Software for Wearable Devices: Challenges and Opportunities

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Abstract : Wearable devices are a new style of portable computer system that provides unique and user-personalized services. Wearable devices reflect new challenges and issues to computer science and technology. This paper summarizes the current siuation, development process and important software research issues of wearable devices. The technology of wearable devices is under-mature. The development of wearable devices is thus bound to face various problems such as incompatibility between operating system and software, comfort of human-computer interaction, data transmission, secrecy of the information, energy-consumption problems brought watch. by regular and uniform running.

Index Terms **- Network communication protocol, Wearable devices; Human-computer Interaction, Software development platform, Software engineering, Big data**

I. INTRODUCTION

1.1 The Definition of Wearable Devices

A wearable device means a computer that is adjusted into the personal space of a user, accessed by the user, and has both interactional and operational constancy, i.e., is always on and always accessible [2]. Wearable devices have the same computing abilities as smart-phones and tablet-computers. In some cases, however, wearable devices are more appropriate for tasks such as navigation, calculation, remote picture than handheld devices due to their portability and characteristics to be detailed below.

1.2 The Development of Wearable Devices

We can have a obvious understanding of the development for wearable- devices from [2][3]. Wearable for many years have undergone since the initial ideas and prototypes appeared during 1960s. During the 1960s to 1970s, wearable devices were in their research period. People designed wearable devices for special-tasks, interests or events. During this period, wearable devices confined in a small-scale field and people less understood their implementation. Edward Thorp, in 1966, a professor in the Massachusetts Institute of Technology (MIT), invented a pair of shoes that could be used imitate at roulette. This is the first innovative wearable device in the world. In 1975, the Hamilton Watch Company introduced the first wearable 'wrist calculator'. In 1977, the CC Collins for the blind designed a wearable device, which transforms images captured from a head-mounted camera into tactile grids located on the blind's vests. From the 1980s to 1990s, wearable devices entered the initial-stage of development. People started paying attention to wearable devices. Although wearable technology had a great amendment, wearable devices were not in use and friendly-users. In 1981, one head-mounted camera has been designed by Steve Mann that to some extent can be regarded as the precursor of Google glasses. In the same year, Steve Mann designed a backpack-style computer with multimedia, image and text functions, displaying through the helmet. In 1997, MIT, Carnegie Mellon University, and Georgia Institute of Technology mutually organized the first International Symposium on Intelligent Wearable Computer (ISWC). Ever since then, smart wearable-computing and smart-wearable devices have attracted wide attention in industry and academia.
Since the 21st century, wearable devices have entered and modernized-stage of development and aroused widespread attention. They become more complicated and are sturctured according to the needs of users or the market. Many companies launched their own designed wearable devices and released corresponding software and hardware development platforms. In 2007, James Park and Eric Friedman laid foundation of the Fitbit Company that is fully dedicated to the development of wearable devices on pedometer and sleep quality detection etc. Google in 2013, launched Google glass and caused an uproar in the world. Meanwhile, Apple, Samsung, Sony and other companies have been developing their smart-watches. In the next upcoming years, predictably, wearable devices will enter a period of popularity and prosperity. The IMS data [3] disclosed that wearable-devices shipments will attain 92.5 million units by 2016. According to Juniper's research [5], the number of wearable devices will cover 130 million by 2018. Moreover, according to IDC's reports [36], we note that wearable devices had been under a rapid progress; the number should reach up to 19 million by the end of 2014; and the predicted products including smart watches and related devices will increase at an annual rate of 78% and reach 112 million by 2018. Therefore, we can believe that wearable devices will gradually enter people's routine-lives and bring comfort to human, and wearable market will attract more participants.

1.3 Classification Standards for Wearable Devices

Currently, there are two standards for classifying wearable devices [27]. One is based on product forms, including head-mounted (such as glass and helmet), body-dressed (such as underwear, trouser and coat), hand-worn (such as gloves, bracelets and watch), and foot-worn (such as socks and shoes).

II. SOFTWARE FOR WEARABLE DEVICES

The technology of wearable devices is under-mature. The development of wearable devices is thus bound to face various problems such as incompatibility between operating system and software, comfort of human-computer interaction, data transmission, secrecy of the information, energy-consumption problems brought watch. by regular and uniform running. This paper explains some primary research issues in the development methos of wearable devices.

Apple Watch

Glove One Phone

Plump Bracelet

Shine Buttons

Figure 1. A variety of wearable devices

Second standard is based on product functions, including healthy life-style (such as sport wristband and smart bracelet), information seeking (such as smart glass and smart watch), and somatosensory control (such as somatosensory controller). Figure 1 en-lists a variety of wearable devices.

III. WHAT MAKES WEARABLE DEVICES DIFFERENT?

A wearable device is easy for users to use and carry due to its compactness, dressing and light-weight. Their forms, usages and functions are different from smart-phones and Tablet-computers. In the wearable symposium held in 1997 [12], Bass L. summarized five characteristics that a wearable device should have [15]:

1) It may be used while the wearer does movement;
2) It may be used while one or both hands are free or occupied with tasks;
3) It exists within the corporeal-envelope of the user, i.e., it should be integral part of the wearer clothings.
4) It must allow the user to maintain control;
5) It must exhibit continuity, in the sense that it should be constantly available.

Steve Mann also provided the definition of wearable devices and described them from three operational modes and six attributes at the International Conference on Wearable Computing (ICWC) [2] held in 1998, three operational modes include augmentation and mediation, consancy. And the Six attributes include un-monopolizing of the user's attention, un-restrictive to the user, observable by the user, controllable by the user, attentive towards the environment and communicative to others.

However, wearable devices display more features as they evolve, such as concealment and diversity [10]. Wearable devices not only change the human-computer relationship and the other way people use computers. Moreover, they produce a significant influence on people's life and task.

Operating system is the interface of hardware and software. Its function is to manage hardware, to control program execution, software and data resources, to improve human-computer interaction, to provide services for users and support for other applications and to enable users to have a good working environment.

The operating system on wearable devices has gone through years of development [11]. As before as in 2000, IBM ventured with the famous Japanese watch-manufacturer Citizen to launch a smart watch named Watch-Pad with Linux as its operating system. Fossil designed in 2003 a wrist-device called Wrist-PDA. It equipped with Palm OS [12] operating system with supporting screen touch, which were very popular at that time. In addition, The SPOT system for smart-watches has been designed by Microsoft. In 2013, Samsung released its first smart watch

Galaxy-Gear using Android as operating system. After that, Samsung launched the second generation of smart watch running Samsung's independently designed operating system Tizen. In March 2014, Google launched a smart Android based watch dedicated operating system called Android Wear [13], whose operation is implemented through Google Now's voice-commands. Android Wear is expected to build a standard and uniform operating system platform, accelerating the development of wearable devices.

At present, there exist a variety of operating systems in wearable devices market. But they may not be comfortrable for users to use. Developers are confused to choose which operating system for the device. And the application for one operating system is not matching for another.

Since operating system is required for wearable devices, we should design wearable operating systems by taking the features of wearable devices into concern so that we can achieve the given objectives as below:

1) Convenience. The design of the operating system should be more comfortable for users to use wearable devices.

2) Effectiveness. The operating system should be accessed more effectively and take advantage of resources like software, hardware and data of wearable devices.

3) Scalability. The operating system should permit new system functions to be tested, developed and included.

4) Openness. The operating system should support integrated-collaborative network work of different manufacturers and devices so that it can achieve the portability and inter-operability of applications.

5) Multitasking. The operating system should be able to run multiple applications concurrently.

In general, there are several choices for developers to develop wearable operating system [4][15]:

1) Develop further on the basis of palm operating system used on mobile phones. The advantage of this approach is to shorten the development cycle and to reuse existing applications. Its disadvantage is that there exist some problems on transplanting the current applications.

2) Develop proprietary operating system based on Linux. However, it is difficult for development and establishing the software of ecological environment.

3) Develop web-based operating system.[4].

This approach would take full benefit of resources and support of the web server, adjust and restructure software system dynamically according to the actual requirements, minimize the resource requirements to wearable devices. The approach has great capacity for development, but will take a long time and cost.

3.1 Database Management System

Wearable devices run regularly, and are ready to interact with users. They will collect user information as much as possible, and store them in database. The user can access the database to query necessary information through the database management system. For example, the Aid smart cane designed by Egle Ugintaite [27], utilises built-in sensors to record user's pulse, blood pressure and temperature in real time, and displays health data through its LCD screen. The user can access the database to obtain various data about his/her recent health status.

In addition to the basic information including gender, age, height and weight, wearable devices can also record user's health status, eating habits, personal temper, and preference information to color and food, etc. These informations may be useful for users achieving their goals. For example, when it is lunch-time, wearable devices are able to search nearby restaurants according to user's taste through the database information, and provide hints to the user; when shopping, the devices can also recommend certain products that the user may need is based on personal preference; when docking smart-appliances, wearable devices can send personal information stored in the database to the terminals, and instruct smart appliance system to control air conditioning in real time according to the user's temperature, or automatically open the audio device and play music fitting the user's mood at that time.

At present, the major task of the database management system for wearable devices is only to deal with simple-data, even some devices do not include the function of database management. The response speed and processing power may not necessarily meet the needs of devices.

Due to the varying functionalities of wearable devices, the recorded data are subject to change and may include the basic personal information, physical health data, and external environment changing data etc. To store these data, not only local databases, but also cloud databases are required and a reliable database management system becomes necessary. Therefore, developers should design specialized database management systems that are able to manage and operate various data, being lightweight and having fast response speed; or should transfer existing database management systems on mobile phones to wearable devices.

3.2 Network Communication Protocol

Wearable devices may exchange data with other devices such as computers, mobile phones and other wearable devices. Therefore, network protocols for wearable devices become important. The network communication mode of wearable devices has been defined by network protocols, and determined exchange data format and problems related to synchronization. Bluetooth (IEEE 802.15.1), ZigBee (IEEE802.15.4), Wi-Fi, NFC (IEEE 802.11) are four currently popular short-range wireless communication protocol standards [16]. Broadcom launched Wireless Internet Connectivity for Embedded Devices (WICED) in 2013 [17]. WICED simplifies the implementation of WiFi in a series of consumer electronics. It can achieve WiFi-networking application or connect mobile phones, tablets computers and wearable devices for data sharing. Bluetooth-Smart [35] is an improved version of Bluetooth 4.0 [19] with the power reduced by ten to twenty times. Furthermore, even devices can still keep connected if the radio are closed in coming time; when data are ready, Devices can be awakened immediately within a very short time. In this way, battery life can be extended, which makes Bluetooth Smart more adaptable for wearable devices. At present, network communication protocols for wearable devices are relatively simple and focus primarily on wireless functions. However, wearable deviceswill eventually implement more and more functions like those implemented in mobile phones, such as WAP, GRS, GPRS, large file or data transmission, etc. Therefore, more reliable network communication protocol supports are demanded. Developers should transfer network communication protocols running on mobile phones, tablets computers to wearable devices, or design special network communication protocols for wearable devices, which are more energy-efficient, safe, and with high throughput.

3.3 Application Development Platform

The rapid development of mobile phones characterizes the success to the large number of available applications. Similarly, the shortage of applications is one of the blockades for the rapid development of wearable devices. Software development requires development environments and a complete set of tools, including interface tools, modelling tools, project management, configuration management tools, and testing tools, etc. Software development kit is often used to support a particular software engineering method, reduce the burden of manual management, and make software more systematic like other software engineering methods. At present, there are many hardware design platforms available for wearable devices. In 2013, Broadcom launched a development platform called WICED [17]. Bluetooth, Wi-Fi, NFC and positioning technology can be integrated into wearable devices. The wireless networking function with low-power consumption, high performance and inter-operability can also be embedded into devices. As the representative of the wearable system platform based on ARM architecture, Freescale launched the open-source, scalable Wearable Reference Platform (WaRP) [20] with over fifteen manufacturer collaborators including Kynetics, Revolution Robotics, Circuits. The platform supports open operating system such as Android and Linux and has features like scalability and flexibility. Wearable device market is currently in the stage of development and promotion of hardware, while application development is lagging behind. In order to accelerate the software application development of wearable market, various software platforms are springing up. In 2014, Google released the software development kit (SDK) including an emulator and other tools for Android Wear [23], which can permit developers to combine Android Wear platform with their own devices and applications that can be available to download. Developers of Android Wear ecological circle manufacturing can utilize all the tools they need to start making apps for the new devices. The development of SDK for Android Wear is expected to bring richer APP experience for future smart watches. Tizen is an open source operating system based on Linux for mobile phones and other smart devices. It has a complete development platform, including simulator, IDE etc. At present, Samsung's Galaxy Gear2 smart watch is running on this operating system. If the promotion is widely successful, we believe that Tizen will contribute to the development of wearable devices.
However, it is still lack of mature software development platform for wearable devices. An important issue for developers is to choose which platform to develop application software. In addition, developers cannot verify which applications have been developed and available. Therefore, developers have several options [22]:

1) Develop application software that supports particular operating systems for a single platform. This approach would simplify work of developer, but the resulting application may not be able to run on wearable devices with other different operating systems;
2) Develop native applications for each platform, but the technology and cost of application maintenance for each platform become the big challenges;
3) Develop mobile web applications, so as to reduce the native code for each platform. But the application may not be able to meet the market demand.

3.4 Privacy and Security

Wearable devices can collect real-time user information so as to provide effective personalized services for users. These data contain various user informations, for example, geographical location, living habits, body temperature, heart rate, account password and conversation, etc. When mishandled, it may bring great danger to the user's privacy and security, and harm the user's property or even personal safety. With the wide-use of wearable devices and the rapid growth of applications, security and privacy issues should become more and more significant. The communication of wearable devices is mainly based on wireless network therefore more private information may be easily attacked or stolen. Wearable industry is not mature and there is still lack of a complete and effective program to protect privacy and security. While the industry may neglect security problems due to cost issues, so the researchers working in wireless sensors and mobile application have done a lot of fundamental work that will help to solve the privacy and security problems in wearable devices. For example, Liu et al. studied the security problems on mobile application [23]. Ameen et al. analyzed the problems of information security and privacy protection on wireless sensor network in the health care area [24].

We can consider from the following aspects to protect user's information and privacy:
1) Research on believable network communication protocols for wearable devices so as to ensure the security of data during transmission;
2) The system should have permission setting. Wearable applications can only be restricted to obtain necessary data so as to reduce data exposure;
3) Reasonable software patterns should be proposed to mitigate these problems. For example, losing the binding between private data and real names and mixing various may help to protect user's privacy and security.

3.5 Energy Consumption

Because wearable devices can only use battery, rather than stationary power, hence it is more problematic to charge wearable devices than mobile phones. Frequent charging or replacing battery can reduce the practicability of devices and satisfaction of users. In addition, the large amount of energy consumption for devices can produce heat. If the cooling problem cannot be handled properly, it will damage user experience. Therefore, the energy consumption of wearable devices is an issue of attention.
At present, through the design of hardware or operating systems manufacturers has been controlled the energy consumption of wearable devices or mobile phones. Since the starting of using wearable devices, their battery life is not very satisfactory. Taking smart watches as an example, the battery life of Moto 360 is up to 60 hours [24] and the one of LG G Watch is only 36 hours [26]. Energy consumption management is an essential issue for wearable devices.

In addition to hardware and operating systems, we can also consider improving energy consumption control from a high-level application layer. Particularly, the control of energy consumption can be considered from the following aspects at the application layer.
1) Reduce hardware electricity consumption through reasonable invoke of system APIs. For example, Hao et al. and Li et al. proposed the code-level energy consumption analysis methods on mobile applications [27][28]. Such methods can be approached to wearable devices to achieve the purpose of reducing energy consumption through invoking less-energy-consumption API or arranging reasonable invoking

sequence.
2) Create adaptive energy-sensitive applications to adjust self-energy usage. When the energy is sufficient, high quality services will be provided; otherwise, unimportant applications will be turned off in order to increase the usage time. Mizouni R et al used in [29] such adaptive strategy to reduce the energy consumption of smart phones in mobile applications.
3) Adopt load-balancing method to transfer complex calculation to the mobile terminal via wireless communication network, thus reducing wearable device's own energy consumption. Kwon et al. presented a method to solve the problem [30]. A similar approach can also be introduced into wearable devices through replacing high calculation energy consumption with low communication energy consumption.

3.6 Human-Computer Interaction

A major feature of wearable devices is to collect user information is a major feature of wearable devices, perceive user physical conditions and the change of external environment, various commands, and assist or remind the user automatically [4]. Wearable devices pursue people-oriented, namely requiring wearable devices being more suitable for the user. Wearable devices would be best to perceive, recognize and understand human emotion, and give sensitive, friendly response. Human-machine interaction is a key-technology of wearable systems, which should resolve the interaction between users and wearable devices and improve the ability of environmental awareness.
There are many ways for users to interact with wearable devices [4]:
1) Contextual Awareness: Wearable devices continuously run and collect data, but in many cases, the user does not use them. Wearable devices should run with freedom, perceive the external environment, and give useful information to the user. Starner T et al. proposed in [34] visualised environment perception method for wearable devices, and pointed out that a wearable device can observe its user to provide information, manage interruptions and tasks, and predict advancing needs without being directly commanded by the user.
2) Augmented Reality: That is a technology that enhances users' awareness to real world through the information such as video, sound, graphics or GPS data generated by the computer [32]. The goal is to apply virtual information to the real world and to super-impose virtual object, scene or system message generated by computers to the original scene. Zhou et al. presented a design approach and a series of practical proposals of wearable user interfaces in real augmented environment [33].
3) Non-keyboard input: The most familiar way to input information into computers or mobile phones is through keyboard or mouse. However it is impossible to connect such input devices to wearable devices because of their small sizes and lightweight. Users can interact with wearable devices through non-keyboard methods such as voice, handwriting, gestures, data glove etc. For the disabled or handicapped, the interaction ways of traditional smart devices cannot give normal experience. But they can wear a wearable device that receives messages from other sensors, which are transmitted to their sensory system after analysis. For example, for a person whose ear-drum is broken, hearing devices are directly connected to his/her skull, which enables him/her to sense the voice that is not passing through ears.
Therefore, as compared to computers and mobile phones, wearable devices can provide many different methods of human-computer interaction for users to strengthen their experience. But these ways cannot fulfill the demand of all users, developers should strengthen the study of human-computer interaction technologies:

1) Apply present mature human-computer interaction methods to wearable devices, such as handwriting, voice and other non-keyboard input. These ways can be easily realized in wearable devices and better accepted by users.
2) strengthen the research of currently-immature human-computer interaction ways, such as contextual-awareness, augmented reality, mediated reality, etc. These ways can enhance user experience and make users have greater interests in wearable devices.
3) Propose new human-computer interaction ways. Some ways may be suitable for particular groups or particular environment. However, this approach will increase the burden to developers, and moreover, it may take time to study and practice these new ways.

3.7 Software Engineering

With the increasing popularity of wearable devices, software engineering for wearable devices is becoming more and more important. Although the research of software engineering for wearable devices is still rare, we can predict some aspects/issues that may be of value and worth studying:
1) Demand analysis: It is worth studying how to perfect the requirement documents should be a problem. From users' comments on the application, the discussion in the BBS or the analysis of related online articles, users' expectation for the functionalities of the wearable devices can be acquired and thus be used to improve the requirement documents.
2) Code recommendation: many functions are about to be re-used in different applications. Through analyzing source code of existing applications, we can suggest function codes to developers to achieve fast development.
3) Application transplantation: it is not necessary to design different applications for each operating system. We can create API mapping among different platforms, and develop an ideal compiler that can complete the application development for multiple platforms.
Software engineering for wearable devices is a rising field that avails many opportunities for researchers to investigate to.

3.8 Big Data

We have entered the era of "big data" with "4V" with the development of technology [34], namely the volume, the velocity, the variety, and the veracity. Internet technology and mobile applications promote the development of the big data. Laurila et al. discussed the challenges and opportunities brought by big data in mobile applications [35].

Big data technology will play a significant role in promoting the development of wearable industry. A large amount of data will be generated in using wearable devices, including basic personal information, health status, as well as the preference to color, food and cloth etc. We can gain a lot of useful information by using big data analysis technology, which will provide a great help for scientific research, social development and users' life. Big data technology can be used to analyze the huge amounts of data collected by wearable devices, and to detect user's body health factors. For example, the analysis for blood pressure and heart rate can understand user's body status and potential risks. It is an indisputable fact that big data technology can help wearable-device users enjoy more comfortable life. Redmond et al. discussed the significance of big data technology for wearable devices in health care [36]. Conversely, wearable industry will also promote the development of big data.

Compared to mobile phones, wearable devices will produce larger amount of data. So it requires big data technology to deal with these collected data even more. For example, the

IV. CONCLUSION

Wearable devices will become the mainstream of the development of mobile smart-devices, and dramatically change modern-way of life. Currently, the development of wearable devices is still in its immature and unorganized stage, and the major functions focus on navigation, calculation, running, remote picture and other related services. However, these services can also be achieved on smart phones. Meanwhile, research on hardware materials and battery life has not achieved a breakthrough; limited screen space makes the product design very difficult; application software development is still in the foremost stage. Due to these problems, it will take a long time for wearable devices to become the mainstream of market.

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