

# Emerging Wearable Medical Devices towards Personalized Healthcare

Jiewen Zheng

The Quartermaster Research Institute  
of the General Logistic Department  
No. 69 Lumicang Street,  
Dongcheng District, Beijing, China  
+86-018811552772

jaroncheng@126.com

Taihu Wu\*

Academy of military medical science,  
Institute of medical equipment  
No.106 Wandong Road,  
Hedong District, Tianjin, China  
+86-013821180858

wutaihu@vip.sina.com

Yuhong Shen

The Quartermaster Research Institute  
of the General Logistic Department  
No. 69 Lumicang Street,  
Dongcheng District, Beijing, China  
+86-018600815107

13611290575@126.com

Guang Zhang

Academy of military medical science,  
Institute of medical equipment  
No.106 Wandong Road,  
Hedong District, Tianjin, China  
+86-013821408453

zhangguang01@hotmail.com

Zhengbo Zhang\*

Department of BME, Chinese PLA  
general hospital  
No.28 Fuxing Road,  
Haidian District, Beijing, China  
+86-013693321644

zhengbozhang@126.com

Hengzhi Lu

Academy of military medical science,  
Institute of medical equipment  
No.106 Wandong Road,  
Hedong District, Tianjin, China  
+86-015900384360

lhz198802@126.com

## ABSTRACT

The increasingly aging population and prevalence of chronic diseases have been observed in many countries, which increase great burden for the health care system over recent few decades. With the technology innovation in IT and biomedical engineering, more and more advanced wearable medical technologies and products are emerging and coming to use by the public. Since wearable medical is deemed as one of the most promising approaches for healthcare monitoring, early diagnose and personalized treatment, wearable medical devices will contribute to the development of more cost-effective and sustainable healthcare system. In this paper, recent advancements in wearable medical products for personalized medicine and E-health are reviewed, including wearable multi-parameter physiological devices, wearable patch physiological monitoring devices, fitness training devices, wearable biofeedback training devices, and mobile phone based healthcare applications. Finally, future development of wearable medical technologies, specially, the related policies and plans in China, are discussed.

## Keywords

E-health; wearable medical system; personalized medicine; health care

## 1. INTRODUCTION

Along with decline of birthrate and rise of average life expectancy, aging of population is unavoidable in next several decades. Aging of the population is a global phenomenon, but it is more serious in China due to the One-Child Policy that will bring

dramatic change in population distribution. The elderly population in China will reach 202 million in 2013, with the aging level reaching 14.8%, according to the China Aging Development Report (2013) released by the Chinese Academy of Social Sciences on February 27, 2013. This report also points out that China will usher an elderly population growth peak and the elderly population will grow at an annual rate of 100 million by 2025 [1]. In addition, the problem will be aggravated by the fact that the disabled elderly population, “empty nester” elderly population, and the number of families who have lost their only child in China will increase year by year.

Chronic diseases have been known as the leading cause of death and disability. If aging of population and growing of population are the consideration alone, the number of cardiovascular disease among Chinese crowd aged 35 to 84 will rise more than 50% from 2002 to 2030 [2].

If there is no effective way to prevent and manage chronic diseases, our society will face severe financial burden. As a result, the current healthcare system is taking place fundamental transformation. The conventional hospital-centered healthcare system, which focuses on diagnosis and treatment, is shifting to individual-centered, family-centered, and community-centered healthcare system with emphasis on early detection of risk factors, early diagnosis, and early treatment [3]. In this shift, wearable medical devices have been recognized as feasible technology for continuously monitoring patients in non-invasive and comfortable method, providing long-term health status monitoring and feedback treatment, giving timely and real-time alarm to patients and physicians when risk condition occurs, and promoting deeper research of chronic disease through acquiring mass physiological and pathological data difficult to obtain in clinic.

This paper summarizes that the state-of-art wearable medical devices for personalized medicine. The paper is organized as follows: 1) to review recent development of wearable multi-parameter physiological devices that will be the main trend of future personalized medicine and M-health. 2) to review the wearable electrocardiograph (ECG) patch monitors, which is a big

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

BODYNETS 2013, September 30-October 02, Boston, United States

Copyright © 2013 ICST 978-1-936968-89-3

DOI 10.4108/icst.bodynets.2013.253725

breakthrough in cardiovascular disease monitoring and diagnosis. 3) to review the fitness training devices, which are the most popular products for white collar in current society. 4) to review the wearable biofeedback breathing training devices, which will be the most hopeful technology to fulfill curing illness without drugs and operations. 5) to review mobile phone based healthcare application, which is experiencing rapid growth in China and will be an effective way to make health care more affordable and accessible. 6) to discuss future trends of wearable medical products and technologies.

## 2. Wearable multifunction physiological monitoring devices

To collect and monitor health information before illnesses become complex and incurable, wearable multifunction physiological monitoring devices have been proposed because of their capability for long-term, continuous, and unobtrusive monitoring of health status that is crucial to understand the pathogenesis of some chronic diseases. It can also capture transient events or symptoms and give early indication of health deterioration. A number of wearable multi-parameter physiological monitoring systems have been developed and put into practical use for health monitoring (Fig.1).



**Figure 1.** Wearable physiological monitoring devices.

Top-L: VitalSense [5]. Top-R: mini-Medic [8]. Bottom-L: Equivital [7]. Bottom-R: BioHarness3 [6]

Vivometrics developed a wearable system called LifeShirt, which is a comfortable, lightweight garment with embedded sensors that continuously collects a range of cardiopulmonary information: ECG, Dual Band Respiratory Inductance Plethysmography (RIP), EEG, EMG, Blood pressure (BP), and so on. The system may also record time-stamped symptom, mood and activity information of user in daily life. Recorded data can be easily imported into the VivoSense software for further in depth analysis [4]. The Respirionics's VitalSense® is a telemetric system capable of collecting core body temperature, dermal temperature, ECG, and respiration signals that can be displayed and recorded in a portable monitor [5]. The prominent feature of VitalSense is core temperature sensor called Jonah™ and Dermal temperature are disposable, but designed for multi-day use under demanding physical and environmental conditions, and using low-power wireless technology communicate with the monitor. Zephyr's

BioHarness™3, a multifunction monitoring strap or garment, is now a market-leading technology in multi-parameter physiological monitoring field [6]. The BioHarness™ 3 can capture comprehensive physiological data and transmit them via Bluetooth to a smartphone or a laptop to be displayed and analyzed by Zephyr's OmniSense software. It's worth mentioning that a single BioHarness™3 system can provide real-time monitoring of up to 64 users. The Hidalgo's Equivital LifeMonitor EQ02 system is almost as similar as BioHarness™3 except that the EQ02 can combine VitalSense®'s Jonah™ and Dermal sensors to acquire core and skin temperatures [7]. The Athena GTX's mini-Medic is a highly compact, lightweight multi-parameter vital signs monitor system that features linking up to 10 patients simultaneously to a handheld wrist-watch device with a line of sight of 100 meters [8]. The mini-Medic is applied to a patient's forehead with novel hydrogel pads, which is capable of detecting and wirelessly transmitting ECG, Heart rate (HR), SPO2, pulse rate (PR), skin temperature, pulse wave transmit time (PWTT), and accurately assessed BP to a wristwatch or a mobile computer.

## 3. Wearable patch ECG monitor

As for long-time ECG monitoring, present Holter monitors still require a periodic replacement of the electrodes and often get poor-quality ECG signals due to movement of leads or electrodes. The advancement in wearable and adhesive technologies have enabled the development of wearable patch ECG monitors that attach directly to the skin with good adhesion and require no electrodes and wires (Fig.2). It enables very long-term monitoring of critical patients while they are carrying out daily activities that will allow clinicians to better diagnose ECG disease.



**Figure 2.** Wearable patch ECG monitor. Top-L: NUVANT [11]. Top-R: V-Patch [12]. Bottom-L: HRV011 [9]. Bottom-R: Zio Patch [10]

The LifeTouch HRV011 is an intelligent cardiac monitor that resembles a lightweight adhesive bandage strip that adheres to the patient's body and analyzes the ECG signals [9]. The HRV011 uses a very low power microcontroller as well as an ultra-low power wireless protocol, which can provide a continuous working lifetime of up to 100 hours. The Zio® Patch is a long-term cardiac rhythm monitor that provides continuous monitoring for up to 14 days that will improve the likelihood of capturing arrhythmias and provides an equal or higher diagnostic yield versus other devices on the market [10]. The Corventis's NUVANT™ mobile cardiac telemetry system was designed as a

patient-friendly solution for comprehensive detection and analysis of cardiac arrhythmias. NUVANT™ can provide up to 30 days of continuous monitoring of cardiac abnormalities [11]. The PiiX®, an unobtrusive, water-resistant, wearable device is used to capture and analyze ECG signals. When either an arrhythmia happens or when the patient manually triggers ECG collection, the PiiX® will transmit the information via a wireless data transmitter called zLink® to the Corventis Monitoring Center. The VPMS's V-Patch system, an intelligent patch vital signs monitoring system, requires no wires and leads and can reduce motion artifact error by over 90% [12]. It contains of a V-Patch attached to the skin with sophisticated biodegradable waterproof skin adhesives can acquire clear and stable ECG signals with diagnostic quality, a V-Pod snapping to the V-Patch can store and analyze data collected by the V-Patch and then forward the information to a hand held device called V-Cell integrating with cellular phone engine that send data to the internet.

Wearable patch ECG monitor is a big breakthrough in cardiovascular disease monitoring and diagnosis that will play important roles in diagnosis and treatment of cardiovascular diseases.

#### 4. Wearable fitness training device

Nowadays, more and more people participate in regular exercise for health, relaxation, and losing weight. In recent years, hundreds of companies launch an abundance of new products. ABI Research in 2011 estimated that the market for wearable sports and fitness-related monitoring devices was projected to reach 80 million device sales by 2016. As following, we will take a look at the range of devices in use allowing consumers to keep health and fitness, and to help lose weight or sleep better (Fig.3).



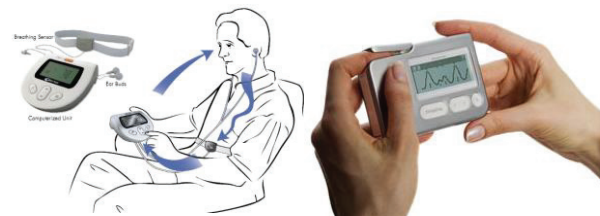
**Figure 3.** Wearable fitness training device. Top-L: FuelBand [13]. Top-R: Fitbit Ultra [14]. Bottom-L: Link Armband [15]. Bottom-R: SmartBand [16]

Nike FuelBand, a fitness monitoring wristband, captures and displays time, calories, steps, and "NikeFuel" used to measure physical activity [13]. The wrist band can synchronize with Nike's website through a built-in USB port, or wirelessly through Bluetooth to iPhone to record the user's activity each day and track progress. The tiny Fitbit Ultra tracks steps, distance, and sleep, as well as counting calories burned [14]. These data can be

wirelessly sent to the Fitbit's site or an iPhone. Fitbit Ultra not only holds an accelerometer but an altimeter that tracks the number of stairs or hills climbed each day. To keep users going, the tracker also displays motivational messages when users start moving. BodyMedia's Link Armband, a body-monitoring armband communicates directly with a smartphone by Bluetooth 2.0 [15]. The device provides real-time, up-to-the minute streams of raw data including heat flux, skin temperature, motion, and galvanic skin response. Applying with proprietary algorithms owned by BodyMedia, it can convert these raw data to key parameters that directly affect people's health and fitness: calorie burn, physical activity duration, steps taken, and sleep duration and efficiency. Codoon's SmartBand and Jawbone's Up seems to have similar functions and styles [16-17]. They are all worn around the wrist to track user movement and sleeping patterns, have the ability of waking user up with vibration at the optimal sleeping cycle, and download data to smartphone with 3.5mm headphone jack for analysis and sharing through website. In addition, several Heart rate straps supporting Bluetooth® 4.0 have been widely used: Wahoo® Fitness, Polar® H7, HxM™ Smart [18-20]. They have one common feature of ultra-low power consumption and ultra-long working time.

#### 5. Wearable biofeedback breathing training device

Biofeedback breathing training is a non-drug, effective, low-cost, and non-invasive method to cure illness and recover to fitness. Through regulating breathing based on heart rate variability (HRV), respiratory sinus arrhythmia (RSA) or other physiological signals feedback, the users can learn to control these audible or visible feedback signals, and then to modify physiological and psychological states aiming to achieve optimal physiological functions. It currently has been widely used to facilitate treatment for a wide variety of illness, including: asthma, cardiovascular disorders, hypertension, cephalopathies, anxiety, and other disorders with psychosomatic factors. In the following part, four typical products emerged in recent years will be introduced [21].



**Figure 4.** Wearable biofeedback breathing training device. Left: RESPeRATE [25]. Right: StressEraser [22]

The StressEraser® (Fig.4) is a finger pulse sensor based portable biofeedback device, which helps user learn to activate his body's natural relaxation response in minutes [22]. It can convert the pulse into an HRV wave and guide user to synchronize breathing with heart rate cycle. The StressEraser uses simple biofeedback symbols – squares and triangles to guide and encourage user take training exercise. It is simple and has been widely used in practice by physicians, psychologists and meditation experts. Especially, it has been used in military field for improving insomnia in combat environment and treating post traumatic stress disorder (PTSD). In 2008, 500 StressErasers had been shipped to U.S. armies in Baghdad and Iraq [23-24]. RESPeRATE® is a portable electronic device used to lower blood

pressure by relaxing constricted blood vessels that consists of a computerized control unit, a wearable breathing sensor fastened around the abdomen, and a set of headphone [25]. Simply listen to personalized melody composed of two distinct inhale and exhale guiding tones through the headphones, RESPeRATE will enable you to easily synchronize your breathing to the tones and lead you to the therapeutic zone of less than 10 breaths per minute, which will significantly relax the muscles surrounding the small blood vessels and reduce blood pressure if staying in this breathing zone for a few minutes [26]. RESPeRATE has been suggested by European and International Societies of Hypertension, as well as many key cardiovascular experts. The emWave2® is also a portable biofeedback training device used to reduce stress just like StressEraser® [27]. But it provides LED displays and audio feedback to user different from StressEraser's HRV wave feedback. Another feature of emWave2 is that it can provide HRV graphics feedback and store much more training data when connecting to a computer. NASA developed a biofeedback training method called the Autogenic Feedback Training Exercise (ATFE) based on wearable physiological monitoring device, Bioharness™ from ZEPHYR to prevent and counter motion sickness for astronauts in space [28]. With the help of wearable technology astronauts and aircrew can wear sensors on the body to self-regulate their own physiological responses and suppress the unpleasant symptoms in space, and can gather much more experimental data for improving ATFE biofeedback training technology. Now NASA has gain much success applying with ATFE technologies to increase motion sickness tolerance for astronauts.

Biofeedback breathing training has been proved having very significant roles in improving of autonomic nervous system (sympathetic and parasympathetic) balance. Especially in individual, home, and community environments, it has been widely applied to relax therapy, physiological and psychological stress regulation, blood pressure reduction, and insomnia relief. By combining biofeedback with wearable technologies, this kind of device will be easier to be accepted and more suitable for long-term use outside hospital. This will help promote early prevention and treatment of chronic illness and low-cost healthcare system.

## 6. Mobile phone based healthcare application in China

With the development of mobile internet and the public concerns of health care, mobile health has begun to grown in China. Data of iiMedia Research shows that the market size of China mobile health achieved 1.86 billion in 2012, a 17.7% increase from previous year. By the end of 2017, the market size of China mobile health will cross 10 billion and achieve 12.53 billion. Currently, there are more than 2000 kinds of health application products [29].

“5Udoctor” is the first family-doctor model based mobile medical service platform in China, which can provide professional health care advice, and make an appointment and treatment services for high-income people and those with special health care needs of the population, such as pregnant women, diabetics, and other people with chronic illness [30]. “Spring Rain Pocket Doctor” is a mobile client enabling self-diagnosis and inquiry-diagnosis [31]. “Medical Documents” provide medical literature retrieval services for medical practitioners [32]. “HaoDaiFu” supports iphone, ipad, and Android smartphone, which can provide information consultation and help find good doctors and

hospital [33]. At present, it can provide free counseling of 52,337 regular hospital specialists and free appointment for 5561 doctors. “Pocket Check-Up Lite” is a smartphone application running in iphone, which can provide examination service including nine tests: heart rate, speech audiometry, vision, color vision, astigmatism, memory, intelligence, personality tests, and body mass index [34]. “DaYiMa” can estimate periods of menstruation and ovulation, and provide information on recuperating of body [35]. “Zhang Shang Yao Dian” provides consulting and inquiries services including drugs, diseases, doctors, hospitals, and first aid knowledge [36].

Mobile phone based healthcare application in China was still in a fledging period. The profit model had not yet been clear in 2012. The key works of developers are accumulating costumers, activating new users and get continuous revenue. Currently, the main profit models of China are only advertisements, value-added services, online inquiries, and so on. Although wearable medical is a general trend and has many merits, it faces with many practical problems, such as unstable and insecure of information environment, less interest for patients and medical staff, and having not great consumer experiences.

## 7. Future trends of wearable medical

As China is still a developing country, especially in the poor rural areas most people can't afford expensive healthcare solutions. Therefore, only low-cost wearable medical products can be put into practice, and used to solve chronic health problem and reduce medical expenditure. Recently, a new medical paradigm called “6P's of medicine” has been put forward to fulfill individual-centered healthcare's requirements. The core idea of this paradigm is to encourage the participation of the whole nation in the prevention of illnesses or early prediction of diseases such that preemptive treatment can be delivered thus achieving a pervasive and personalized healthcare, which ultimately aims to lower healthcare expenditures and improve people health [37]. So, in order to reach the goals of “6P's of medicine”, future development of wearable medical technologies must be having following trends and features: 1) Smaller and more comfortable. Only wearable medical device can almost not influence user, even vanish into artefacts around us. People will accept and be willing to use wearable medical devices, so that pervasive and personalized medicine can be realized. 2) Real-time and high-level diagnosis and alarm. Accurate and timely diagnosis and alarm enable preventive and preemptive medicine. 3) Health status identification and regulation. Identifying health status through data mining for acquired long-time, continuous and multi-parameter physiological data, and giving appropriate treatment, intervention or regulating, such as biofeedback training exercise will bring patients or sub-health people back to health with relatively low medical cost. This implies there will be less time and less treatment before the illness becomes complex and out of control, which is an effective way for saving resources and enabling predictive and preemptive medicine [38]. 4) More attractive in social health network function. Social network can influence people's emotions, behaviors, and lifestyles. More attractive the wearable medical product, more people will join the fitness training exercise that boost participatory and pervasive medicine .

## 8. Conclusion

“China's 12th Five-Year development plan for the Internet of things” released in 2011 by Ministry of Industry and Information Technology of the People's Republic China, put forward in 4th column that “to develop family- and community-oriented telemedicine service based on physiological signals and medical parameters acquisition and analysis” [39]. “Healthy China 2020” Strategic Research Report released in 2012 by Ministry of Health of the People's Republic of China, took “medical model transformation and medical system research” as one of the six important parts. In view of above national policies, it's conceivable that wearable medical technologies and products will certainly arouse more and more interest and obtain great development in China. Wearable medical is the most feasible method to take preventive health monitoring and to treat patients with a personalized approach at an early stage, which will speed up the transform of healthcare system and promote current healthcare system from conventional hospital-centered healthcare focusing diagnosis and treatment to individual-centered, family-centered, and community-centered healthcare emphasizing early detection, early diagnosis, and early treatment.

In addition, iiMedia Research, a world famous research institution, released 2012-2013 china mobile health market research annual report that showed the market size of China wearable or portable mobile health products achieved 420 million in 2012, and it will achieve one billion by 2015 and 5 billion by 2017. This report showed that more and more companies and investment organizations such as mobile operators, medical apparatus and instruments companies, terminal manufacturer, system integrators, and software solution partners, have swarmed into wearable medical and mobile health markets. And seeing from another angle, more investments seem to mean that more customers such as chronic patients, clinicians, druggist, and general public have noticed or experienced wearable medical products.

With improvement of people's fitness and health awareness, promotion of national policies, and advancement of information and communication technologies and biomedical engineering technologies, wearable medical will achieve new technical breakthroughs and get practical applications in individuals, families, and communities.

## 9. ACKNOWLEDGMENTS

This project was supported partly by the Natural Science Foundation of China (Grant Number: 60801009, 60971044), Beijing Natural Science Foundation (Grant Number: 3102028, 3122034) and General Logistics Science Foundation (Grant Number: CWS11C108).

## 10. REFERENCES

- [1] China Aging Development Report (2013). Chinese Academy of Social Sciences, 2013.
- [2] Report on cardiovascular disease in China (2011). National Center for Cardiovascular Diseases. CHINA (NCCD), 2011.
- [3] “Healthy China 2020” Strategic Research Report. Ministry of Health of the People's Republic of China, 2012.
- [4] LifeShirt. <http://vivonoetics.com/products/sensors/lifeshirt/>
- [5] VitalSense. [www.respironics.com/](http://www.respironics.com/)
- [6] BioHarness3. <http://www.zephyranywhere.com/>
- [7] Equivital LifeMonitor EQ02. <http://www.equivital.co.uk/>
- [8] mini-Medic. <http://www.athenagtx.com/>
- [9] LifeTouch HRV011. <http://www.isansys.com/>
- [10] Zio Patch. <http://www.irhythmtech.com>
- [11] NUVANT. <http://www.corventis.com/us/nuvant.asp>
- [12] V-Patch. <http://www.vpatchmedical.com/>
- [13] FuelBand. <http://www.nike.com/>
- [14] Fitbit. <http://www.fitbit.com/product>
- [15] Link Armband. <http://www.bodymedia.com/>
- [16] SmartBand. <http://www.codoon.com/>
- [17] Up. <https://jawbone.com/up>
- [18] Wahoo Fitness. <http://www.wahoofitness.com/>
- [19] Polar H7. <http://www.polar.com/>
- [20] Hx Smart. <http://www.zephyranywhere.com/>
- [21] Zheng, Y.P. 2003. Clinical Practice of Biofeedback. Higher Education Publishing Company. China.
- [22] StressEraser. <http://stresseraser.com/>
- [23] Zucker, T.L., Samuelson, K.W., Muench, F., Greenberg, M.A., and Gevirtz, R.N. 2009. The Effects of Respiratory Sinus Arrhythmia Biofeedback on Heart Rate Variability and Posttraumatic Stress Disorder Symptoms: A Pilot Study, *Appl Psychophysio Biofeedback*. 34,2(Jun.2009),135-143.
- [24] McLay, R.N. and Spira, J.L. 2009. Use of a portable biofeedback device to improve insomnia in a combat zone, a case report. *Appl Psychophysiol Biofeedback*. 34,4(Dec.2009),319-321.
- [25] RESPeRATE. <http://www.resperate.com/>
- [26] Sharma, M., Frishman, W.H., and Gandhi, K.2011. RESPeRATE: nonpharmacological treatment of hypertension. *Cardiol Rev*. 19,2(Mar-Apr.2011),47-51.
- [27] emWave2. <http://www.heartmathstore.com/>
- [28] Monitors Track Vital Signs for Fitness and Safety. [http://spinoff.nasa.gov/Spinoff2011/cg\\_5.html](http://spinoff.nasa.gov/Spinoff2011/cg_5.html)
- [29] China Mobile Health Market Research Annual Report (2012-2013). iiMedia Research, 2013
- [30] 5Udoctor. <http://www.5udoctor.com>
- [31] Spring Rain Pocket Doctor. <http://www.chunyuyisheng.com/>
- [32] Medical Documents. [www.xingshulin.com](http://www.xingshulin.com)
- [33] HaoDaiFu. <http://www.haodf.com/>
- [34] Pocket Check-Up Lite. <http://www.wali.com/>
- [35] DaYiMa. <http://dayima.us/>
- [36] Zhang Shang Yao Dian. <http://jiankang.manle.com/>
- [37] Poon, C.C. and Zhang, Y.T. 2008. Perspectives on high technologies for low-cost healthcare. *IEEE Eng Med Biol Mag*. 27,5(Sep-Oct.2008),42-47.
- [38] 2011-2012 Report on advances in biomedical engineering. China Science & Technology Press. Beijing, 2012.
- [39] China's 12th Five-Year development plan for the Internet of things. MIIT of the People's Republic China. 2011.