the WHDS can be divided into two main areas – monitoring and medical, with further splitting into four sub-categories [3]:

- Activity – fitness, monitoring of an active life style and recovery procedures.
- Prediction – identification of upcoming events, based on the gathered personal data and preventing of chronic problems.
- Anomaly detection – identification of unusual and unexpectable patterns in personal data.
- Diagnosis support – providing the help in most important task of clinical monitoring based on the retrieved data of patient vital signs and various other health records.

The WHDs purpose shows a high need of devices to being reliable, accurate, secure, comfort and ergonomic that creates several design challenges discussed in this paper.

Being highly emerged technology it shows a great rate of new devices development as well as constant update of existing ones, therefore posing difficulties for non-technical users to navigate among this variety. The Consumer Technology Association (CTA) [4] has presented a guidance on WHD solutions along with customers market review. CTA states several advices, that should be considered by consumers on using wearables. Those advices mainly address the customer goals, while questions on data security, privacy, reliability etc. are lightly stressed out. The deep analysis of such crucial questions to WHD technologies as connectivity, security, data safety and integrity are presented separately in [3, 5-8]. This paper presents survey of up to date WHDs market and shows the analysis of basic vital signs that can be tracked using specific wearables. Along with challenges we provide list of main characteristics that have to be encountered while selecting the device which fits the most to solution of existing problem. Finally, we present the initial development stage of children diabetes management application for both iOS and Android.

2 Wrist Worn Motion Trackers and Smart Clothes

2.1 Wrist Worn Motion Trackers

Wrist worn motion tracker are designed to monitor and track outdoor activities and measure different fitness metrics. Starting from sport to recreation the person motion detection this trackers have a wide range of application. There already were employed

a lot of semiconductor-based tracking system to allow users to access various types of interface control with body motions and gestures [9]. While motion tracking is an important for healthcare due to need for high accuracy, these wrist worn devices are typically used for fitness and training purposes instead of medical application.

This wrist worn motion trackers have already gained the maximal popularity among customers of all ages. The Tables 1, 2 present results of comparison on basic design features of the most popular wristband trackers from top companies – Fitbit, Garmin, Polar, Withings, Xiaomi. Data from long-term tracking is extremely helpful for further medical diagnostics, therefore the greater internal storage capacity is needed from wrist worn devices. As we can see, the greater storage is provided by top Fitbit motion trackers, while the other trackers expect customers to make frequent synchronization of their WHDs with smartphones.

Table 1. Comparison of design and communication features of Fitbit and Garmin trackers

Features	**Fitbit Versa 2**	**Fitbit Ionic**	**Garmin Vivosport L**
Price ($)	199.95	249.95	169.99
Size (mm)	40 x 12	38.59 x 12.2	21.5 x 14.8
Weight (gm)	38	30	24.1
Display size (mm)	36	36	72 x 144
Storage size	4 Gb	2.5 Gb	14 days of tracking
Screen type	AMOLED	LCD	LCD
Screen protection	Gorilla glass 3	Gorilla glass 3	No
Usable time (days)	6	4	7
Wireless interface	BLE, Wi-Fi 802.11 b/g/n, NFC	BLE, Wi-Fi 802.11 b/g/n, NFC	BLE, ANT+/ANT
GPS	No	Yes	Yes
OS	Fitbit OS	Fitbit OS	Proprietary OS

Table 2. Comparison of design and communication features of Polar, Withings and Xiaomi trackers

Features	**Polar Ignite**	**Withings Steel**	**Mi Band 4**
Price ($)	199.90	119.95	69.99
Size (mm)	43 x 43	36.3 x 11.5	21.6 x 10.8
Weight (gm)	35	37	30
Display size (mm)	30.48	40	24.13
Storage size	3.5 days	7 days	16 Mb
Screen type	LCD	OLED	AMOLED
Screen protection	Dragontrail glass	No	Gorilla glass 3
Usable time (days)	5	25	20
Wireless interface	BLE	BLE	Bluetooth 5.0
GPS	Yes	No	No
OS	Proprietary OS	Proprietary OS	Proprietary OS

All trackers are waterproof and several devices provide users with additional screen protection, therefore preventing of damaging devices during active outdoor time spending. All wrist bands are equipped with Bluetooth technologies which is suitable to create connection with a personal smartphones, and several devices also have a Wi-Fi module inside. All trackers are compatible to iOS and Android operation systems but come only with customized software application.

2.2 Smart Clothing

Smart clothing can monitor the physical condition of the patient, they include a wide list of wearables, starting with sportswear, smart shirts and body suits to e-textiles , chest straps, specific medical apparel, work wear monitoring clothes and military apparel.

The "smart clothing" design was presented in [10]. It shows how to obtain ongoing healthcare signals from various indicators by forming a source data center for comprehensive health monitoring [10]. With smartphones, mobile applications, cloud computing and big data analytics the smart clothing systems becomes intelligent [11]. The Figure 1 shows how smart clothing is communicating with outside world through embedded sensors. It should be noted that existing traditional health monitoring systems, that mainly collect a limited number of body signals, are not useful for chronic diseases in a full-range health monitoring system.

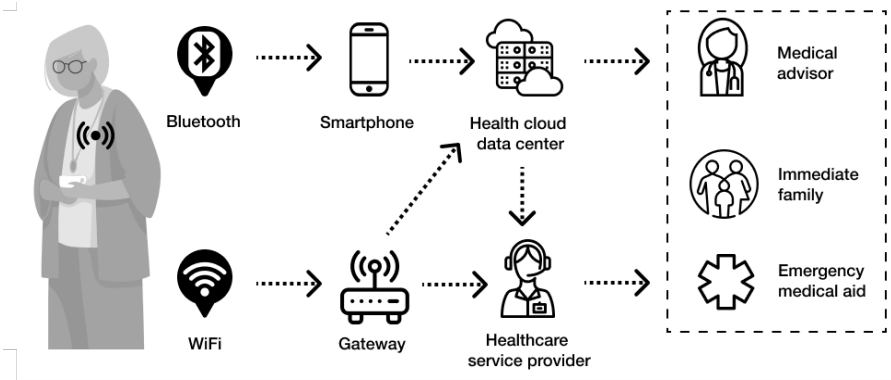


Fig. 1. Communication of smart clothes with outside world

The sensors deployed on the patient body is the main difference between old wearable devices and smart clothing. The smart clothes integrate all sensors into textile, which additionally prevent possible skin irritation. Sensors have to be placed properly to provide an accurate user data, thus this is known to be crucial point. To provide efficient design, the quality of the used sensors, as well as accurate positioning, layout of flexible cable, low-power wireless communicators and patient comfort are of high importance. The patient data, gathered from embedded sensors, is transferred via Bluetooth or WiFi. The presented in 2009 Bluetooth Low-Energy (BLE) technology, which is Bluetooth version 4.0, is widely used in WHD because of low-power con-

sumption and low prices. It provides a 100 m communication range with 1 Mbps data rate, while consuming only 10 mW. The WiFi protocol lower layers were also adopted for WHD use and are mainly applied when a higher distance for communication is needed as it provides a 150-200m range with 1 Mbps data rate under 1 W power consumption. The gathered raw data further flows through gateway or mobile application on the smartphone to the health cloud data center where the collected data is cleaned, converted into machine-readable form, processed with machine-learning algorithms, stored and transmitted for further decision making. Finally, the healthcare service provider along with medical advisor and family receive a constant update on patient health information. Using, such approach a great variety of vital signs can be constantly monitored to prevent a health threatening situations.

3 Vital Signs

There are five vital signs that should be monitored during long term period to show the potential problems and guarantee elimination of life-critical events, namely – body temperature (^{o}C), heart rate (bpm), blood pressure (mmHg), respiration rate (breaths/min), blood oxygen saturation (%):

- Heart rate (HR). HR is one of the basic everyday measurements that can be gathered through smartwatches, activity trackers or even with smartphone camera. Meanwhile, the most accurate data about person heart rate can be extracted from ECG.
- Blood pressure (BP). BP is weighted as the most important cardiopulmonary parameter. With two basic values – systolic (upper value) and diastolic (lower value) pressures the BP indicates how blood flow is pushing against the artery walls. Previously the BP was measured with pressure cuffs and stethoscope, but this approached has been fully automated [7]. While continuous BP monitoring is an important part of patient diagnosis and medical treatment the long wearing of automated pressure cuffs can lead to the sleep problems and skin irritation.
- Respiration rate (RR). RR is known as one of the main physiologic indicators during patient observation as it shows the number of breaths during a minute. Nowadays the pulmonary function tests, such as spirometry, lung volume and diffusion capacity etc. are widely used to measure the respiratory function. The various accelerometers, wearable pulse oximeters and ECG results are applied for repetitive RR analysis.
- Blood oxygen saturation (SpO_2). The value of SpO_2 presents amount of oxygen circulating in human blood, normally varying between 95% and 100%. The arterial blood gas test is commonly applied in medical practice to detect SpO_2 level. Even through this test is accurate it can be hardly made at home as it requires taking patient blood samples and specific medical equipment. Thus, the wearable pulse oximeters can be applied for repetitive analysis of SpO_2 level at home. Another one non-invasive approach - photoplethysmography sensor ring that can be wear all day for continuous SpO_2 monitoring is under development [10].

- Body temperature. The major part of clinical patient state analysis starts or include process of measuring body temperature. This value shows balance between body heat production and loss. While it changes through the day in the normal diapason [36.2°C – 37.0°C], the increase of body temperature over 38°C indicates the illness and infection of human organism. The all-day temperature measurement using wearable technologies can be performed via adhesive patch-type devices or wrist-worn bands [11].

While, listed above vital signs are essential to understand ongoing condition of patient health, there are several more signs that can be extremely helpful in specific situations:

- Electrocardiography (ECG) is a painless widely applied test that shows the electrical activity of patient heart and detects abnormal or hidden heart rhythms and diseases, monitor recovery from heart attack and even several non-heart conditions. The wet silver or silver chloride electrodes are commonly used for measuring ECG. The main disadvantage of such electrodes is that they cannot be used continuously as the electrolytic conductive gel dries over the time and can cause skin irritation or even allergic reactions. Those problems led to development of dry electrodes that can be embedded into the fabric [9]. While, the dry electrodes do not causes skin irritation they provide several body motion artefacts into resulting ECG that decrease its accuracy and readability.
- Stroke volume [12] presents information on volume of blood pumped from the ventricle per heart beat and can be calculated from echocardiogram.
- Capnography [12] provides the breath-to-breath ventilation data as it presents a concentration of CO_2 in patient exhale air. The capnography is one of the main indicators of patient health state during intensive care and anesthesia.
- Glucose rate [13, 14] is an essential signs that should be constantly monitored if patient has a diabetic disease.
- Pain and level of consciousness [12] are also address mainly critical for health states, thus are important during intensive care situations.
- Urine output [12] can indicate such critical states as kidney failure and low blood supply for kidneys, that can be caused by dehydration or blood loose.
- Skin perspiration and actigraphy [6] analysis helps during analysis of patient neurological function, circadian rhythms and motion control. The sweating is one of prime forms of body temperature regulation thus altogether with five main vital signs it helps to clarify and enlarge the analysis of patient clinical state. With wearable technologies the skin perspiration level can be observed using epidermal-based and fabric plastic-based sensors [15].

The main five vital signs form the foundation for initial patient health state analysis and are commonly used at the beginning of the disease diagnostic. The Figure 2 presents placement of sensors on the patient for basic vital signs and ECG with skin perspiration level analysis.

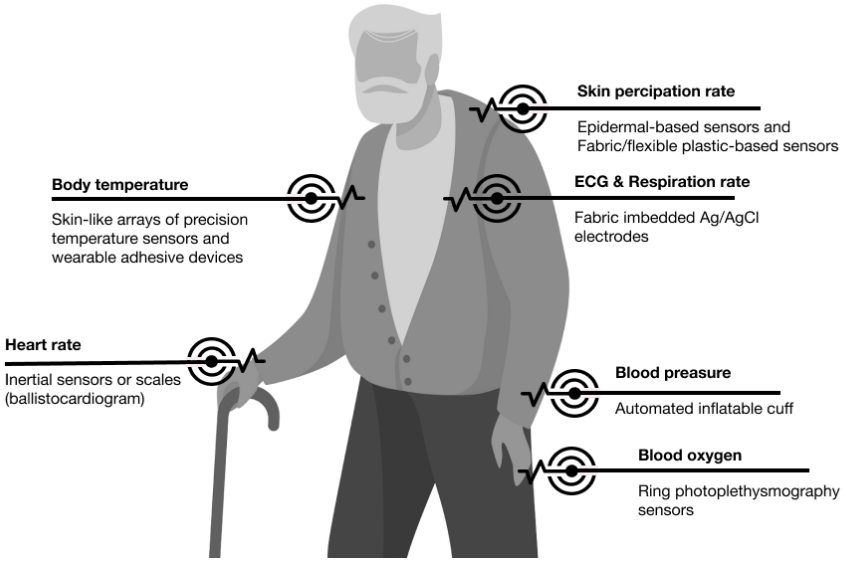


Fig. 2. Positioning of the basic sensors for vital signs analysis

4 Challenges and Directions

Various systems and platforms were created and proposed by the community of developers in scientific areas of bio-metric and bio-medical measurement. The future of healthcare could be even more data-driven and personalized than it is today. In such a world, people would receive care on a frequency determined by their own unique situations, rather than an arbitrarily set cadence. With the array of continuous-monitoring wearables already on the market or in a prototyping or R&D phase, technologists are certainly continuing to push the envelope in terms of the types of data that could be collected non-intrusively. Medical professionals are stepping into the digital health world. Though, it is a future for healthcare, there are some serious challenges to get there.

These are the core parameters for every leading platform:

- Connectivity - ease of connection between devices and is a must for this kind of tools. IoT platform should be confident enough in data collection, data transmission to a server or hub, and permanent storage and check in a medical station [16, 17].
- Security - considering data collection and transmission between different devices and especially hubs or clouds, these systems must have the decent level of security, so data encryption is necessary [13, 18].
- Data safety and integrity - data safety is mostly about dealing with data loss, especially during disconnections when transmitting data from microcontroller to a cloud storage or device. This can be achieved with a proper memory management and different techniques, like temporary data saving or buffering [13].

- Reliability - the interpretation of any data must not only be accurate but reliable. The challenge lies in handling “borderline” data. Any interpreting strategy or algorithm faces data sets that it finds ambiguous. For an algorithm to be reliable, users must be able to quantitatively understand its detection limits and error characteristics [13, 19].
- Wearability - healthcare wearable devices are in charge of different types of biomedical monitoring to help users check their health during their normal day routine. This point is really important when these devices are intended to be used by elder people. The devices must be comfortable and easy to wear [13, 14].
- Design - wearables should follow the basic principles and properties. They should not be too visible, and should not distract from daily routine and activities. We should also consider how frequently would this be used, and it should be comfortable for different time periods. Also they must be close to the body to measure, so need to feel comfortable [13, 14].
- User Acceptance - this is a serious case, considering, interface specific, visuals, personalization and data. We need to be able to follow the lifestyle of the target audience, for example, adapting the form, or choosing it as the option as well as being able to customize various settings considering user requirements [14].
- Battery life - last, but not least is battery life. Obviously there it is one of the biggest challenges for devices nowadays. We can use hardware, interface, or even software to lower the battery consumption. We can also use the alternative energy harvesting techs, as kinetic or solar approaches. Or using algorithms or specific firmware we can reduce the power consumption. Another way of doing it is prioritizing the functions, to keep only the necessary ones, so battery won’t be used for the high-res screen, for example [13, 14].

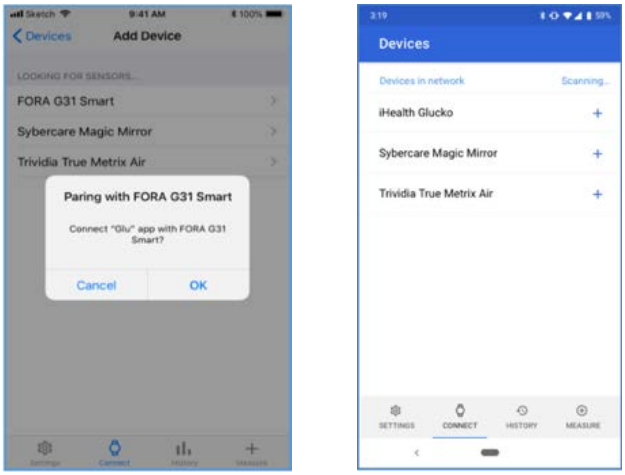
5 Case Study: Glucose Management Application

In section 3, we have stated the glucose rate as one of additional important health signs that have to be constantly analyzed. While, being not included in the main five vital signs it becomes crucially important when diabetes was diagnosed. Especially, it is important when it comes to childhood diabetes, as children should learn the specifics of their life style caused by disease such as taking only well-balanced, free from sugar-sweetened beverages, tracking carbohydrates and food portion sizes, constantly check the glucose rate with hydration level etc.

The International Diabetes Organization informs that in 2019 there were already 1.1 million children and adolescents living with type 1 diabetes among 1.92 billions worldwide [20]. The importance to track many vital signs along with one of the most critical – glucose rate, pose the need for automatically gather and process user data. We have developed such glucose rate management applications for iOS and Android [13, 14]. The applications are built on the native system components and supports:

- connection and data synchronization via Bluetooth with off-the-shelf devices that are nearby user smartphone (Fig. 3a) and management of connected WHDs (Fig. 3b);

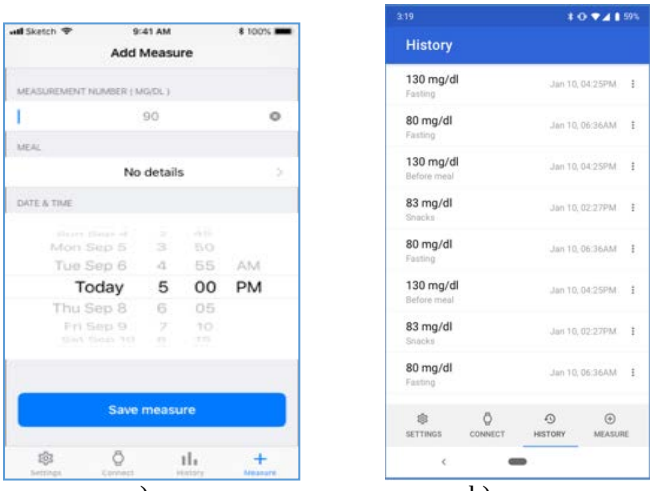
- ability to manually add new measurement data, set data units, dependence on meal, data and time (Fig. 4a);
- saving and editing the glucose measurement history (Fig. 4b);
- send reminders for the upcoming glucose measurement (Fig. 5a);
- connect to the Health (iOS) and Google Fit (Android) or WHDs to get data about latest training and heart rate measurements (Fig. 5b).



a) b)

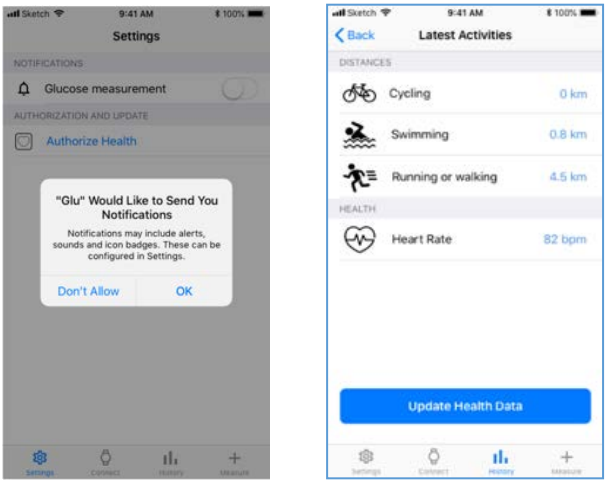
Fig. 3. Application GUI: a) connecting to glucometer (iOS); b) managing WHDs (Android)

The applications are planned to be provided for children diabetes center of the biggest medical-health resort in Ukraine CJSC “Mirgorod Kurort”.



a) b)

Fig. 4. Application GUI: a) adding new measurement (iOS); b) history table (Android)



a) b)

Fig. 5. Application GUI: a) activating notifications (iOS); b) latest activity sessions data (iOS)

6 Conclusions

Wearable health devices are an emerging technology in healthcare and still under development with the aim to be successfully integrated into the medical systems. The paper gives an overview of main wearable tracking devices that are presented on the WHDs market. We have also provided the list of major vital signs that can be accessed using WHD sensors.

We have shown the main challenges that WHDs developers are facing: connectivity, security, data safety and integrity, reliability, wearability, user acceptance and battery life. Considering the presented challenges, while creating, buying or investing in any of the wearable devices in healthcare the person can check listed characteristics to make a confident selection.

We have also presented the developed glucose rate management (GRM) applications for iOS and Android OS, which aim to help young patients and their parents in managing the everyday routine diabetes measures. The future steps will be connected with analysis of the results of pilot implementation of the GRM applications and extending of mobile measures for e-health systems.

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