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Health Care with Wellness Wear

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1. Introduction

As the new medical practice paradigm of ubiquitous health care has gradually evolved, "smart" clothes with noninvasive sensors that obtain biosignals, such as ECG, respiration, SpO_2, and blood pressure data, have great potential (Axisa et al., 2005; Lauter, 2003). We call such clothes "*wellness wear*." A wellness wear system is an integration of biosensors that attach to clothes, digital yarns that transmit biosignals and other data, integrated circuits and microprocessors that process those signals, wired and wireless communication, and software applications that process and analyze vital signs obtained from the biosensors.

The need for wellness wear systems is clear. Wellness wear enables the continuous monitoring of health conditions at any time and place because the clothing is worn continuously. Thus, the use of wellness wear can promote easier home care. Both patients and nonpatients experience efficient and comfortable health care and disease prevention (Saranummi, 2002). This is particularly important because as the aging population increases, the interest in quality of life grows quickly. Undoubtedly, the physical boundaries and distances that restrict doctors' treatments can be reduced. Generally, wearable systems provide real-time feedback about one's long-term health condition, and can even provide alarms in potentially health-threatening situations (Pantelopoulos and Bourbakis, 2010). From an economic point of view, the increasing cost of medicine will be also reduced by the usage of wellness wear because some portion of expensive traditional health-care practices will be replaced.

Despite the need, however, there is not yet a stable market for wellness wear. Additionally, it has not achieved its goal of providing either low-cost or ubiquitous health-care services. One critical reason for this is that biosensors attached to clothes cause motion artifacts; thus, the quality of biosignals may be unreliable. This means that they have not yet been validated clinically. Many sensors can also cause skin irritation or allergies. Further, wellness wear is not of sufficient quality in terms of fashion, usability, and acceptability in consumer culture. There are probably more reasons that wellness wear has not been successful nor actively commercialized; the major reason is likely that wellness wear is still in its infancy. We believe that the currently immature technical, clinical, and cultural aspects of wellness wear will gradually improve, eventually increasing its use.

In this chapter, we shed some light on health care with smart clothes. First, we briefly review previously introduced smart health clothes. Second, as an example, we present a wellness wear system that we are developing that assists with weight loss by using software called the Calorie Tracker, which works together with wellness wear.

2. Wellness wear and related medical services

This section presents a survey of the state of research and development of smart clothes for health care. The general architecture and basic design considerations of smart clothes are introduced briefly. Research prototypes and commercial products of the main smart clothes that have been developed so far are then reviewed.

2.1 An overview

Figure 1 shows the general architecture of smart clothes for health care (Park and Jayaraman, 2010). The miniature *sensors* that are integrated into the textile measure biosignals from the wearer and the environment to provide physiological and contextual information. The *signal processing system*, which serves as the system's central node and usually takes the form of a hand-held device or carry-on electronics, provides temporary data storage and may also preliminarily process sensory data to acquire appropriate parameters, including vital signs. The *communication system* transmits the raw data and extracted parameters to a remote station for long-term storage and further analysis. The *decision support system* installed in the station obtains and interprets the data to assist in the diagnosis and treatment by health-care professionals.

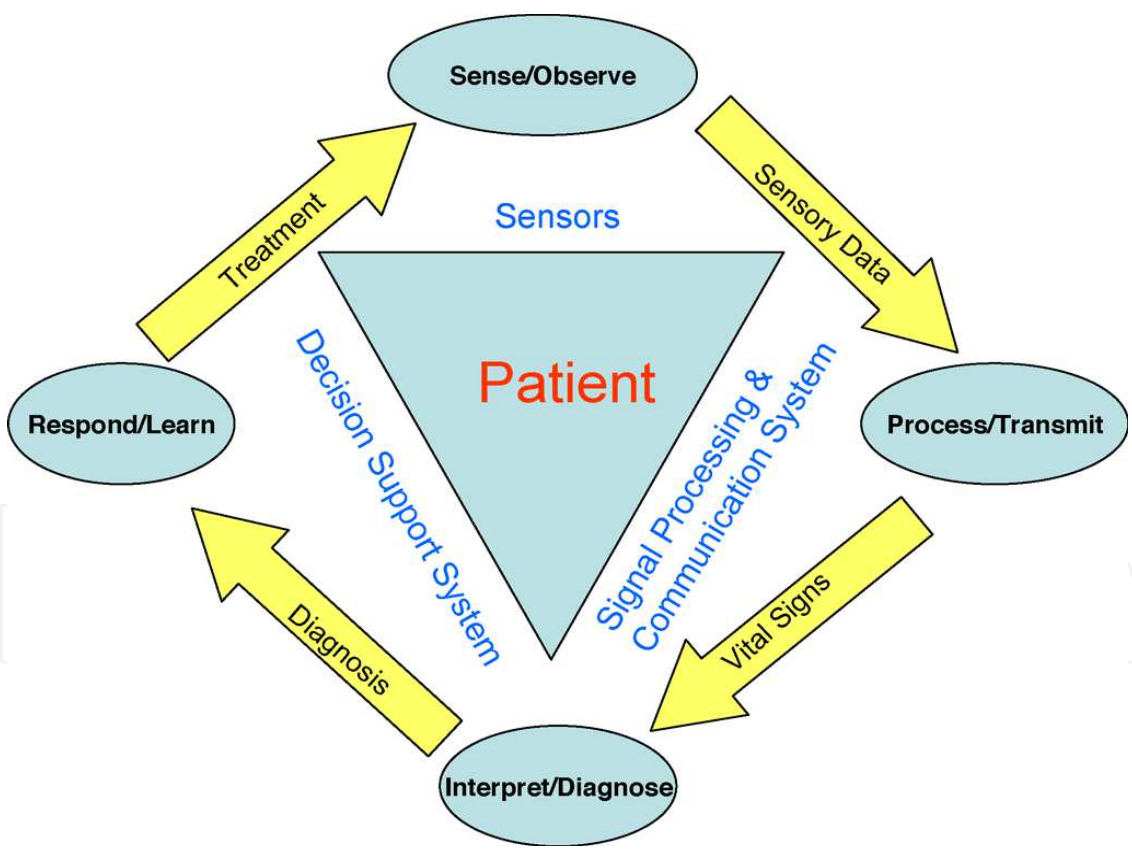

Fig. 1. Architecture of smart clothes (from Park and Jayaraman, 2010, p. 87)

This smart clothes framework shows that the design and implementation of such a system is a challenging task. Many constraining and sometimes conflicting requirements must be considered in enabling smart clothes to become an efficient and applicable health-care solution in real-life situations. More specifically, smart clothes should:

1. satisfy the need of wearability (low weight and small size to enable a comfortable experience);
2. provide an easy-to-use interface to minimize the cognitive effort of the user;
3. incorporate noninvasive biomedical sensors, which allow for biosignal measurements on humans without radiation or infection concerns, to comprehensively estimate and evaluate the wearer's health status;
4. enable real-time processing to facilitate use and track the timing of emergencies, which could be lifesaving;
5. possess a certain level of intelligence to aid health-care professionals in identifying and addressing health problems
6. acquire biosignals with high accuracy and low distortion and present results with a high degree of reliability to gain the trust of professionals;
7. deploy appropriate security and privacy solutions that mainly focus on data transmission and storage to protect the status information and personal medical data of the user;
8. provide reliable communication channels for transmission of biosignals from the sensors to the system's central node and then from the smart clothes to a remote medical station (or to a physician's hand-held device);
9. enable low power consumption to support extended operation times and system miniaturization
10. enable scalability and reconfigurability to improve system applicability and user acceptance, such as adding or removing sensors; and
11. undergo testing in clinical situations to demonstrate validity and practicability, the outcome of which can help to convince stakeholders.

2.2 Research and development of smart health clothes

As one of the most important applications of wearable technology, smart clothes for health care started in early 2000 (Lymberis and Olsson, 2003). Since then, this promising area has attracted much attention from both the research and business communities. In the following two subsections, we review the main achievements from both research and commercial aspects.

2.2.1 Research prototypes

The VTAMN (Vêtement de Télé Assistance Médicale Nomade—Undergarment for Nomad Medical Tele-assistance) project was supported, in part, by the French government and aims to measure physiological information on the wearer as well as environmental and activity parameters in daily life situations (Fig. 2). Six-lead ECG signals (from 4 textile electrodes), breathing frequency (from 2 coil pneumographs), and ambient and mid-temperature (from 2 I_2C temperature sensors) are transmitted automatically or on demand to the remote station using a GSM placed onto the belt. This enables remote detection and tracing of cardiac arrhythmias. The system also incorporates a fall detection module (a 2-axis accelerometer and a microcontroller embedded on an electronic board) to enable an alarm to launch by a cell phone and subsequent rescue to occur with the help of GPS localization. Evaluation has shown simple and comfortable wearing, significant ECG readings, correct breathing frequency and temperature, and functional activity sensing during normal activities. However, some shortcomings also exist, including bulky batteries and electronics and a QRS issue (Noury et al., 2004).

Fig. 2. VTAMN garment with the belt

The HealthWear (Remote Health Monitoring with Wearable non-Invasive Mobile System) project is supported by the European Commission and is based on the WEALTHY prototype with improved thermal and wearing comfort of the textile. The HealthWear system aims to deliver a service that provides uninterrupted and ubiquitous monitoring of the health condition of patients undergoing rehabilitation, patients out of the hospital with chronic diseases or after an acute event, high-risk people, such as the elderly, and others. The measurement capabilities of the system include ECG signals and deduced parameters such as heart rate (HR) and QRS duration (from 6 textile electrodes), oxygen saturation (SpO_2, by oximetry), respiration (by impedance pneumography), activity (from a 3-axis accelerometer integrated into the portable unit), and temperature (from 4 I_2C skin temperature sensors).
Figure 3 shows the HealthWear portable unit and garment. The portable unit is responsible for deciphering and transmitting (to the remote station through GPRS) the sensory data, which are collected from the sensors integrated into the garment (Paradiso et al., 2008).
The MagIC (Maglietta Interattiva Computerizzata) system was developed by researchers in Milan, Italy, and aims to unobtrusively monitor cardiorespiratory and motion signals during spontaneous behavior in clinical practice and daily life. The system consists of a washable sensorized vest and portable electronic board (Fig. 4). Two electrodes made by conductive fibers are woven at the thoracic level of the vest to obtain an ECG lead. A textile transducer is also included in the vest to measure respiratory activity. The obtained ECG and respiratory signals are transmitted by conductive fiber connections to the vest's portable electronic board, which is responsible for motion detection through a 2-axis accelerometer and wireless data transmission to the remote station. Tests performed on patients in bed and during physical exercise showed good signal quality (except in the case of maximal physical activity), correct identification of arrhythmic events, and correct estimation of the average HR (Di Rienzo et al., 2005).

Fig. 3. Portable unit (left) and garment (right) of HealthWear

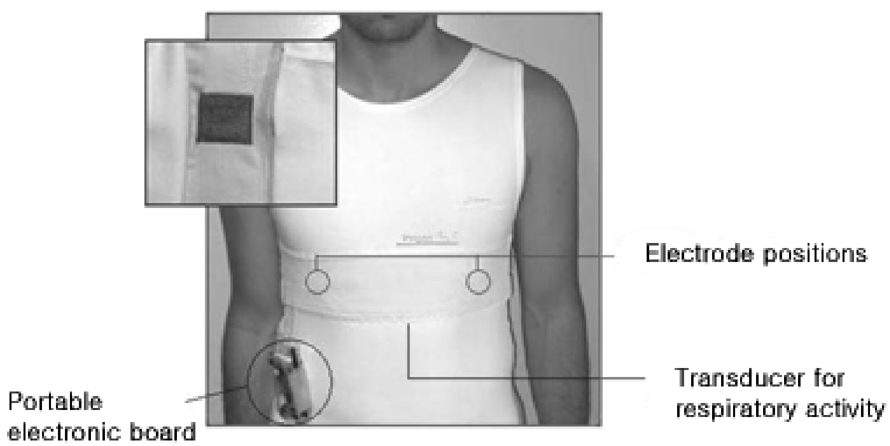

Fig. 4. The MagIC system

The MyHeart project (Fig. 5) is supported by the European Commission and involves 33 partners from 10 countries, including industrial partners such as Philips, Nokia, Vodafone, and Medtronic. It aims to systematically fight cardiovascular diseases by promotion of a preventive lifestyle, early diagnosis of acute events, and interaction with various stakeholders (e.g., local feedback to the wearer and remote feedback to professionals) (Habetha, 2006). An on-body sensor network is applied using integrated or embedded sensors and conductive wires knitted like normal textile yarns to reduce the size of sensor nodes and avoid the presence of both a local battery and an additional wireless module. On-body signal processing is performed to estimate HR from textile-ECG and continuously classify ambulatory activity (resting, lying, walking, running, and going up/down stairs) based on a 1-axis accelerometer within the on-body electronics. Bluetooth wireless communication is also established between the on-body electronics and a cell phone, which is then used to forward the processed signals to a remote monitoring station (Luprano et al., 2006).

Fig. 5. Inner layer of MyHeart shirt (left) and first prototype of the on-body electronics (right)

SmartVest, a wearable physiological monitoring system, consists of a vest, data acquisition and processing hardware, and a remote monitoring station. The sensors (Fig. 6), integrated into the vest, can sense vital parameters, such as ECG signals, photoplethysmography (PPG) readings, HR, blood pressure, body temperature, and galvanic skin response (GSR). Good ECG quality (no baseline wander or motion artifact) is obtained without the use of gel. Blood pressure is measured by a non-invasive, cuffless method. Data fusion provides a more comprehensive picture of the wearer's health state (Pandian et al., 2008).

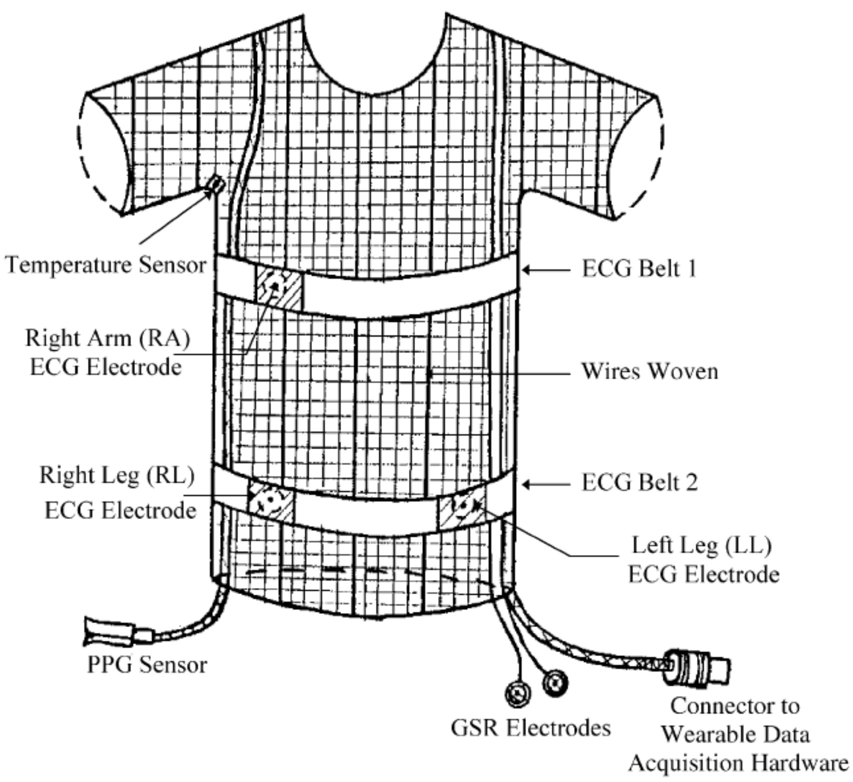

Fig. 6. Sensors integrated at specific locations in the vest

The BIOTEX (Biosensing Textile for Health Management) project is partly funded by the European Commission and aims to develop biochemical-sensing techniques that can be integrated into textiles for medical applications, including the monitoring of diabetes, sports activity, and obesity. The capabilities of BIOTEX include monitoring of pH, conductivity, sweat rate, electrolyte concentrations in sweat, SpO_2, and protein levels in blood and plasma (Luprano et al., 2007). The results of BIOTEX will be also used in the PROETEX project, the applications of which target at-risk professionals.

2.2.2 Commercial products

The LifeShirt, released by Vivometrics, is the first commercially available piece of smart clothing. It consists of a washable lightweight vest, a data recorder, and PC-based software. Its capabilities include continuous monitoring of the ECG, respiration, activity, and posture (Fig. 7) (Grossman, 2004). It has been used in various studies, and its potential applicability in future studies has been acknowledged. Additionally, its performance, such as HR detection, has been demonstrated to be accurate (Heilman and Porges, 2007). Foster-Miller's Watchdog physiological monitoring tool is a comfortable, garment-based system for monitoring HR, respiration rate, posture, activity, skin temperature, and GPS location. The Smart Shirt, manufactured by Sensatex, contains sensors that monitor vital signs, such as ECG, HR, respiration, and blood pressure (Pantelopoulos and Bourbakis, 2010).

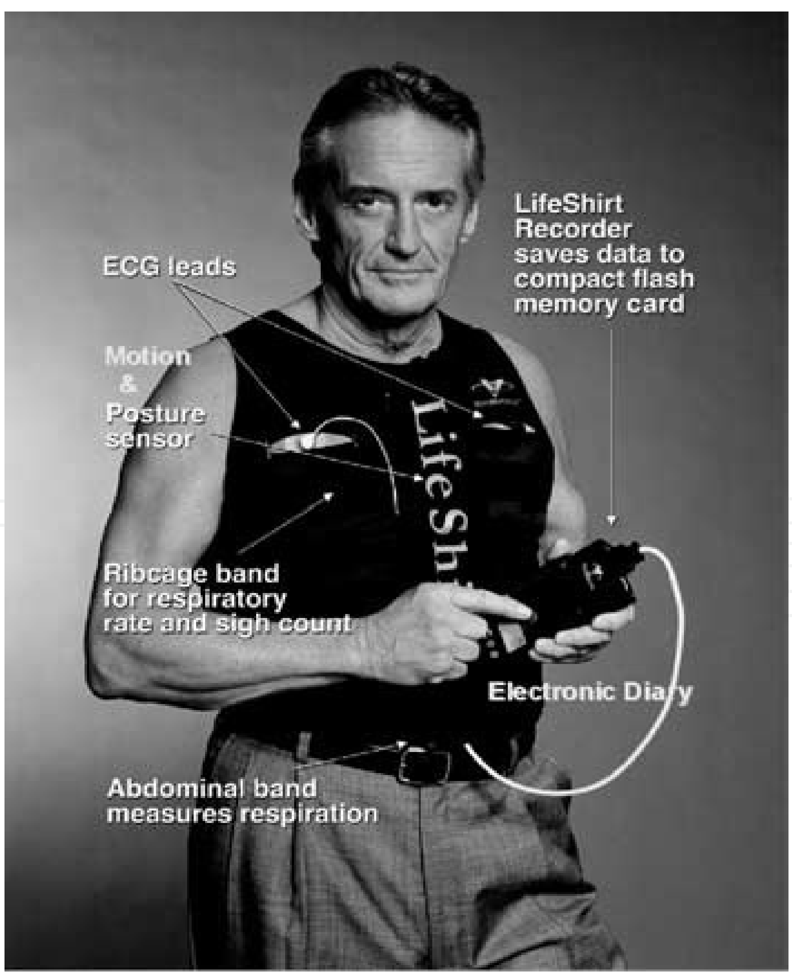

Fig. 7. The LifeShirt system

The Zephyr BioHarness technology is well-known because it was used in connection with the rescue operation of 33 trapped miners in northern Chile's San Jose mine (Zephyr Technology, 2010). It has also been adopted by NASA for use by astronauts in training. The BioHarness, a chest strap with sensors and wireless technology, monitors and transmits the wearer's vital signs, such as ECG data, HR, breathing rate, skin temperature, posture, activity, acclerometry, blood pressure, and pulse oximetry. Vital signs are transmitted with ISM or Bluetooth for remote monitoring anywhere in the world. The software platform OmniSense is used to display the BioHarness data.

Fig. 8. The Zephyr BioHarness technology

3. A wellness wear system

A wellness wear system is an integrated system consisting of wellness wear, biosensors, hardware, and software. One of its advantages is easy aquisition of vital signs at any time and anywhere, which provide important basic data for monitoring health status. In this respect, advanced sensor technology is recommended to ensure the accuracy of the signals. The development of digital or conductive yarns also plays a crucial role in the formation of a body area network (BAN) within the clothes. These special yarns enable wired transmission of the data over the clothes. Further, hardware is used for digital signal processing (DSP), wired and wireless communication, and integration of multiple biosensors. However, another important technology is software.

In particular, the success of wellness wear systems depends highly on the quality of the medical information extracted from that data by the software and the medical content that is provided. In this section, we present a nanofiber technique–based wellness wear system that we are developing as an example of wellness wear. This system has a particular emphasis on software applications, including a fundamental service framework as an infrastructure and an application called Calorie Tracker, which runs on Android-based smartphones and enables weight loss and exercise management (Kim et al., 2011).

3.1 An overview

Here, we introduce a wellness wear system that we are currently developing. A primitive but fundamental scenario that we assume is that the user wears smart clothes with noninvasive and comfortable biosensors that typically measure ECG, respiration, body temperature, and the like. While the subject is sitting, sleeping, walking, running, exercising, or performing any other activity, biosignals are recorded and transmitted to the terminal and/or the server. Smart phones can be both terminals that transmit the data and devices that enable the application software to run. The software system analyzes the signals and other general data such as age and gender, and provides the user with a relevant medical recommendation. Figure 9 illustrates the scenario described.

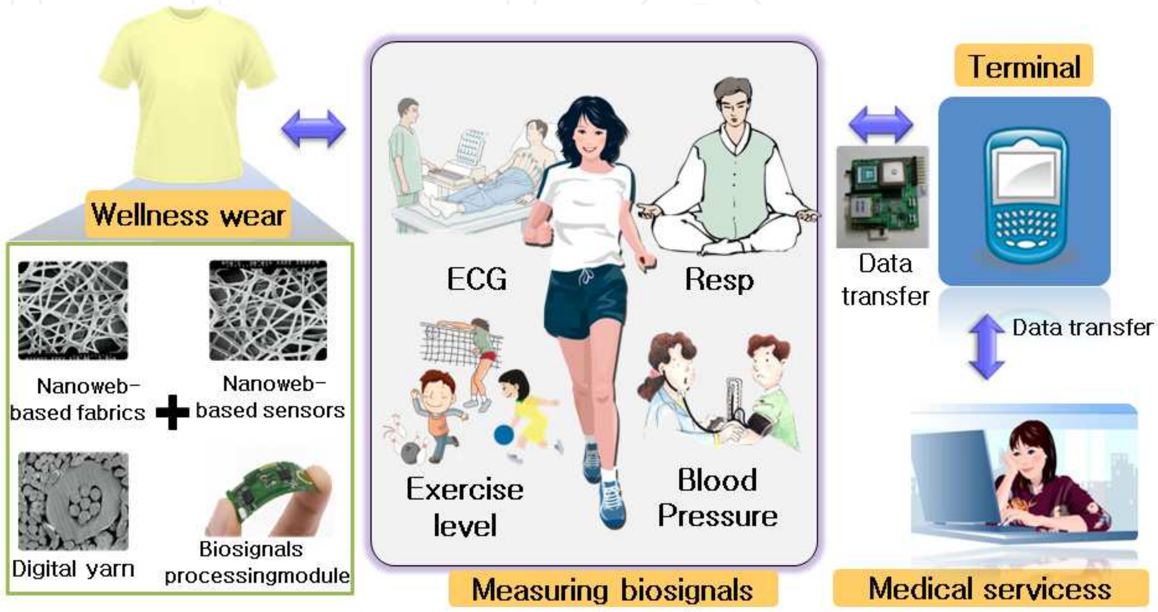

Fig. 9. Use scenario of a wellness wear system

Using calorie tracking as an example, here, we describe four of the important elements required for the development of the wellness wear system that we are implementing: biosensors, digital yarns, a software framework, and communication and medical services.

3.2 Biosensors

When we develop biosensors that are attachable to wellness wear, two crucial factors are accuracy of the obtained signals and user comfort. However, a tradeoff is typically required between them. Generally, the more accurate wearable biosensors are, the less comfortable they are, and *vice versa*. Thus, a future goal concerns how to overcome this. Comfort is a particularly important element. Because biosensors are adhered to smart clothes and touch the skin, they should be small, comfortable, and noninvasive. This is one of the reasons for the requirement for nanofiber. In fact, nanofiber is comfortable even when sensors are attached to smart clothes. For example, the physiological sensor belt (PSB), which detects the breath and pulse (Kim et al., 2009), is poromeric and protected from electromagnetic waves. It is much more comfortable than ordinary hospital devices that sense vital signs.

Several typical vital signs can be detected by biosensors attached to wellness wear. As we saw in the previous section, the ECG is one biosignal that most smart medical clothes aim to detect. It is ideal to detect life-threatening diseases early and to monitor patients and manage health through wireless communications (Taylor and Sharif, 2006). HR variability (HRV) extracted from ECG is also an important biosignal that helps in diagnosing heart-related illnesses and can check the efficiency of exercise and even stress. Respiration monitoring is also required to monitor walking and detect sleep apnea. Recently, fabric-based respiration sensors for wellness wear have been developed, and the quality of the signal has improved (Catrysse et al., 2004). Accelerometers have become popular to evaluate the amount of exercise. The number of steps taken can be identified by accelerometers. Together with GPS, one can determine the distance walked or run. For the elderly, accelerometers can support fall detection. They are also used to monitor chronic obstructive pulmonary disease patients (Mathie et al., 2004). Additionally, researchers are making efforts to develop wellness wear–based biosensors to obtain skin temperature, SpO_2, and blood pressure.

3.3 Digital yarns

To produce wellness wear, several technologies are needed, such as sewing, knitting, and embroidering technologies. More importantly, however, digital yarns that require highly advanced technologies play an important role in the transmission of biosignal data. In fact, conductive or digital yarns that transmit data within the clothes form a BAN. Dr. Gi-Soo Chung at the Korea Institute of Industrial Technology (KITECH) developed a digital yarn in which the major material is a copper alloy (Chung et al., 2006; Chung, 2007). His digital yarn is divided into two parts: a core and an outer part. As seen in Figure 10, its core consists of 7 microwires and a special resin. Its outer part is covered with dyed normal yarn. Electric resistance of the digital yarn is fairly low, at 7.5 Ω/m, compared with previously developed conductive yarns (Bekaert, 2011; Linz et al., 2005; TEXTILE, 2005).

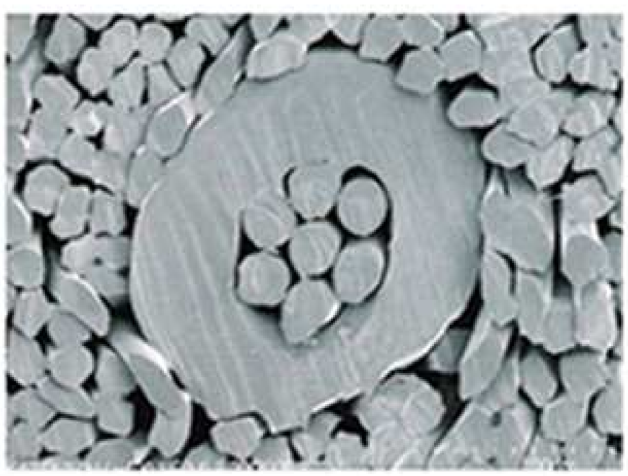

Fig. 10. A digital yarn

A digital garment is made with both ordinary yarns and digital bands for data transmission. Here, a digital band is a set of 10 to 30 digital yarns that are used as a communication line. The transmission speed of the yarn is very high (approximately 80 Mbps). This indicates that it could transmit an 800-MB movie file within approximately 1.5 min (Chung and Kim, 2011).

3.4 Software: Framework and software solution

Software aspects consist of a framework and a software solution. The framework is a foundation on which software applications are built, and the software solution concerns everything related to the software that is implemented on the framework.

3.4.1 Framework

Applications to provide medical service content are more complex and larger to build than many realize. This is because issues such as standardization, interoperability, reusability, reduction of maintenance cost, and readability must be addressed, which requires a sustainable and flexible infrastructure before application development. For this purpose, we have developed a framework that underlies all wellness wear application systems (Kim et al., 2009).

The primary idea is that vital signs from the wellness clothes are transformed into a metamodel-based abstract tree on which health-care services are defined through Object Constraint Language (OCL) (OMG-OCL, 2009) with the help of medical specialists and engineers. This idea implies that each service must be clearly defined and that integrated management is much easier when a repository of biosignal data is constructed. It also helps to make additions, deletions, and updates of services convenient. In particular, because the framework expresses the biosignal data as an HL7 (HL7, 2009) metamodel. based on MetaObject Facility (MOF), the M3 level, defined by the Object Management Group (OMG), standardization of the data and interoperability and integration between the biosignal data. is achieved.

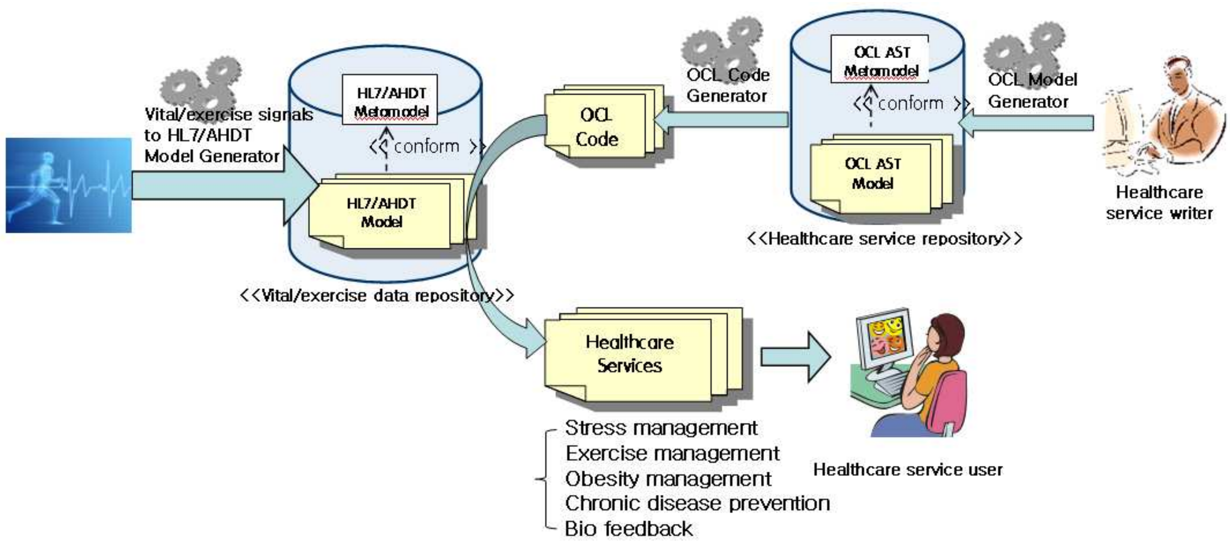

Fig. 11. Framework for a software solution in the wellness wear system

3.4.2 Software solution

Once the biosignal data obtained from sensors are accurate and stable, what is then important is how to support proper health management services, such as stress management, food control, an exercise plan, and general health management. When these services are perceived as useful by different stakeholders, the whole system, including other technologies such as the digital garments, DSP, and biosensors, will eventually succeed. In this respect, software and related medical services are primary elements for the success of the wellness wear system.

We consider that the software solution has four critical areas. First, algorithms and data mining techniques to process and analyze the given biosignals are required. Noise detection and filtering must be very basic techniques, and analysis of the biosignals, including both single and multiple biosignals, is important. In particular, multiple-signal analysis is a relatively new and important research field that involves understanding stress and the amount of exercise by analyzing the relationship between ECG and respiration. Second, development of health-care service content by medical specialists is key. Their roles are to plan and organize health-care service content using their expertise and cooperating with engineers. They will also develop health indices in the context of wellness wear systems, such as a wellness index and HR variation index. Third, both wired and wireless communication are required for the wellness wear system. For example, Bluetooth or ZigBee is used for short-distance wireless communication of vital signs. Another important task is to accept the international standard ISO/IEEE 11073 communication model and add its related communication protocols for processing vital signs information in different medical devices. A standardized protocol is not urgently needed in the near future; however, many experts anticipate that communication between personal health devices (PHDs) will be standardized eventually. It is also meaningful to follow a communication standard. Finally, an application service system provides health-care services. It is the central system that integrates various modules, including the biosignal analysis module, service components, and communication. Next, we present a software program called Calorie Tracker, which works together with the wellness wear system.

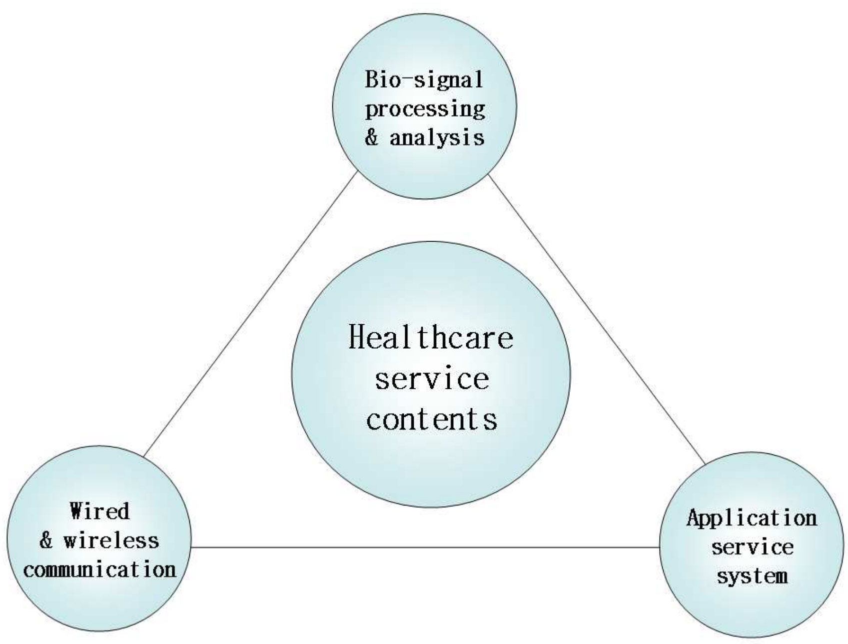

Fig. 12. Software solution in the wellness wear system

3.5 Calorie tracker: A medical service example

There must be a large number of potential medical services supported by a wellness wear system. We have developed a software application involving a calorie tracker (Kim et al., 2011) and herein describe how wellness wear is used with the software for health care.

3.5.1 Why calorie tracker?

The calorie tracker, which runs on an Android-based smartphone, analyzes HRV extracted from the ECG data obtained by wellness wear and provides a weight-loss program. The calorie tracker is useful in managing obesity. As we know, obesity reduction is a top priority in most developed countries. Obesity not only affects one's physical appearance, but also leads to a number of weight-related diseases, such as insulin resistance syndrome, cardiovascular disease, and type 2 diabetes. It is also leads to various chronic diseases. Generally, obesity is treated with food control and exercise. The calorie tracker was designed to evaluate the amount of exercise, show the number of calories burned during the exercise, and recommend simple exercise plans.

The choice of Android as an operating system was made primarily because of its multitasking performance, which is important for real-time continuous transmission of ECG data. If multitasking is not supported, ECG data transmission will suddenly cease when another application begins running or when the user initiates or receives a telephone call. The smartphone is both a device that handles client programs and a terminal that exchanges data with a server. The ECG data acquired from the wellness wear are transferred to the smartphone using Bluetooth, and the system on the smartphone transmits the data to the server using the XML form that conforms to the HL7 standard.

3.5.2 Usage scenario

The calorie tracker is best understood in terms of its four phases of use. First, it acquires ECG data from the wellness wear. More specifically, ECG data are obtained while the user is performing an activity such as running, walking, or sitting for a certain period of time; for example, 5 min. Figure 13 shows an ECG signal obtained from wellness wear. The user also provides the calorie tracker with other general data, such as the user's weight, height, age, gender, and more. Additionally, the user must provide information regarding whether he/she is at rest or active, is taking medications, or is diabetic.

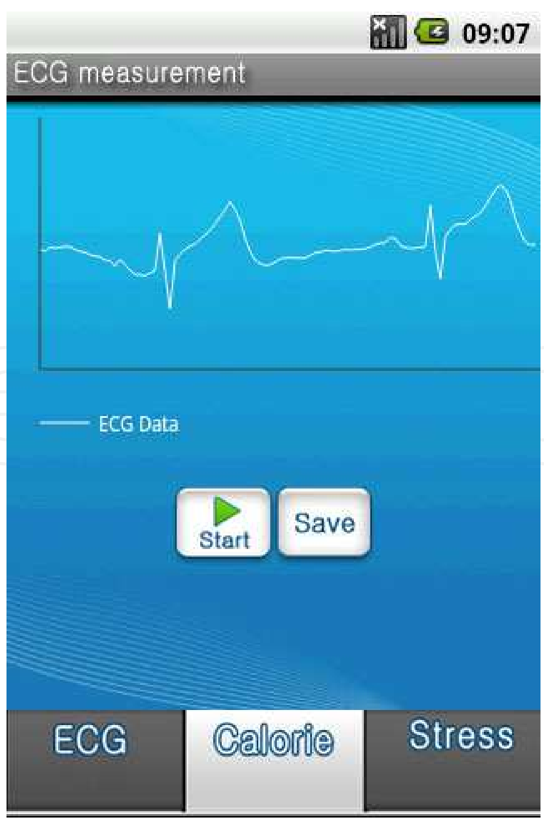

Fig. 13. Screenshot of the user interface of the calorie tracker

Second, the system measures HRV from the ECG data. ECGs consist of waves of P-Q-R-S-T, with R peaks being the highest of the five. Figure 14 illustrates an ideal ECG signal, showing adjacent R peaks and the R-R interval. Here, the HRV indicates the variablity of intervals between R waves, which are called R-R intervals. Thus, HRV is a time series of intervals between successive R peaks in the ECG. HRV has relevance for physical, emotional, and mental functions. The variability in HR is an adaptive quality in a healthy body. Generally, HRV is useful for evaluating functions of the autonomous nervous system, whereas ECG is better for the diagnosis of various heart-related diseases. Well-known HRV indices include the normalized beat-to-beat interval (NN), the standard deviation of those intervals (SDNN), and the percentage of the interbeat intervals differing from neighboring intervals by 50 ms or more.

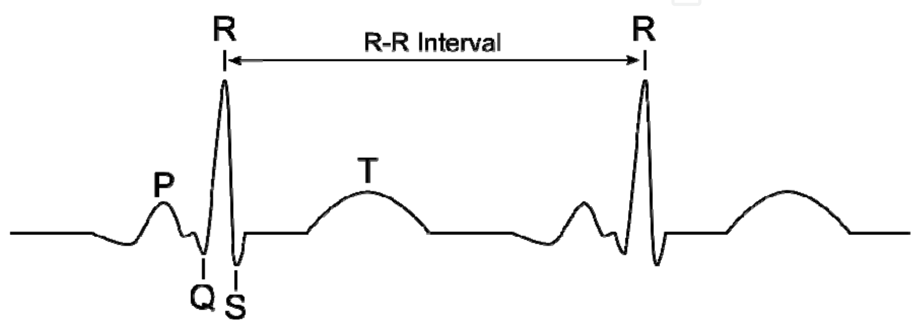

Fig. 14. R peaks and R-R intervals on an ECG

Third, the system calculates the number of calories burned (energy expenditure) and the body mass index using the HRV and other general data. Energy expenditure is crucial to the determination of how much and how intense exercise should be for each person. To determine calorie consumption, the maximal oxygen consumption per min (%VO_2max) is obtained using HRV measurements, including the average resting HRV (HRV_R) and the maximal HRV (HRV_M), according to the user's age (Lubell and Marks, 1986). Next, the number of calories burned during exercise or other activities for a given period of time is calculated from %VO_2max and the user's weight.

Finally, the system offers the user a weight-loss program. For example, it may state, "You need light exercise for two hours a day to reduce weight by 1 kg in a month." Based on the HRV data recorded during a certain period of the user's activity (e.g., 5 min), the system determines the intensity of exercise related to the user. It then makes a recommendation for an appropriate exercise level to help the user reduce weight according to his or her weight loss goals (Fig. 15).

4. Conclusions

Wellness wear systems are expected to be used for health care in the near future. In this chapter, we described wellness wear systems in general and introduced in detail a wellness wear system that we are currently developing. In doing so, we have demonstrated the potential for health care using wellness wear. Additionally, we presented a weight loss program called Calorie Tracker, which works together with wellness wear, as an example of a medical service. Although a stable market for wellness wear has not yet developed, we believe that a healthy life with wellness wear will eventually be realized as certain technological problems are resolved.

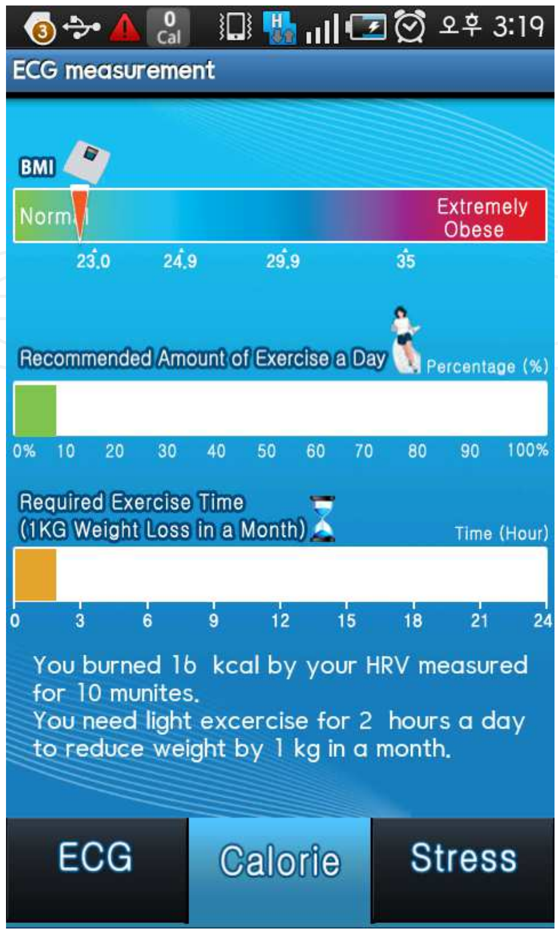

Fig. 15. The calorie tracker's evaluation and recommendation

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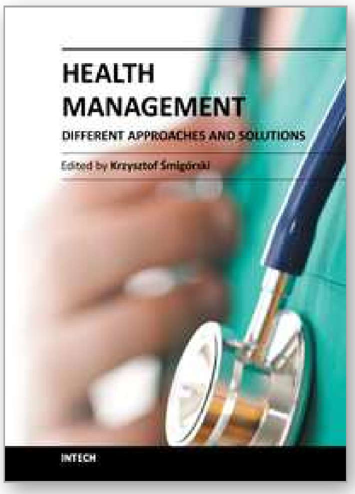

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The development in our understanding of health management ensures unprecedented possibilities in terms of explaining the causes of diseases and effective treatment. However, increased capabilities create new issues. Both, researchers and clinicians, as well as managers of healthcare units face new challenges: increasing validity and reliability of clinical trials, effectively distributing medical products, managing hospitals and clinics flexibly, and managing treatment processes efficiently. The aim of this book is to present issues relating to health management in a way that would be satisfying for academicians and practitioners. It is designed to be a forum for the experts in the thematic area to exchange viewpoints, and to present health management's state-of-art as a scientific and professional domain.

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