Wearable sensors for athletes

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12.1 Introduction

The biggest advantage of wearable health monitoring systems is nonstop real-time monitoring throughout a long period (Lymberis and De Rossi, 2004). Nonstop real-time monitoring is possible when the sensor is worn on the human body by means of clothing or accessories. Various types of e-textiles are adopted to formulate textile sensors. Technical analysis of physiological signals captured by the sensors is performed by small electronics outside of the clothing. These electronics can deliver the health data to a designated person or institution – hospitals or coaching staff – from a distance through wireless communication. Figure 12.1 describes the schematic structure of a typical wearable health monitoring system. It consists of three basic components: sensors for input, an electronic module for processing, and a mobile device for output.

Textile sensors are created by incorporating conductive materials into textile structures. Silver has been employed most commonly in textile sensors, though other conductive materials are available, such as gold, copper, and stainless steel. Conductive materials are combined with nonconductive components, which are polymers. Fabrication methods include weaving, stitching, couching, knitting, and printing (Suh, 2010).

The electronic module rectifies the signals collected from textile sensors and transmits them to an output device through Bluetooth™ technology. An electronic module is a miniaturized version of conventional electronics. It consists of an amplifier, microcontroller, and wireless communication units (Kumar et al., 2013), which are scaled down to millimeter levels and housed in a compact case. Although it is possible to produce electronic modules small enough to be embedded as an intrinsic part of the textile sensor, an electronic module remains an extrinsic component in real products, mostly because of the challenges of stability against chemical and physical interferences such as moisture and mechanical deformations. Small and lightweight enough to be attached to the textile surface (Table 12.1), the electronic module is designed to process multiple types of signal data, according to the purpose of the textile sensor.

Mobile devices function as a platform to output visual or auditory feedback. By installing the managerial software in conventional smartphones or tablet PCs, the health data received from the electronic module is filtered and analyzed to formulate professional advice customized to the wearer's condition. It can take the role of the coaching staff or a medical attendant. Depending on the application, it can also send the health data to the designated institutions or personnel from a distance.

Several commercial products are available in the sportswear market. The sensors are often worn on the chest, arm, or wrist. These products do not aim only at vital

Electronic Textiles. http://dx.doi.org/10.1016/B978-0-08-100201-8.00013-8

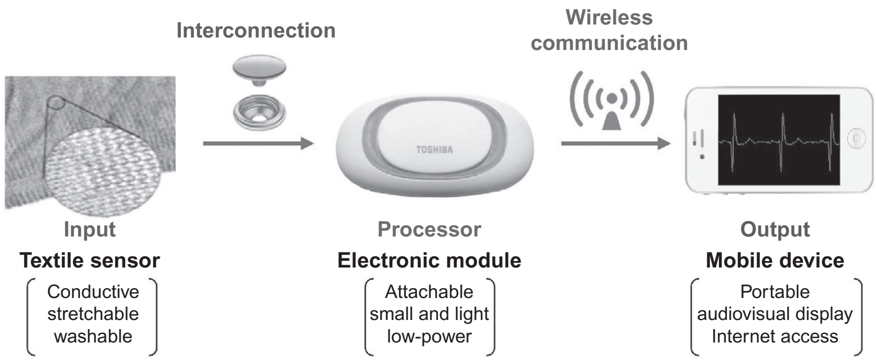

Figure 12.1 Schematic structure and components of a wearable health-monitoring system.

Table 12.1 Sensor module product specifications

Product	Size (mm)	Weight (g)	Measurement
Toshiba Silmee™	60.0 × 25.0 × 10.0	10.0	ECG wave, pulse wave, temperature, and motion
Adidas miCoach™	63.0 × 38.0 × 10.5	19.5	Heart rate, calories, and auditory and visual feedback
Hidalgo EquiVital™	78.0 × 53.0 × 10.0	38.0	Heart rate, respiration, temperature, body position, and accelerometry

signal monitoring, but also at providing performance analysis such as calories burned and location and time information. Some systems are developed to provide personal training based on the vital signs and performance data collected.

In this chapter, wearable health-monitoring system for athletes will be discussed, focusing on textile sensors. Section 12.2 presents various textile sensors monitoring different types of vital signals, such as electrocardiogram (ECG), electromyogram (EMG), respiration, and motion. Fabrication methods and technical challenges will be addressed, which are critical to making those sensors wearable. In Section 12.3, several examples of real products currently available in the market are introduced. Future trends in wearable health-monitoring systems and a brief conclusion follow in Sections 12.4 and 12.5, respectively.

12.2 Textile sensor technology

Along with the increased demands of performance monitoring, personal training, and injury prevention, wearable sensors have been attracting much attention from the sportswear market. The typical textile sensors embedded into commercial sportswear products are biopotential sensors for ECG/EMG monitoring, respiration sensors, and motion sensors.

Early research incorporated those sensors by putting them in a pocket or by attaching them temporarily to the fabric surface, but recent advances in textile technology enable them to be an intrinsic part of the fabric. The primary aim of fabrication is to create reliable conductive tracks or surfaces that do not hinder the wearer's movement with mechanical constraints. Not adding bulkiness, the textile sensors need to be flexible, stretchable, and washable. Also, the surface should not get snagged, broken, and tangled by any external triggers that might be present in the wearer's daily environment. The performance of the sensor should remain intact, even if the fabrics are creased and stretched.

12.2.1 Biopotential sensors for ECG/EMG monitoring

Electrocardiography (ECG) and electromyography (EMG) have been widely used in sports and clinical settings. They are the electrical potentials periodically changed by cardiovascular and muscle activities, respectively. Nervous stimuli and muscle contraction can be easily detected by measuring the ionic current flow in the body. This measurement is accomplished by attaching biopotential electrodes to the skin surface.

In traditional ECG/EMG-monitoring systems, the electrodes are either made of gel or stuck to the skin using conductive adhesives in order to develop better contact to the skin. However, gelatinous substances dry out over a long period of time and cause the electrode to come off the skin. Adhesives can irritate the skin, leading to a loss of signal quality. As an attempt to improve the contact between the electrodes and the skin, skin preparation is required, such as shaving, abrading, and cleaning the skin surface.

Typically, a wearable electrode is created by weaving, knitting, or stitching silver yarns on the inner surface of the clothing. Due to irregular surface structures, it creates high impedance, and therefore high-frequency noise. One of the challenges of wearable electrodes is to create a reliable interface between the electrode and the skin, which can last for an extended length of time. Because textile electrodes are dry electrodes that are not fixed on the skin, they are susceptible to body motion, and the contact impedance between the electrode and the skin might be higher than in traditional ECG electrodes (Comert et al., 2013).

There have been a few methods that have tried to resolve this difficulty and acquire firm electrode–skin contact. Kang et al. (2008) suggested active electrodes, which can resist surrounding noises better. Containing an additional ultra-low noise preamplifier, active electrodes acquire noise-resistant signals but require a power supply and power lines within the electrodes. For passive electrodes, it is still recommended by most manufacturers to have the electrode surface wet before it is worn. The electrode adheres to the skin closer with high-stretch knit fabrics (Paradiso et al., 2005). The contact interface could be greater if the electrode is located on the brassiere band or waistband, where the clothing is tightened.

Finni et al. (2007) tested the validity, reliability, and feasibility of textile electrodes and concluded that textile electrodes are a valid and feasible method that is parallel to traditional electrodes. The amplitude of the signal collected by traditional electrodes was greater than that from textile electrodes, but good agreement was shown between the two. Textile electrodes provided similar or even better reproducibility than traditional electrodes, with a precision error between 5% and 17%.

12.2.2 Respiratory sensor

Most respiratory sensors are based on the pneumography and measure the changes of chest or abdomen circumference. As the circumference increases or decreases, the electrical property of the textile sensor changes, and this change could be interpreted into inhalation and exhalation activities of the wearer. The most common methods include respiratory inductive plethysmography (RIP), piezoresistive sensors, and piezoelectric sensors (Merritt et al., 2009).

RIP signals can be caught by an insulated sinusoidal wire coil embedded into a stretchable textile strap (Figure 12.2). Wound around the chest or abdomen, the textile strap is supposed to be stretched by the respiration. The coil inductance is directly governed by the change of sinusoid shapes. This method has been widely adopted in several commercial products, including LifeShirt®.

A piezoresistive sensor is a flexible strain gauge that becomes resistive when mechanical deformation is applied. The typical form of a textile piezoresistive sensor is to have piezoresistive coating over the fabric surface. Due to the durability issues of the thin coating layer, possible shortcomings are poor repeatability and performance deterioration after washing or repeated folding (Huang et al., 2008). Another fabrication method is to knit conductive yarns with nonconductive base yarns (Zhang et al., 2006). This is the method adopted for Wealthy (Paradiso et al., 2005) and MyHeart projects (Paradiso and De Rossi, 2006). It was found that the impedance changes in the knitted strap were approximately linear to the volume of air exchanged by the respiration under most circumstances (Loriga et al., 2005). By having conductive materials within the yarn structure, sensing performance could be improved with repetition. Recently, yarn-based piezoresistive sensors were introduced, which opened more fabrication options for smart textile sensors (Huang et al., 2008).

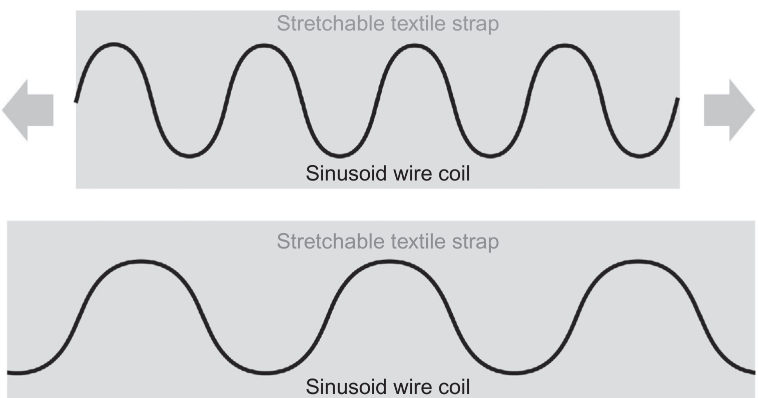

Figure 12.2 Respiratory inductive plethysmography (RIP).

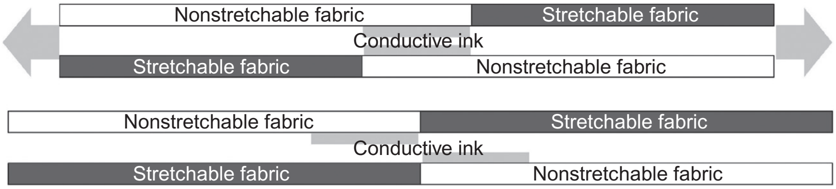

Figure 12.3 Principle of capacitive sensor for respiration monitoring.

A piezoelectric sensor is a device that can convert mechanical stress into an electrical charge, and vice versa. An electric polarization occurs in a fixed direction when the piezoelectric crystal is deformed. The polarization causes an electrical potential difference over the crystal. Natural piezoelectric materials are quartz and tourmaline, and synthetic polymers such as polyvinylidene fluoride (PVDF) exhibit piezoelectricity several times greater than quartz. Because the effect is reversible, which means that the electrical stimuli can lead to mechanical deformations, the piezoelectric effect is also useful to create some actuators in smart clothing.

An interesting new approach tried by Merritt et al. (2009) was to use electrical proximity sensors to monitor respiration. A proximity sensor detects the presence or absence of the object using electromagnetic fields. Based on the inductive or capacitive sensing, proximity sensors are applied to detect the object in a close distance, within a few centimeters. Capacitive displacement sensors operate with two capacitor plates that slide parallel to one another (Kang, 2006). Capacitors are printed over the fabric, consisting of stretchable and nonstretchable sections, and the layers slide parallel to each other (Figure 12.3). The respiration can be monitored by measuring the change in area between two capacitors (Merritt et al., 2009).

12.2.3 Motion sensor

An accelerometer is a basic technology that converts mechanical motion into an electrical signal. It is an electromechanical device that measures acceleration force, whether caused by gravity or motion. There are many different types of mechanisms involved in the accelerometers, including piezoelectric, piezoresistive, capacitive, Hall effect, magnetoresistive, and temperature sensors (Table 12.2). Piezoelectric, piezoresistive, and capacitive types are the most common in commercial devices.

A typical accelerometer takes the form of integrated circuitry mounted on a custom circuit board, consisting of the accelerometer chip, transceiver for wireless communication, and battery connection (Lombardi et al., 2009). It measures the speed of movement of an object to which it is attached and sends the measured data to the nearby device. Advances in technology such as low power consumption and miniaturization of components make the accelerometers wearable, enhancing the precision enough to enable the detection of complex motion patterns. This has opened the potential for rehabilitation and fitness training. The quality and quantity of exercise became measurable by wearable accelerometers (Nugent et al., 2005).

Table 12.2 **Types of accelerometers**

Sensor type	Key technologies
Piezoelectric	Piezoelectric crystals that get stressed by accelerative forces
Piezoresistive	Resistance changing by the acceleration
Capacitive	Capacitance changing by relative location of two objects
Hall effect	Motion converted to electrical signal by sensing the change of magnetic field
Magnetoresistive	Material resistivity changes in the presence of magnetic field
Temperature	Location of heated objected tracked during acceleration by sensing temperature

Another technology to measure the activity of the body employs strain sensors. Mattmann et al. (2007) embedded several strain-sensor threads into a tight-fitting garment. The strain sensor was created in a thread shape from carbon black powder and a thermoplastic elastomer (Mattmann et al., 2008). The threads showed a linear rise in resistance when up to 100% strain was applied, and a small hysteresis was observed, which enabled a direct measurement of the elongation (Mattmann et al., 2007). The strain sensors were placed on every distinctive position of the garment prototype in order to detect the movements of shoulders, arms, and the spine. From the strain sensor readings, they could classify 27 body motions, such as rotating or bending the torso, and lifting the shoulders.

An advanced strain sensor for human motion detection was introduced by Yamada et al. (2011). It uses a new material: thin films of aligned single-walled carbon nanotubes. Unlike traditional rigid materials such as silicon, nanotube films fracture into gaps and islands, and bundles bridge the gaps (Figure 12.4). This allows the films to function as strain sensors capable of measuring strains up to 280% with high durability (Yamada et al., 2011).

12.3 Applications in the market

From original applications in space suits and military uniforms, wearable health-monitoring systems are being expanded exponentially nowadays to general consumer products such as sportswear and underwear. Up to now, wearable health-monitoring technology has been actively utilized for athletes and soldiers who go through intensive physical training on a regular basis. Wearable health-monitoring systems can prevent sudden cardiac death or acute myocardial infarctions during physical activities (Kumar et al., 2013).

Systems' integrators have developed special expertise in the incorporation of components into textiles. Denmark-based Ohmatex, Italy's Smartex, and the Finnish firm Clothing+are such companies. Possible challenges in wearable health-monitoring

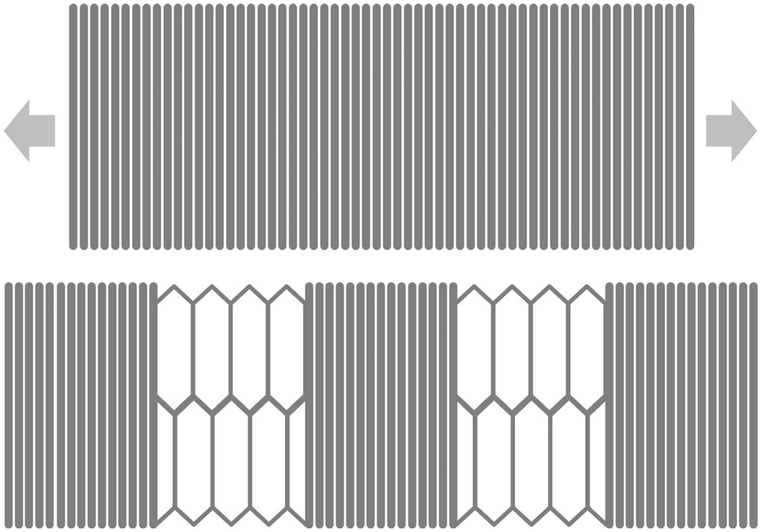

Figure 12.4 Principle of carbon nanotube strain sensor.

systems are cost of the overall system, accuracy of the signal obtained, low power consumption, interconnection method, and unobtrusive design (Kumar et al., 2013).

12.3.1 LifeShirt®

LifeShirt® (VivoMetrics Inc., Ventura, USA) is one of the initial models of wearable health-monitoring systems, introduced to the market in the early 2000s. The system includes a garment, a handheld device, and PC-based analysis software.

The garment, in the form of either a vest or a chest strap, continuously monitors ECG, respiration, activity, and posture. This garment is designed as a platform that houses various sensors (Figure 12.5). The ECG signal is detected by traditional ECG leads inserted through the slits on the vest. Respiratory data is measured by RIP. A sinusoidal wire is woven into high-stretch Lycra® knit fabrics and worn around the thorax and abdomen. A two-axis accelerometer is embedded on the center front of the vest and records the wearer's posture and activity level. Those sensors are wired into the handheld device, which records, encrypts, and uploads the data to the Vivologic™ database for analysis. Optional sensors for electroencephalography (EEG), skin temperature, blood oxygen saturation, and blood pressure can be plugged into additional ports within the system for multifunctionality (ABD, 2007).

It has been reported through many investigations (Kent et al., 2009; Heilman and Porges, 2007) that the accuracy and precision of the LifeShirt® agrees with traditional laboratory equipment at an acceptable level. LifeShirt® has been verified to be robust

Figure 12.5 VivoMetrics LifeShirt®.
Source: www.vivonoetics.com.

in system operation, comfortable as a garment, and user-friendly in the interface. The system has been used in leading research institutes, medical schools, and hospitals for clinical or research applications (Lymberis and de Rossi, 2004). Notably, it has been actively applied to monitor different kinds of sleep apnea.

12.3.2 Wearable Wellness System

The Wearable Wellness System (WWS; Smartex, Pisa, Italy) was developed from a series of research projects such as Wealthy (Paradiso et al., 2005) and MyHeart (Paradiso and De Rossi, 2006). Those research projects were funded by the Commission of the European Communities and conducted as collaborations among several European countries. With the advances in sensor technology as well as in communication technology, a new generation of health care systems was established. Similar to prior wearable health-monitoring systems, the WWS consists of a garment, an electronic device for data acquisition, and a software kit for data analysis. The degree of technology integration has been innovatively improved by integrating ECG and

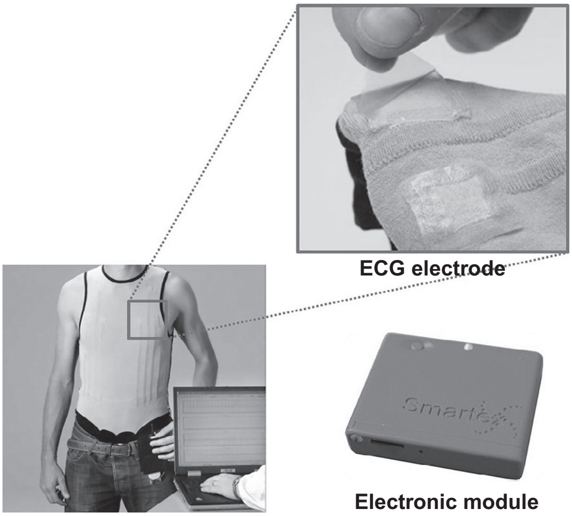

Figure 12.6 Smartex Wearable Wellness System.
Source: www.smartex.it.

respiratory sensors into a textile interface. The garment could become as comfortable as everyday wear.

ECG electrodes were created by knitting conductive yarns into a conventional knit fabric. The conductive yarn included two stainless steel wires twisted around a nonconductive core yarn. Having a double-layered knit structure, the electrodes could be insulated from the external environment. To improve signal quality, a hydrogel membrane covered the rough electrode surface, and a higher percentage of elastomer was incorporated into the base (Figure 12.6). Respiratory sensors were made from piezoresistive yarns, which were knitted into Lycra® fabric coated with carbon-loaded rubber (Paradiso et al., 2005). A triaxial accelerometer was embedded within the knit structure to monitor the wearer's posture and movement.

A small electronic device, called SEW (Figure 12.6), is designed to acquire, process, store, and transmit data collected from the sensorized garment. It became small and light enough to be hidden in the pocket of the garment. Replacing conventional wires, USB cables or Bluetooth® transmitted data to a desktop computer for analysis (Smartex, 2012).

12.3.3 Intelligent Knee Sleeve

The Intelligent Knee Sleeve (IKS; CSIRO Textile and Fibre Technology, Clayton South, VIC, Australia) is a device developed for injury prevention. It provides immediate audible feedback to the wearers with respect to their knee angle. A fabric sleeve is worn around the knee, with a flexible strain gauge attached over the kneecap and linked to small electronics (Figure 12.7). The electronic module has been miniaturized into a few centimeters and simply snapped to the side of the sleeve (Munro et al., 2008).

The core-sensing technology is a piezoresistive sensor, which is applied to detect local strain on the fabric. A flexible strain gauge is created by coating the Lycra® fabric with a thin layer of polypyrrole, which is inherently conductive (Wang et al, 2011;

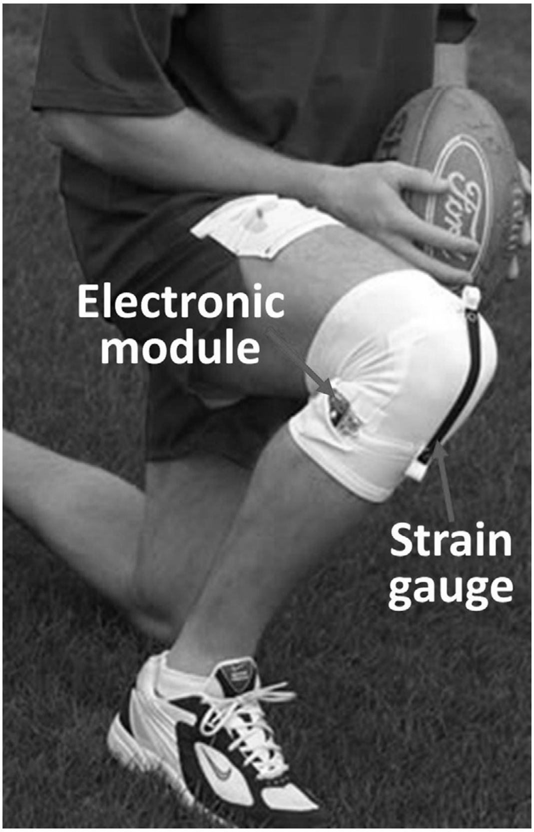

Figure 12.7 SCIRO TFT Intelligent Knee Sleeve.
Source: www.csiro.au.

Li et al., 2005). It was observed that the strain gauge undergoes strain without mechanical damage to the polymer coating, textures, and mechanical properties of the base fabric (Wu et al., 2005). It showed a wide linear dynamic range with good sensibility. The length of the strain gauge was found to increase by 24% with 25° knee flexion and 31% with 45° knee flexion. As the strain gauge stretches, the resistance changes. The module beeps different alerting tones at a predetermined threshold resistance (Munro et al., 2008).

The major market of Intelligent Knee Sleeve is sporting applications such as basketball and football, where knee injuries prevail due to recurring jumping and landing activities. The system assists athletes and trainers for the prevention of injuries, particularly for ligament injuries. It can be also used as a rehabilitation aid after injury to reteach patients correct joint movement during treatment.

12.3.4 miCoach™

Adopting body-monitoring systems in active sportswear for the public was initiated by Nike+. Nike+ is a training system for runners developed by the collaborative project between Nike (Beaverton, USA) and Apple (Cupertino, USA). These products are

Figure 12.8 Adidas miCoach™.
Source: www.adidas.com.

provided in the form of a watch. Connected to mobile electronics through Bluetooth technology, the watch tracks workout performance metrics such as distance, duration, calories burned, and steps taken while the wearer is running.

Adidas launched a body-monitoring system called miCoach™ (Herzogenaurach, Germany). It is similar to Nike+, but miCoach™ employs a soft textile strap instead of a watch. It was developed in partnership with Polar Electro (Kempele, Finland) for ECG electrode applications. Because the strap is embedded around the chest in sports bras or T-shirts, it allows the collection of vital signals in the immediate vicinity of the heart. Contacting skin, the inner surface of the strap is constructed in a rib knit of a silver yarn. Through two metal snap buttons, a small sensor module is attached to the textile strap (Figure 12.8). This sensor module picks up electrical signals of the heart from textile electrodes and wirelessly transmits ECG data to nearby mobile electronics such as smartphone and tablet computer.

Depending on the types of electronic modules, the system collects parameters such as ECG, running distance, speed, calories consumed, and others. Performance was evaluated by a series of researchers (Miller, 2012; Porta, 2013). It showed a successful performance to estimate the distance, speed, and calories under the laboratory setting with a treadmill, but speed and calories were found less accurate in the field test.

12.4 Future trends

The degree of body and technology integration has been classified into three categories, shown in Table 12.3. The degree of technology integration is highly dependent on the demands for expressiveness and functionality expected for the smart clothing (Suh et al., 2010). According to Seymour (2008), sportswear is ranked at the medium levels for both expressiveness and functionality. It implies that wearable sensing technology for athletes is expected to be fashionable, which means the technological parts should

Table 12.3 Degree of technology integration

Degree		Description	Example
Portable		Small and light enough to be handheld	Mobile devices
Wearable	Includable	Clothing for the container of technology	Putting into pockets
	Attachable	Physically attached or embedded into clothing	Sandwiching between fabric layers
	Integratable	Fully combined into the fabric as an intrinsic part	Weaving or knitting conductive yarns
Implantable		Housed inside of body	Sensor pills

be either invisible or have an attractive appearance for a stylish look. At the same time, it should guarantee mechanical/thermal comfort as well as technical functionality.

The degree of technology integration has evolved dramatically through many wearable body-monitoring systems. While earlier models were based on the portable and includable technologies, later models tend to integrate technology closer to the body (Figure 12.9). For example, electronic modules started from a form of handheld devices in earlier models but became slimmer and lighter to be wearable. Recently, Toshiba developed a wearable sensor module, Silmee™ (smart health care intelligent monitor

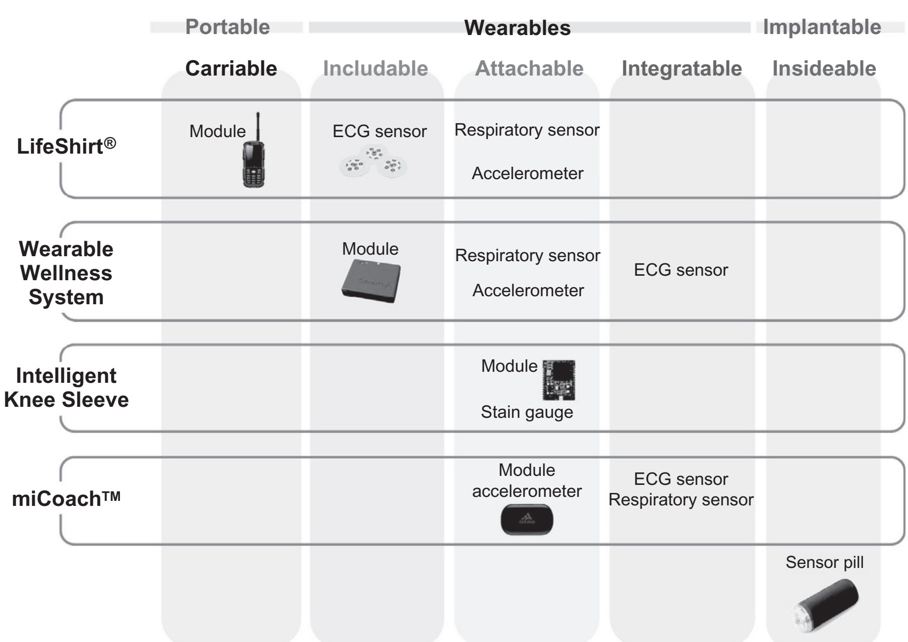

Figure 12.9 Degree of technology integration.

engine and ecosystem), based on the pseudo-SoC (system on chip) technology with a flexible multichip module (Suzuki et al., 2013). Being fairly small in size and weight (Table 12.1), it was designed to directly attach to the human body, even without a textile medium. Similar to other electronic modules, it collects and transmits various kinds of vital signals, such as pulse wave, ECG, body temperature, and motion.

Another recent trend is the transition of technology integration from an *in vitro* to an *in vivo* environment. Some manufacturers such as Hidalgo Ltd. (Cambridge, UK) have already started adopting *in vivo* techniques for core temperature sensing. Ingestible and disposable capsules will be swallowed with liquid—just like a medicine—and stay inside the wearer's body to measure the internal temperature. This sensor capsule is 8.6 mm × 8.6 mm × 23 mm in size, 1.6 g in weight, and made of biocompatible material, polycarbonate. The nearby electronic module outside of the body picks up the data from the capsule through wireless communications.

However, there could be many potential concerns or issues related to implantable sensing technology. Biocompatibility might be the greatest concern. Because physiological reactions to the implants might vary depending on the individual, biological safety of the technology will be the most important requirement of implantable sensors. From a technical perspective, the performance of the sensor needs to stay intact inside the body. For example, the wireless communication environment should be totally redesigned considering *in vivo* conditions. Also, psychological hostility toward implanted devices is one of the challenges to overcome. In addition, due to human rights and privacy issues, implantable technology would be limited in some applications.

12.5 Conclusion

Focused on technical development and its application in commercial products, wearable sensing technology was introduced and investigated in this chapter. The most popular sensing technology was to capture biopotential signals, respiration activities, and body motion/posture. It was found that there is the shared technical base of electrical engineering in many of those sensors, such as piezoresistive or piezoelectric effects. Among the smart clothing already available in the market, four products—LifeShirt®, Wearable Wellness System, Intelligent Knee Sleeve, and miCoach™—were addressed to see which technology each functionality is based on, and how it is realized in a textile product.

The degree of technology integration was the focus of interest. Wearable sensing systems have advanced dramatically to increase the degree of technology integration, and future development of wearable sensors will follow this trend. Along with further cutting-edge technology, the degree of technology integration will be the key issue to make smart clothing products less intrusive and clumsy, and therefore more user-friendly and marketable.

12.6 Sources of further information and advice

12.6.1 Relevant books with comprehensive views (in chronological order)

- Smart Fibres, Fabrics and Clothing
  Tao, X. (Woodhead Publishing)

- Wearable E-Health System for Personalized Health Management: State Of The Art and Future Challenges
  Lymberis, A. and De Rossi, D. (IOS Press)
- Personalized Health Management Systems: The Integration of Innovative Sensing, Textile, Information and Communication Technologies
  Nugent, C., McCullagh, P. and McAdams E. (IOS Press)
- Intelligent Textiles for Personal Production and Safety
  Jayaraman, S. and Grancaric, A. (IOS Press)
- Body Sensor Network
  Yang, G. (Springer)
- Biomechanical Engineering of Textiles and Clothing
  Li, Y. and Dai, X. (Woodhead Publishing)
- Clothing Biosensory Engineering
  Li, Y. and Wong, A. (Woodhead Publishing)
- Intelligent Textiles and Clothing
  Mattila, H. (Woodhead Publishing)
- Fashionable Technology: The Intersection of Design, Fashion, Science, and Technology
  Seymour, S. (Springer)

12.6.2 Previous projects and researchers (in chronological order)

- Smartshirt
  Sundaresan Jayaraman and Sung-mi Park
  United States Navy
- Vêtement de Télé-Assistance Medicale (VTAM)
  David Blanc, Bernard Comet, Norbert Noury, and Jean-Luc Weber
  France Ministry of Research and New Technologies
- Wealthy
  Angelo Gemignani, Brunello Ghelarducci, Giannicola Loriga, Rita Paradiso, and Nicola Taccini
  Commission of the European Communities
- MyHeart
  Rita Paradiso and Danilo De Rossi
  Commission of the European Communities
- Smart Textiles and Wearable Computing
  Tünde Kirstein, Ivo Locher, Corinne Manttmann, Jan Meyer, and Gerhard Tröster
  Commission of the European Communities
- Intelligent Knee Sleeve
  Toni Campbell, Bridget Munro, Julie Steel, and Gordon Wallace
  Australia National Health and Medical Research Council

12.6.3 Leading manufacturers (in alphabetical order)

- Adidas (Herzogenaurach, Germany)
  http://micoach.adidas.com/
- Clothing + (Kankaanpää, Finland)
  http://www.clothingplus.fi/en/home.html
- Hidalgo EquiVital™ (Cambridge, UK)

http://www.equivital.co.uk/
- Ohmatex (Aarhus, Denmark)
  http://www.ohmatex.dk/
- Philips (Amsterdam, Netherlands)
  http://www.hitech-projects.com/euprojects/myheart/
- Polar Electro (Kempele, Finland)
  http://www.polar.com/us-en/products
- Smartex (Pisa, Italy)
  http://www.smartex.it/index.php/en/products/wearable-wellness-system
  http://vivonoetics.com/products/sensors/smartex-wearable-wellness-system/
- Suunto (Vantaa, Finland)
  http://www.suunto.com/en-US/
- VivoMetrics Inc. (Ventura, CA, USA)
  http://vivonoetics.com/products/sensors/lifeshirt

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