CHAPTER 10

Wellness, Fitness, and Lifestyle Sensing Applications

Physical fitness is not only one of the most important keys to a healthy body; it is the basis of dynamic and creative intellectual activity.

—John F. Kennedy, 35th President of the United States

Chapter 9 considered how sensors are playing an increasingly important role in health-related applications, such as chronic disease management. Medically, health is sometimes described as the absence of one or more of the "five Ds": death, disease, discomfort, disability, and dissatisfaction. Consequently, the focus is on determining whether disease is present and, when present, managing that condition (Edlin et al., 2000). Wellness takes a different perspective on health. It looks at the entire person, the manner in which they live their life, and lifestyle influences on their well-being. Wellness encompasses six distinct dimensions of well-being: emotional, intellectual, spiritual, occupational, social, and physical (Hettler, 1976). Collectively, these dimensions are often referred to as the *holistic* model of wellness. Sensors can be applied to quantify all dimensions of wellness to a certain extent. Of these dimensions, only physical wellness is monitored by individuals in the consumer domain. This chapter focuses on physical well-being and how sensing can be used to monitor and maintain physical wellness. Positively influencing physical well-being can also have significant benefits for other aspects of well-being, such as socializing with others during physical activities and helping to reduce emotional stress.

A variety of factors can influence personal wellness, including diet, exercise, poor habits, proactive self-care, and seeking medical intervention when appropriate (Edlin et al., 2014). As such, wellness is a dynamic process that is constantly changing based on the daily decisions we make about what we eat, drink, how much exercise we do, and so on. It is easy to lose track of wellness with the demands of busy, modern lifestyles. Technology is now having a positive effect on individuals by helping them to manage their physical wellness. This trend will continue to grow in the future as sensing and supporting technologies are seamlessly integrated into our daily lives. Discrete sensors and sensors integrated into smartphones are already enabling us to monitor our activity levels, fitness, performance levels, and calorie burn/consumption through smartphone apps and web portals. In a broader context, pervasive sensing in our homes and leisure areas will provide passive monitoring on a long-term basis of our physical activities, interactions with our environment, and other physiological, cognitive, and biochemical parameters of interest without activity restriction and behavior modification. The collected data can be used to notify us of immediate risk or to identify trends in parameters that are outside of normative ranges. Sensing sleep quality, in babies and adults, is a now a common application of pervasive sensing. The consumer does not actively track their sleep in real time but they need to be alerted immediately if sleep apnea is detected. Increasingly, we share this data and information about our activities via social media with friends and family. Doing so adds context to the data and supports continued engagement in physical activities through positive social reinforcement. Monitoring, supporting, and improving wellness through the use of sensor technologies will play an increasingly positive role in maintaining health and well-being.

Drivers and Barriers: Sports and Fitness Sensing

The sports and fitness sensing market has been primarily driven by body-worn sensors, which are often integrated or connected to discrete devices with global positioning system (GPS) receivers. The sports sensing market is expected to be worth circa $975 million by 2017 (PRWEB, 2013). Companies such as Apple, adidas, Nike, Motorola, Reebok, and Under Armour are now entering the growing sports and fitness wearables market. This market also includes sensors that can be attached to sports equipment, such as power meters for bikes to monitor the rider's performance and sensors embedded into textiles.

Drivers for Sports and Fitness Sensing

The use of sensing for sports and fitness applications is driven by a variety of factors, as shown in Figure 10-1. For example, people are becoming more aware of the role physical activity plays in maintaining their health. A variety of social and technology factors are now influencing and supporting engagement in physical and sports activities. The following sections examine some of the key factors in more detail.

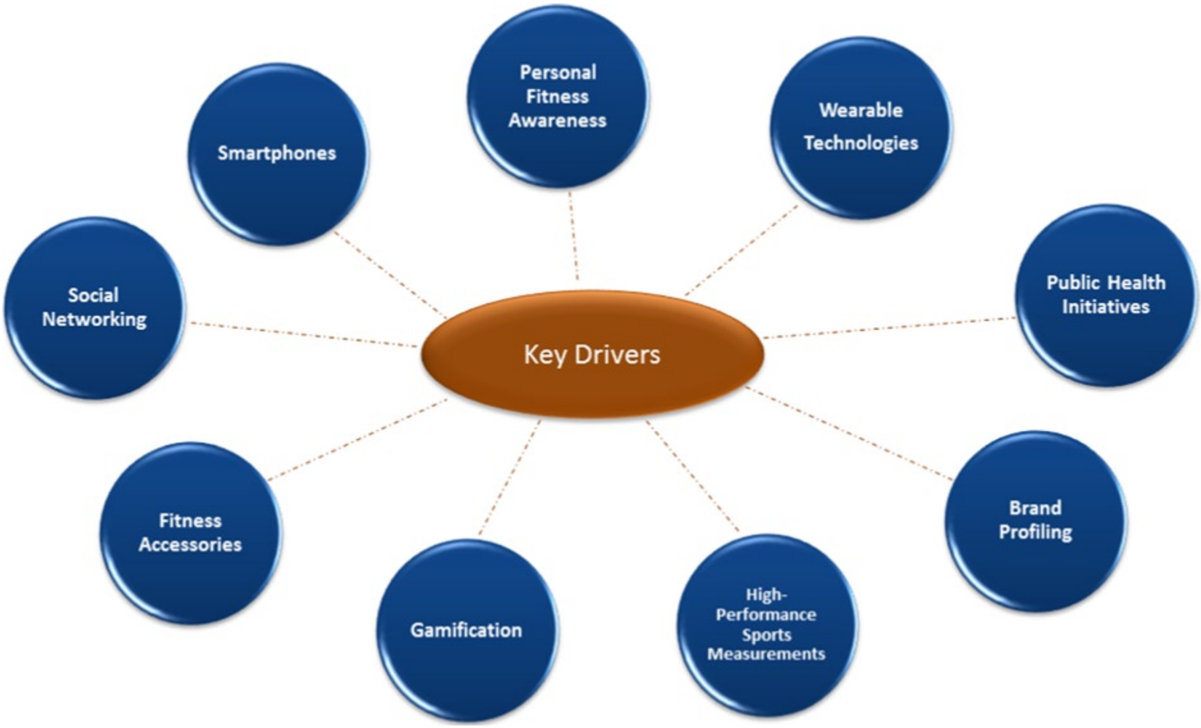

Figure 10-1. *Drivers for fitness sensing adoption*

> ***Fitness awareness***: General interest and participation in fitness continues to grow. The increased availability of magazines that focus on generic fitness and specific sports, such as cycling, running, mountain biking, and triathlons, helps to raise awareness and interest. These publications, along with various web sites, are exposing people to information on what types of technologies are available and how to use and interpret fitness statistics.

Public health awareness initiatives: Public health awareness campaigns are making people more aware about the positive influence of sports activities. There is growing awareness among the public about the linkages between being physical inactive and health-related issues, such as obesity and obesity-related conditions, including diabetes and cancer. Activity monitors provide an easy way to track activity levels. Data from these devices can often be shared with peer groups through social networking to gain support and maintain motivation.

Smartphones: The proliferation of smartphones, especially among key fitness demographics, provides essentially a zero-cost sensing and software platform for basic fitness monitoring. This single form factor provides location via GPS, inertial sensing from the built-in accelerometer and gyroscope, mapping software, data analysis apps, large touchscreen display, music players, and connectivity via wireless (Bluetooth, Wi-Fi, ANT, and NFC) and mobile phone networks. From an app developer's perspective, smartphones provide both a development platform and a significant market for innovative apps that allow apps to be rapidly developed and shared with consumers. As a result, the consumer can avail of a large selection of apps for free or for a small one-off fee. As discussed in previous chapters, app developers do not have to be sensor experts, because the smartphone development environment abstracts the functional details of the underlying sensors. This is an advantage to nonsensor experts, but this abstraction can affect the accuracy of sensor measurements. For this reason, smartphones can also connect wirelessly to dedicated external fitness sensors for more accurate sensing.

Availability of wireless fitness accessories: The availability of wireless fitness accessories, such as heart rate monitors (HRMs), step counters, cadence sensors, and power meters, allows consumers to add fitness functionality to their existing smartphones and/or outdoor GPS handhelds. These accessories communicate over standard interfaces, including ANT, Bluetooth, Wi-Fi, and near field communications (NFC) and provide APIs that smartphone developers can use to capture data from the accessories. This removes the need to purchase expensive dedicated fitness data loggers, such as fitness watches. The availability and popularity of fitness accessories is expected to increase as interoperability standards, particularly Bluetooth Smart (a Bluetooth low-energy protocol)(Bluetooth SIG, 2013), are adopted by both smartphone and accessory manufacturers.

Wearable technologies and intelligent textiles: The use of wearable technologies, such as the Fitbit, is becoming increasingly common among the general public. Where once wearing an obvious sensing device, such as a Holter monitor or personal alarm, was seen as a "badge of dependence" or a sign of illness, wearable sensors are now fashion items and "a badge of honor" that indicates the user is actively interested in maintaining their wellness. The form factor of wearables are becoming increasingly small, to the point that they are seamlessly integrating into our normal clothing, such as a sports bra or vest, and lives. The cost of these devices, such as smart wristwear devices like the Nike+ Fuelband, is falling and becoming more accessible to the casual fitness or wellness enthusiast.

High-performance sports: Professional sports teams and athletes are continually seeking methods to gain a competitive advantage over their opposition. The data analytics team and sports scientist team are becoming as important as a coach in the sporting domain. Sports scientists provide insight into the athlete's fitness and well-being and continually monitor the athlete's parameters to optimize their training, nutrition, and rest requirements. Sports "stats" such as team formations, recent results, and real-time status are now an integral part of the television sports viewing experience. Professional sports teams analyze all aspects of their own performance, their opposition's performance, and even the referee's performance to identify weakness, which they can exploit to their own advantage, and strengths, which they must plan to counteract. For example, a study in New Zealand used GPS technology in combination with heart rate to assess the accuracy of the decision-making experience of soccer referees (Mascarenhas et al., 2009).

Brand profiling: Fitness sensing technologies are becoming increasingly visible because of the entry of high-profile brands such as Nike and adidas to the fitness sensing market. These manufacturers have partnered with existing fitness technology manufacturers, such as Polar and Garmin. These partnerships have raised the profile of existing technologies and are giving this previously niche market a desirable lifestyle choice position. High-profile technology brands, including Apple, Motorola, and mobile operators, are also actively monitoring this market for new service opportunities. The presence of these high-profile companies is a clear indication that these companies view significant potential for a technology enabled fitness market.

Social networking: Another important driver of fitness applications is the integration of a social networking dimension. Users can upload their data from integrated or external fitness sensors to the Web/Cloud and share their fitness statistics online with their families, friends, and peer groups. It is also possible to follow each other's activities in real time using Internet-enabled devices. The ability to track and share fitness data online can enable positive reinforcement by peer groups, which encourages people to remain engaged in their physical activity and set new goals. Like magazines, online fitness communities provide a valuable channel for discussing and making people aware about personal fitness sensor technologies and applications. For example, the RunKeeper app allows runners to track their distance, speed, and pace on their smartphone. In addition, it utilizes social networking to allow runners to stay in touch with friends on Facebook, Twitter, Google, and other sites by adding them to their Street Team. The Street Team features enables users to share details of their workouts, including course maps, topography details, and various statistics such as distance covered, pace, and so on (`www.RunKeeper.com`).

Gamification of fitness data: Building on the social networking angle of fitness data sharing, gaming features are becoming a driver for the adoption of fitness technologies. Gaming also allows like-minded users to interact, compare, and compete. Such techniques will be used to encourage usage and create "stickiness" for applications. For example, the "tag it" feature in Nike's iPhone running tracker app enables users to tag each other, bringing multiple friends to a game of tag. Whoever starts the game decides whether the game is based on the distance run, time of run, or being the last to run. Another example of this type of approach is used by the Basis B1 fitness tracker, which monitors heart rate, perspiration, steps taken, and skin temperature. The data is transmitted to a web application that provides analysis of your daily patterns and encourages you to adapt your existing habits or to develop new healthy ones by gamifying your lifestyle (`www.mybasis.com`).

Barriers to Sports and Fitness Sensing

Despite recent advances in the adoption and utilization of technologies for fitness applications, a number of barriers remain in place. These include limitations in smartphone form factors, fitness apps, proprietary wireless protocols, and costs. The following sections now examine some of the key limiting factors in more detail.

App selection: The App Store and Google Play store contain thousands of fitness monitoring and education apps. The most common app categories are body mass index (BMI) and calorie calculators, diet guides, exercise guides, and sport tracking apps. Like health apps, the sheer number and diversity of such apps means that selection of a relevant and high quality app can be a frustrating challenge, unless you use an app designed by the manufacturer of a specific sensor. As discussed in Chapter 6, the quality and accuracy of information provided by fitness apps is generally not regulated, and misleading information may be provided by these apps. It is therefore essential to exercise caution when following advice provided by such apps and to consult with a "gold standard" reference, such as a health/fitness professional or a professional-grade sensor device if you suspect information or data from the app is inaccurate or worrying.

Smartphone design: Although ideal for the casual fitness users who simply want to track time and estimate distance, smartphones may not be appropriate as a fitness sensing device for serious outdoor and fitness users. Most smartphones lack the necessary ruggedization, such as toughened enclosures, waterproofing, and impact protection, required by serious fitness users. Smartphone form factors are relatively large for fitness and running applications and can actually impact performance. GPS is still a relatively new and evolving sensor on mobile devices. GPS performance may not be optimal for fitness applications, especially when compared to dedicated devices. Although battery technology is continually improving, the battery life of a smartphone may not be sufficient for continuous capture of sensors with high power requirements (for example, GPS) and analysis for longer endurance events such as mountaineering.

Proprietary wireless connectivity protocols: Until recently, discrete fitness sensing devices from the major device vendors were based on the proprietary ANT personal wireless protocol. Penetration of the protocol was high among device vendors because it encouraged people to remain with the same vendor in order to exploit their previous investments in sensing devices and aggregators. Nevertheless, apart from a couple of niche offerings, there was almost no adoption of this protocol in mobile phones. Standardization of wireless device communications is now underway with the rollout and adoption of the Bluetooth Smart standard; however, Bluetooth Smart will take a number of years to reach critical mass.

Device costs: The cost of dedicated sensors, particularly those with integrated GPS tracking, remains relatively high. This high cost limits their market potential to professional or serious fitness enthusiasts. However, new entrants into the market and the inclusion of sensors in smartphones are expected to decrease device costs.

Sports and Fitness Applications

It has been estimated by ON World that by 2017 the annual market for mobile sensing health and fitness applications will be in the region of 500 million units (PRWEB, 2013). Large retailers such as Best Buy and Target are providing more and more shelf space to these types of devices to meet the growth in popularity. Sensors can be found in a variety of form factors to support different usage patterns:

Sensors integrated into sports equipment: Fitness sensors are commonly integrated into gym equipment to monitor biomechanical parameters, such as force, torque, cadence, and so on, or physiological parameters, such as heart rate, respiration rate, and more.

Sensors attached to sports equipment: This method of sensing is growing in popularity, particularly as the size of sensor units decreases. Data from these sensors are typically used to analyze the mechanics of performance and to provide insights into how a particular style is positively or negatively impacting performance level.

Personal body-worn sensors: This is probably the most common method of sensing fitness and wellness. Fitness wearables typically capture physiological and kinematic datasets from small lightweight sensors worn on the body during training and everyday living.

Wearable fitness sensors were initially discrete sensors, such as simple pedometers. But these devices are now being replaced by "smart devices" that provide both local computational capabilities and remote connectivity to another device. These devices include both smartphones and sports watches (for example, the Polar sport watch with integrated GPS tracking and heart rate monitoring, at www.polar.com). Data from these sensor devices can be combined with other information sources to create a holistic picture of an individual training session and longer-term trends. The data may also be incorporated into a web-based portal for additional processing, sharing among family and friends, or for comparative purposes among peer groups.

Companies operating in the wearable fitness sensor market include specialist companies that focus exclusively on fitness and wellness devices such as Polar and Fitbit; large sportswear companies like Nike and adidas; and new companies such as Jawbone that develop fitness and wellness peripherals. Wearable sensors come in a variety of form factors, including armbands, wristbands, clip-ons for clothing, and sensors directly integrated into footwear and clothing.

Supporting Wireless Technologies

A key capability of "smart" fitness sensors is their ability to communicate with external devices, such as smartphones. Although some devices feature wired USB connections, the majority support wireless connectivity. Wireless connectivity between sensors and a master device like a smartphone, is a key requirement to avoid movement restrictions during activities. A variety of proprietary protocols have been utilized by vendors, including Polar's proprietary W.I.N.D. wireless protocol, ANT from Garmin's acquisition of Dynastream, Simpliciti from TI, BodyLAN from FitLinxx, and BlueRobin from BM innovations.

Of the proprietary protocols, ANT has the greatest penetration in the fitness sensors market. As outlined in Chapter 3, ANT is a low-cost, low data rate, ultra-low power protocol designed to work on the same batteries for months or years. It is primarily used for heart rate monitors, speed/cadence sensors, and power meters to provide connectivity to devices such as fitness watches. It can also be found in fitness equipment. To support interoperability between devices that use the ANT protocol, the ANT+ standard has been created. ANT+ defines network parameters and the data content for ANT-based communications. This allows ANT-based devices from different manufactures to communicate with others and exchange data. ANT has been estimated that there is over 60 million ANT+ sport, fitness and health devices currently available (www.thisisant.com).

Bluetooth (BT) has made limited inroads into the fitness sensor domain because of its relatively high power requirements. Nevertheless, Bluetooth low energy (BLE) or Bluetooth Smart—a low-cost, low-power, low data rate extension of regular Bluetooth—is predicted to be widely adopted by the market because it has comparable power consumption performance to ANT. Power consumption of Bluetooth Smart is about one-tenth that of Bluetooth, which enables a standard button cell battery to power devices for more than a year. A comparison of ANT and BLE is shown in Table 10-1. IMS Research has estimated that by 2016 the penetration rate of Bluetooth Smart in sports and fitness devices will overtake that of ANT with around 45 percent of devices featuring Bluetooth Smart (IMS Research, 2012).

Table 10-1. *Comparison of Bluetooth Smart and ANT Specifications*

Specification	Bluetooth Smart	ANT
Frequency range	2.4GHz to 2.483GHz	2.4GHz to 2.483GHz
Network standard	IEEE 802.15.1	Proprietary
Software stack	128–256KB	16KB
Security	128-bit AES	128-bit AES
Data rate	1Mps	1Mps
Power consumption	15mA Rx and Tx	15mA Tx and 17mA Rx
Range (free field)	100m (outdoor)	100m (outdoor)
Topology	Simple star topology only	Complex topologies
Network type	WPAN	WPAN

Fitness Sensing

Wireless sensors allow smartphones or bespoke aggregators to capture and process sensor data into parameters of interest, such as speed, cycling cadence, and heart rate. In most fitness applications, sensors cannot be integrated into the master device, because they have to be close to the source of the signal, such as the heart, the cycle wheel, or the foot. In cases where sensors are integrated into the master device, the quality of the resulting data depends on the location of the master device relative to the parameter to be sensed. This is particularly true for any kinematic-related parameter captured. For example, integrated accelerometers often provide poor data quality because of the counter movements of the arms holding the device. Discrete kinematic sensors will continue to provide superior sensor data quality for the foreseeable future.

The ability to wirelessly connect sensors and master devices allows the fitness enthusiast to track their performance in real-time. Friends, peers, and coaches can also track real-time sensor data online, provided the master device has Internet connectivity and the data owner is willing to share the data. From a form-factor perspective, the screen size requirements for the master device are somewhat activity specific. "Black box" sensors, such as bicycle power meters and heart rate monitors, have no screen and therefore depend on a master device to visualize the data in real time. Large screens are advantageous for activities such as cycling, while a small smartwatch screen may be desirable for activities such as running to minimize any impact on the wearer. For many users, the ability to interrogate the data beyond real-time information display is an important requirement. Data can be viewed offline in a number of ways, such as visualizing basic summary data directly on the master device or uploading the data to a tablet/PC or the Internet for complex analysis and visualization. It is important to note that the quality of the supporting software tools is becoming as important to the user who wants to improve and analyze their performance as the quality of the device itself. Sharing fitness data and statistics with friends as well as adding a competitive element to fitness activities can be closely tied to the rising popularity of social networking. Competing with a friend or peer group or exchanging statistics can make fitness a more enjoyable activity and helps maintain engagement over a longer period of time. Sharing data can also enable a degree of flexibility as people move to new locations for varying amounts of time. It allows them to connect with like-minded individuals with similar motivations, independent of geographical location. Converged applications are central to engaging new users by providing them with a real-time dimension, which is important for the instant gratification expected by the current tech-savvy generation. In addition, longitudinal presentation of data with sharing capabilities provides both the motivational and social elements for individuals who live online. Many fitness solutions include interfaces with multimedia features that allow users to listen to their preferred music or take geotagged photos during fitness activities to share with others.

A number of wearable form factors have emerged that provide real-time physiological and/or biomechanical fitness monitoring. Fitness accessories, targeted at consumers, are typically smartphone enabled to reduce the total cost of the system and leverage the connectivity, processing power, and display capabilities of the smartphone. The most common form factors are as follows:

> ***Chest straps***: This form factor is placed close to the chest to measure cardiac parameters, including heart rate and R-R interval. Many chest straps also feature inertial sensors to calculate speed, distance, and body position. Associated smartphone apps or wearable display devices, such as smartwatches, provide both real-time and summary data. A fitness enthusiast can monitor in real-time their pace and the cardiac zone that they are training in and can adjust their training intensity accordingly. Chest straps are also used to view summary data after a training session to analyze training intensity, calories burned, and recovery time. In professional team sports, sports scientists can monitor the cardiac parameters of individuals in real time during training sessions by assigning each player a chest strap. A sports scientist can analyze the data after the training session to identify whether any team members are overtraining and adjust their training to prevent injury. In the consumer domain, companies such as Zephyr are providing SDKs with their fitness accessories to allow them to be integrated into third-party applications. For example, the Zephyr BioHarness[T] chest strap (Zephyr, 2013) can be interfaced with a number of free and paid third-party fitness apps, including Endomondo (www.endomondo.com) and Fit4Life (www.fit4life.com).

Wristbands: The wristband form factor is portable and quick to access. The simple digital wristwatch with timer functionality was one of the first mainstream consumer fitness accessories. Advances in sensor, processor, and battery technologies have allowed device manufacturers to embed much more intelligence in the wristband form factor. As a result, two new device types, sports watches and smartwatches, have emerged in recent years. Sport watches, such as the Polar RC3 GPS, combine built-in sensing and may also have the ability to communicate with external accessories, such as a chest strap. All processing is performed on the sports watch, and the results are presented to the user on the sports watch's display. Data from the sports watch can often be connected to a tablet/PC or smartphone for long-term data storage and analysis. Smartwatches, such as the Pebble (`getpebble.com`), allow the fitness enthusiast to leverage the processing power of a smartphone without the challenges of wearing and reading the smartphone device during a training session. The smartphone has the processing, storage, and battery capabilities to integrate data from multiple integrated and body-worn sensors. The smartwatch simply displays the relevant summary data to the user in a manner that can be quickly and easily read by the athlete.

Footpods and insoles: Accelerometer and/or gyroscope-based footpods are attached to running shoes to directly measure pace, speed, and distance from the motion of the foot. These small, lightweight devices are paired to a sports watch or smartphone device, which process the data from the pod. The Nike+ iPod sensor is one of the most popular foot pod devices. It is inserted into the sole of Nike+ running shoes or attached to the laces of incompatible running shoes using a shoe pod holder. Data from the Nike+ sensor is streamed to an iPhone or Nike+ SportWatch GPS. Pressure sensitive insoles were initially only used by podiatrists in a clinical setting to dynamically measure interaction between foot and footwear. This data was applied to identify asymmetry in foot placement and to create corrective orthodontics for health and sporting purposes. Insoles are becoming increasingly common outside of the clinical setting to monitor sporting performance. Nike+ basketball shoes have pressure sensors built into the sole of the shoe. That data can be combined with accelerometer data to calculate movement-related parameters such as vertical jump height (Nike, 2012).

Sensor patches: Small form factor sensors can be attached to the body adhesively (like Band-Aids) and can transmit data wirelessly to a smartphone app. For example, Somaxis MyoLink is a sensor patch, which measures muscle energy output. It can measure how warmed up your leg muscles are as you start to run and provide data on the intensity of the workout, fatigue levels, endurance, and recovery level. Muscle symmetry can be measured by using a MyoFit sensor on each leg. Identification of asymmetry can be an early indication of potential injury onset (Davies, 2012). In professional sport, a Slovenian company called TMG-BMC uses tensiomyography (TMG) to diagnose muscle imbalances associated with athletic injuries. The sensor is designed to measure the muscle contractions, which are induced artificially with an electro stimulator. As the muscle enlarges, a displacement sensor in contact with the skin measures the radial enlargement of the muscle. Results are presented as time/displacement curves. This technology has been used by Olympic sprinters and the FC Barcelona soccer team (TMG-BMC, 2013). ECG/EKG sensor patches that provide continuous heart rate measurements are becoming increasingly popular and may soon replace chest strap devices in the fitness domain. Like chest strap devices, EKG/ECG sensor patches, such as the Somaxis MyoBeat and the Zepher BioPatch, are typically paired with a smartphone and provide continuous heart rate measurements.

Portable devices: An emerging trend is the development of miniature versions of bulky lab equipment that can be used by individuals outside the confines of the lab. For example, this approach has been used by the Breezing Company, an Arizona State spin-off, to develop an innovative portable metabolism tracker, shown in Figure 10-2. The sensor provides accurate estimates of energy expenditure by using the well-established indirect calorimetry technique. The technique, frequently used in sports clinics, measures carbon dioxide production and oxygen consumption during rest and steady-state exercise. The traditional approach is to use a metabolic cart with bulky and expensive equipment resulting in limited mobility and access. The small form factor of Breezing's sensor means it can be easily carried by athletes during training (Coxworth, 2013). Apart from measuring metabolism, the sensor also determines respiratory quotient (RQ), which is the ratio of produced carbon dioxide to consumed oxygen. It can also identify the type of "energy source" the body uses, whether someone is burning carbohydrates, fats, or a mix of both. Data from the sensor is sent via Bluetooth to either an Android or iOS device, where users can view and track their metabolism history, RQ, and weight (either via wireless scale or manual input). It also has an intelligent algorithm to support users in defining their fitness or weight loss plan. A similar indirect calorimetry device called the BodyGEM RMR is available from Microlife. It produces what the company calls a Metabolic Fingerprint (BodyGem, 2013). The device measures resting metabolic rate and is designed for use in fitness programs that target weight loss.

Figure 10-2. *Breezing, a metabolism tracker device, is battery-operated and syncs with a smartphone. It includes an application used as user interface (image used with permission from Breezing Company)*

The use of sensors for sports and fitness applications continues to evolve. Although many of the currently available products have an acceptable performance and form factor for amateurs, they may be less acceptable to elite athletes and sports scientists. In the professional sports arena, specialized sensing capabilities are used to provide highly accurate measurement of specific physiological and metabolic parameters, which cannot be supplied by general consumer sensing devices. But as the capabilities of low-cost body-worn sensors continue to improve, the need for more expensive proprietary solutions will reduce. Performance sensing can often result in what is known as the *observer effect*, where the athlete's awareness of the sensor impacts their performance. The goal for these users is to make the sensors undetectable. Ideally, the sensors should not result in any perceived inertia, and the attachment mechanism should not result in any discernible discomfort (Harle et al., 2012). As fabrication techniques evolve, the reduction in the size of sensors will address some of these issues. Another part of the solution is to integrate sensors directly into sportswear clothing; which is discussed in the next section.

Clothing

The integration of sensors into clothing is driven by a growing convergence between electronics and new forms of fibers and textiles. Clothing provides a natural platform for human subject monitoring during exercise and sporting activities. More recently, intelligent or smart materials that sense and respond to environmental stimuli or that monitor the physiological well-being of the wearer have emerged. This form of sensing is often referred to as *smart clothing* or a *smart clothing system* (Kaur, 2012). These systems can provide insights to vital signs, movement, biopotential, and ambient environment (Jeong et al., 2013). The use of sensors in clothing offers a number of advantages including making sensors invisible to external observers. Using carefully designed clothing as the mechanism to hold the sensors on the body can address tricky issues related to sensor placement and orientation. A well-fitted smart clothing sensor can also greatly simplify data analysis by reducing unwanted motion artifact in the measured signal. Wired connects between sensors and support electronics can be integrated into the fabric of the clothing, which potentially can improve the reliability of communications over wireless sensors.

Various products ranging from T-shirts, tank tops, and even women's sport bras with heart-sensing capabilities from companies such as adidas and Textronics have been demonstrated and are commercially available (Textronics, 2013, Eric, 2012). Emerging products and prototypes provide full end-to-end connectivity based on smartphone compatibility. The availability of Bluetooth Smart could also drive the popularity of smart clothing for sports-related applications. There are several smart clothing applications, including the following:

- ***Detection of physical impact***: Physical impacts during contact sports, particularly head impacts, have been an area of concern for many years. Sportswear manufacturer Reebok and device manufacturer mc10 developed the CheckLight head impact indicator, targeted toward American football players. The concept behind the product is to give a visible indicator when a player has taken a dangerous blow to the head. The sensor is worn by the player in a special skullcap. The sensor, in the form of a strip, provides information on directional and rotational acceleration and impact location and duration. Data fed into a microcontroller is processed using a proprietary algorithm to determine the severity of the impact. The output of the algorithm is used to light one of two LEDs in the sensor module. One flashes yellow after moderate impacts, and the other flashes red to indicate a severe blow (Gorman, 2013).

- ***Biosignal monitoring***: More than half of the world's heart rate belts are created by Finnish company Clothing+. These textile transmitter belts are found in products created by adidas, Garmin, and Philips. Researchers at Northeastern University have developed a prototype electromyography (EMG)-based, sensor-based shirt that tracks the electrical activity of muscles during workouts. Data is streamed in real-time to an Android smartphone that reports heart rate and repetition countdown. Data is also sent to a web-based portal for historical data analysis (Belezina, 2012).

- ***Biomechanical monitoring***: The Danish company Danfoss PolyPower has developed sensors based on dielectric electroactive polymer (DEAP) technology. As the material stretches, its thickness changes, resulting in a measurable change in capacitance. This change in capacitance can be used to measure biomechanical changes in the body such as joint angles, range of motion, and shoulder alignment. The elastic material's thin, low-profile form factor makes it possible to integrate into clothing, muscle wraps, protective gear, and other sportswear. PolyPower has demonstrated a wireless version of the sensors based on Bluetooth Smart, which can connect to mobile devices. The prototypes also feature integrated inertial sensors (gyroscope, accelerometer, and magnetometer). PolyPower has also demonstrated a prototype golf training sleeve based on the sensing material. In this application, the wireless sensor system is used to measure the angle of the elbow and metrics of the swing. The sensor stretches with elbow movement, measuring changes in joint angle; this data is coupled with data from additional body-worn inertial sensors (acceleration, force, and so on). The combined datasets are sent wirelessly to an iOS device, which then provides feedback, informing the golfer how to improve their swing (Weiss, 2013).

- ***Biofeedback***: The Move project is focused on producing clothing with embedded sensors as part of a platform that can help people improve their Pilates technique. The Move project platform consists of a garment with four stretch and bend sensors (*resistance* decreases when bent or flexed in either direction) located in the front, back, and sides, as shown in Figure 10-3(a). The mobile app with cloud service is shown in Figure 10-3(b). The sensors track the specific positioning of back and abdominal muscles. The mobile app assesses whether the position is correct. Real-time haptic feedback is provided through haptic components located in the hips and shoulders to correct inaccurate movements. The cloud service provides historical tracking of performance and a library that can be used to store new custom moves or to access predefined moves (Krakauer, 2012).

(Credit: fashion photographer Leo Lam)

Figure 10-3(a). *Prototype version of the MOVE sensing garment (image used with permission from* `electricfoxy.com`*)*

Figure 10-3(b). *MOVE user interface (image used with permission from* `electricfoxy.com`*)*

- ***Environmental monitoring***: Smart clothing is also attracting interest in the outdoor sporting market and in other recreational activities. Sensors and actuators can be used to change response to environmental conditions or other local external stimuli (Bye, 2010). Many of the sensing technologies emerging in this new category have military origins. For example Brenig has embedded wearable technologies in polar-expedition lines of clothing to create a sleeve compass.

The symbiosis of sensors, clothing, and wearable computing and mobile devices will continue to evolve in terms of capabilities, robustness, and applications. From a sensing perspective, applications will continue to be a mixture of direct/near and indirect skin contact. Sensors will be enclosed in layers of fabric or integrated into the fabric itself using sensing modalities such as piezo-resistive yarns, capacitive materials, and optical fibers. The role of fashion will also have an important influence. There is a growing interest in the confluence of fashion and technology in the form of fashion-forward wearables. This will be an area of rapid and exciting innovation over the coming years (Higginbotham, 2013, Darmour, 2013).

Sports Equipment Sensing

The integration of sensors and ICT technologies into sports equipment provides a platform to deliver new insights into athletic performance and the athlete's interaction with sports equipment. Sensors can be attached or integrated into the sports equipment or can be worn by the athlete as they use the equipment. One of the key advantages with the use of modern wireless sensing is that it now frees the athlete from the confines of the laboratory and allows data to be captured in conditions closer to competition settings. The combination of equipment-specific sensing with standard physiological and kinematic sensing can provide a rich multisensor dataset. This dataset can reveal nonobvious relationships between parameters and give a more informed picture of performance improvements and areas to target for further improvement.

Cycling

Sensing requirements for cycling are similar to general-purpose fitness sensing: tracking speed/distance, elevation, energy expenditure (calories), and heart rate. In sports such as cycling, which use some form of equipment, there is an opportunity to capture additional equipment-specific parameters. Two parameters highly useful in cycling are cadence and power. Cadence sensors generally use magnetic-based technology. A magnet is fitted to one of the rear wheel spokes, and a receiver is fitted to the frame of the bike. The receiver detects each revolution of the magnet and streams data from the receiver to a display fitted to the handle bars. The display allows the cyclist to maintain a target cadence normally in the 95 revolutions per minute range (Maker, 2011).

A more recent development in the mainstream sports cycling market has been the availability of power meters (Cycling Weekly, 2013). Digital display units mounted on the bike's handlebars can provide real-time information on a variety of power metrics, such as instantaneous, maximum, and average power. These displays can also connect to other wireless sensors, such as heart rate monitors, to provide a multisensor view of performance. Power meters are useful for providing an objective measurement of the cyclist's real output and are regarded as a better metric of training progress than pure physiological measurements, such as a heart rate. Power meters are available from a variety of manufacturers including Polar, Garmin, Quarq, SRM, and Power2Max. These sensors can be either placed on, or integrated into the crank of the bike or onto the wheel hub. Power meters are normally based on a combination of strain gauges and accelerometers. Strain gauges measure torque applied, and accelerometers measure velocity. This data is combined to calculate power. Power sensors cost in the region of $2,000 to $3,000. Cheaper alternatives include external magnetic sensors mounted on the crank, sensing chain tension and chain speed, or measuring wind speed using a handle-mounted sensor. Each of these approaches has its respective limitations and is less accurate in comparison to strain gauges.

An Irish company, Brim Brothers, has developed an innovative approach to measuring power. Its prototype data collection pod, weighing just 18 grams, clips to the instep of a shoe, as shown in Figure 10-4(a). The pod includes motion sensors to measure the rotational position and velocity of the pedal and the crank and to calculate cadence. As a result, no magnets are required to detect cadence. The motion sensors also have the potential to provide detailed continuous information about a rider's pedaling style and efficiency on the road. This capability can currently be achieved only with static bikes in research laboratories. Power measurements are collected from proprietary sensors based on piezoceramics. This type of sensor is more robust and less temperature sensitive in comparison to strain gauges. They measure force without the need for a mechanical part to bend, and therefore the whole force measurement system can be made extremely small. The force sensors are embedded in the cleat rather than being attached to the cleat, as shown in Figure 10-4(b). That means that there is no increase in cleat size or stack height, and the system is bike independent (Brim-Brothers, 2013).

Figure 10-4. *(a) Data collection pod, (b) strain gauge sensors attached to cleat (image used with permission from Brim Brothers)*

Golf

Because of the technical nature of the sport, golf has a long history of players utilizing various aids and mechanical devices to improve either their swing or their putting accuracy. Golfers are also generally characterized as having higher purchasing power to invest in such aids. Professional golf coaches use IR optical sensing, video analysis, sonic sensing, and Doppler radar as aids in helping to improve a player's golf swing. More recently, the use of inertial sensors has emerged in golf. The sensors can be attached to the golf club, hand, or arm. Some examples include the following:

- The Golfsense product utilizes four MEMS-based inertial sensors, integrated into a small unit. The unit weighs 17 grams and is attached to the back of a golf glove, as shown in Figure 10-5. Data from the sensor unit is streamed via Bluetooth to either an iOS or Android mobile device for analysis and display. Parameters such as club speed, club position, swing tempo, and swing path are calculated and displayed (GolfSense, 2013). A key advantage of this approach is its flexibility. It can be used anywhere and without assistance. An alternative approach to swing sensing is to attach the sensor directly to the shaft of the golf club as used by products such as SwingSmart (`www.swingsmart.com`) and SwingTIP (`www.swingtip.com`) and Swingbyte (`www.swingbyte.com`). These products also use wireless transmission of data to a mobile device for analysis.

Figure 10-5. *The GolfSense inertial sensor for golf swing analysis (image used with permission from Golfsense)*

- Although the majority of sensor-related products are for golf swing analysis, 3Bays has developed an innovative sensor product called 3BaysGSA Putt. The device, which weighs less than 10 grams, is based on 9-axis inertial sensing. The device attaches to the end of a putter and streams data via Bluetooth to an iOS mobile device. The 3BayGSA PUTT app provides a variety of metrics including face angle at impact, backswing time, downswing time, and so on (3BaysGSA, 2013).

In January 2006, the use of range-finding devices (GPS and laser) were sanctioned for use in competition by the USGA (United States Golf Association) and the R&A (Royal and Ancient – Golf Club of St Andrews), subject to the approval of the local competition committee. Laser range finders can measure the distance to any object on the golf course that can reflect light, including trees, hills, bunkers, and so forth. They can also be used to determine distance to players who are putting on the green ahead to obtain an accurate measurement of distance to the pin. GPS units are used to display distances to preselected points on the course. Many devices can provide a color aerial view of the hole, which can be useful in determining the most appropriate approach shot. Other products, such as the Garmin Approach 1, provide simple distance from the green information in a wristwatch form factor. Some of the more advanced devices provide a virtual fly-over of the entire hole. GPS systems are generally smaller than laser devices, which require sophisticated optics to measure distance.

Sensing in Other Sports

Sensors are now being adopted in a variety of other mainstream and niche sports, particularly those that have a technical element to them or use some sporting equipment. Doppler radar sensors, such as those from Sports Sensors, are used in sports such as archery, baseball, and tennis (Sports Sensors, 2013). These sensors provide real-time velocity feedback, which can be used to improve performance. The sensor may be attached directly to sports equipment, for archery and baseball, or used in a noncontact mode in the case of tennis or golf. The data can be used to improve speed, accuracy, and consistency. In activities, such as mountain climbing, paragliding, hang gliding, and hill walking, barometric pressure sensors are used to determine altitude. They are commonly combined with GPS units or into a variometer (measures rate of descent or climb) for paragliding use. For mountaineering applications, the sensors can be incorporated into wristwatch form factors, such as the Casio PROTREK watch. Apart from altitude data, changes in barometric pressure can be used to indicate impending changes in weather conditions. However, the accuracy of these sensors can vary because of barometric drift and temperature, which may cause large errors in altimeter measurements.

In swimming, the Australian Institute of Sports has used sensors in its elite training program to track the number of laps, the time taken, the stroke rate, and the type of stroke for each lap. This has allowed coaches to replace written training diaries with web-based data portals that are accessible anywhere and at any time (Chaganti et al., 2011). AvidaMetric produces a system that comprises body-worn wireless sensors attached to the wrists, ankles, and head. Data is streamed to a pool-side laptop that can process the data from up to 100 swimmers at a time (Zarda, 2010). Sensors have also been used to measure performance parameters such as approach time, contact time glide, kick time, and stoke time during a swimmer's tumble turn with comparable accuracy to that achieved using digital video analysis (Sage et al., 2012). The system has been adopted by a number swimming programs in U.S. universities. Sensors are also used in martial arts to measure speed and force of impact during a striking motion (Cowie et al., 2008).

Sports and Fitness Statistics

The granularity and sophistication of fitness data analysis and presentation depends on the type of end user. An amateur generally has less complex requirements compared to a professional athlete and coach, who often require a myriad of physiological and biomechanical parameters. As our data literacy improves and we become more attuned data consumers, the gap between the expectations of the amateurs and professionals is diminishing, particularly among more committed amateurs. In fact, access to unlimited amounts of data and information has become almost a basic expectation. As already mentioned, social media is driving the sophistication of fitness statistics as knowledge and analysis can be freely shared among group members.

The raw sensor output can be analyzed using specialized algorithms that provide interesting insights into athletic performance, but this analysis can only be as good as the quality of the data. It is important to consider that sensors, particularly inertial sensors, have limitations that become more pertinent in certain types of sports. For example, many general-purpose MEMS accelerometers are rated in the 2–9g range, which is sufficient for activities such as running. However, the centrifugal acceleration may exceed the range of these sensors in sports such as basketball, baseball, cricket, and golf. For example, fast cricket bowlers generate accelerations in the forearm in excess of 70g (Wixted et al., 2010). Specialist accelerometers rated up to 100g and higher are commercially available but are currently too expensive for use in consumer products.

It is important to consider that the majority of body-worn fitness sensors aren't 100 percent accurate. The performance may be inferior to bench-top systems found in sports clinics, but the differences are likely to be relatively small and may only be noteworthy for consideration by elite athletes. Certainly, the majority of available sensors will deliver superior accuracy over any form of manual estimation such as heart rate (Wixted, 2012).

Data and statistics have been an integral part of professional sports for many years. Performance metrics such as batting average, points scored, yards covered, driving distance off the tee, and goals scored have been routinely tracked. These metrics describe the output of performance. Sensors can be used to provide insight into how that performance was achieved and how it might be improved. Sensing is being applied in both competitive and training scenarios. In team sports, GPS sensors are worn by players in sports such as Rugby Union and Australian Rules Football to track the distance covered on the pitch during the game (Wisbey et al., 2010, Waldron et al., 2011). The sensor can also provide data on the player's proximity to play and their speed throughout the match. During training, team members may also wear heart rate monitors to measure the athlete's heart rate and recovery during a training session. This data, recorded during team sessions, allows the coach to identify a team member who is showing early signs of fatigue and determine whether they need rest or additional training. Identifying early signs of fatigue and intervening can prevent injury, which is also a key concern for highly paid athletes. Both professional and amateur athletes and their coaches are turning toward using rich sensor datasets to find a competitive edge over their opponents. The theory of "marginal gain," in which making slight improvements in numerous aspects of performance results in a cumulatively large improvement, is becoming increasingly important in competitive sports. Sensing and advanced data analytics allows athletes and coaches to identify potential areas of marginal gain and quantify improvements in these areas.

In personal fitness, the Quantified Self movement is going beyond simply tracking the time and distance of our runs or bike rides. Casual athletes are becoming much more data driven. Access to more sophisticated data sets from wearable sensing devices and advanced statistical analysis are taking this to the next level. By using motion sensor subsystems, we now have the data to analyze our activity throughout the day. How much time did I spend sitting, walking, exercising, and sleeping? How does this match to the activity goals I've set for myself? While exercising, did I expend more calories on my 30-minute run or that pickup game of basketball?

A vast array of biomechanical and physiological parameters can be calculated. Some are common across all activities, and some are activity specific. The most common range of fitness statistics includes these:

- Distance covered
- Speed (maximum, average moving, and overall speed)
- Time
- Heart rate
- Cadence
- Number of calories burned
- Total energy expenditure
- Lap measurements

These statistics can be used to provide insight into questions such as these: How much time am I exercising? Am I improving? Which activity resulted in the highest calorie burn? Did I reach my target for today? Movements such as the Quantified Self are increasing our awareness about ourselves through sensing, data, and statistics.

Beyond their use in training and performance improvement, sensor data and statistics are increasingly playing a role in the broadcast media to enhance the viewing experience. For a number of years, motorsports such as Formula One and NASCAR have been providing on-screen real-time telemetry from in-car sensors ranging from acceleration, braking, g forces, and so on. With the availability of low power, small form factor, and wireless-enabled sensors, real-time data from the athlete for broadcast media purposes is now possible. Viewers at home will have access to highly granular statistics on how someone is performing and how their performance compares to others. In the future, there may be no hiding place on the field or track. Sky Sports, which broadcasts Premiership soccer in the United Kingdom, already provides extensive analysis of player performance from video analysis. If sensors were to be placed on the players, viewers may soon be able to obtain data on the speed of each player as they run down the wings, their energy expenditure during the game, their acceleration in chasing a ball, and so on. This could potentially make the game even more engrossing for the soccer fan. A trial has already occurred in the MLS (Major League Soccer - US) all-star game in July 2012. Players were equipped with wearable sensors from adidas that allowed viewers of the game to track individual performance statistics of players via their PC or tablet (Householder, 2012).

Activity and Well-Being

Activity and wellness monitoring devices feature the same motion sensing capabilities as fitness sensors. In many cases, the line between them is blurred. The key difference with activity devices is to encourage movement in sedentary individuals and to maintain a minimum level of activity that will benefit their health and well-being. While activity and calorie balance are an important element of wellness, additional measurements that can be captured by sensors are being added to the base activity-related measurements. These measurements include sleep quality, which is a clinically proven element of personal wellness. Popular devices in this category include the following:

- Fitbit's product range comprises of both clip-on and wrist worn activity and sleep tracker sensors. The Fitbit One, for example, clips to a waist band, weighs only 8 grams and has both accelerometer and altimeter sensors. The sensor tracks steps taken, distance traveled, calories burned, stairs climbed, and recent activity. It also acts as a watch with a time display. It can interface to a free smartphone or tablet app and a web-based portal using Bluetooth Smart. The web portal allows users to track what they eat from a database of products and foods with corresponding calorie content. Although imperfect, it gives a useful indication of calorie intake versus calories burned. The Fitbit Force feature a wristband form factor and an OLED display that provides up-to-the-minute statistics such as steps taken, distance travelled, calories burned and so forth, similar to the Nike+ FuelBand. The Force also incorporates NFC, allowing instant download of data to another NFC-enabled device such as a smartphone by simply bringing it into close proximity of the other device. The sleep monitoring capabilities of the Force are similar to those of clinical actigraphy sensors, which are commonly used in sleep monitoring trials.
- The Jawbone Up has a similar wristband form factor to the Fitbit Force and is designed to be worn continually. It positions itself to take a holistic approach to a healthy lifestyle by providing sleep, 24/7 activity, and food/drink tracking. The Jawbone has no visual display to minimize size and weight (less than 23 grams). It is water resistant and can be worn in the shower. The Up band provides standard pedometer capabilities to detect steps and measure overall activity level. Data is sent from the wristband via a cable to either an iOS or Android mobile device. The supporting app for the mobile devices calculates a variety of statistics including the number of calories burned (based on age, height, and gender), total active time, longest period of activity, longest idle period, hours of sleep, and more. It also provides a means to track calorie consumption via web portal. The device has a configurable idle alert function that vibrates the band if movement is not detected after a specified time limit (Bennett, 2012).

The concept of the smartwatch has been around in various forms for many years. Recently the concept has experienced a resurgence, with new smartwatches, such as the Samsung Galaxy Gear and the Pebble, featuring integrated inertial sensing. Here are two more smartwatch developments:

- The MotoActv smartwatch from Motorola is aimed at the sports and activity tracking market. The MotoActv has the same basic capabilities as many sports GPS watches, including those from Nike, Timex, and Garmin, and offers a number of significant additional capabilities. Android-based, it features a variety of apps including a music player that downloads songs from your PC and wirelessly uploads your fitness data (including GPS tracks) to its web site. The watch can also connect to other fitness sensors, such as heart rate monitors, via either ANT or Bluetooth Smart. Workouts can be synced with `Motoactv.com` using the watch's Wi-Fi radio. The watch can also operate in different modes for different sports and activities such as running, gym workouts, walking, and cycling (Maker, 2011).

- Finnish company Vivago Oy's Vivago Watch is focused on 24-hour wellness monitoring. The watch continuously measures physiological signals, including movement, body temperature, and skin conductivity. During the initial phase of use, the watch and supporting software learn the wearer's normal behavior patterns. After this learning phase, the system sends an automatic alert after a predetermined period if it detects a significant change from normal activity patterns. The watch also measures total activity in real time and tracks it historically. It informs the user if physical activity has increased or decreased in comparison to the previous four weeks' average value. The watch also tracks calorie consumption on a 24-hour basis and sleep quantity and quality. Sleep tracking is coupled with an intelligent alarm capability that is designed to wake up the wearer during the lighter stages of sleep, which improves their feeling of well-being (Vivago, 2013).

Another approach to wellness monitoring is the integration of sensors directly into clothing. These sensors can collect data such as physiological, biochemical and biomechanical measurements directly from the wearer's body. Examples of this approach include the following:

- First Warning Systems is developing a breast tissue screening bra. The sensor-layered bra is designed to measure circadian rhythm-based temperature changes that occur as blood vessels grow and feed tumors. Predictive analytic software, co-developed with Nanyang Technological University and Lytix, Inc., categorizes abnormal patterns in otherwise healthy cellular behavior within the breast. This data can be used by a clinician to make an informed clinical decision. In three clinical trials, the bra correctly identified 92.1 percent of tumors, compared to the 70 percent accuracy of routine mammograms (First Warning, 2012). In a conceptual approach, Electrifoxy has created the Modwells prototype for personal wellness monitoring. The system comprises of input/output objects called *mods*, which are worn as part of your clothing. The mods are sensor modules that collect environmental or biometric data sets. The company has demonstrated a prototype concept for assessing posture. The posture garment consisted of a stretch sensing eTextile to which a "move" mod is attached. The mod is used to power the garment and collect data. The garment's stretch sensing capabilities allows the measurement of body movement in various directions. The mod processes the data and provides haptic feedback that alerts if the posture does not match a defined goal (Electricfoxy, 2013). Though speculative in nature, it provides interesting insight to how sensor technologies can be integrated into daily life to improve health and well-being.

Obesity and Weight Management

Obesity is recognized as a major public health issue in the Western world. In the United States, two-thirds of the population is estimated to be overweight, including 35.7 percent who are classified as being obese. The problem is also growing among children, with an estimated 16.9 percent of kids aged 2 to 19 being obese (CDC, 2012). Sensors and accompanying technologies are increasingly being used to monitor an individual's participation in a weight management program and to provide motivation to maintain engagement. There is a significant overlap with the sensor technologies utilized in the fitness market and weight management market. Early devices were based around standard pedometers, with data being transferred manually or via PC to web-based portals. More recently, MEMS-based inertial sensing devices such as Gruve (`www.gruvetechnologies.com`) are being utilized in the weight-management domain. Data from the sensors are transferred to web portals that are designed specifically to deliver custom weight loss and management programs. These programs are based on a combination of data tracking and visualization, online coaching, and nutrition management. One limitation in this form of sensing approach particularly for weight reduction programs is the accuracy in determining calories burned. Data collected from accelerometers during physical activities that require high-energy expenditure but low levels of movement (such as lifting weights) can underestimate calories burned (Cready et al., 2013). A multisensor approach may be a more accurate method to measure calorie burn. Products such as BodyMedia's armband body monitoring system contain skin temperature, heat flux, and galvanic skin response (GSR) sensors in addition to standard accelerometer-based inertial sensors. GSR provides a mechanism to determine how much you are sweating through changes in the skin's electrical conductivity. Skin temperature is also reflective of activity level. Finally, heat flux determines how much heat is being produced by your muscles and radiated into the ambient environment. Collectively, data from the sensors is claimed to measure calorie burn with less than 10 percent error. In addition, the sensor module also measures sleep quantity and quality. There is growing evidence to show the correlation between weight gain or loss and sleep because of the effect on hormone levels in the body, particularly leptin and ghrelin (Kollias, 2011, Thomson et al., 2012). These hormones are responsible for the stimulation and suppression of appetite. Their production can be affected by both the quality and quantity of sleep. The use of sleep sensors is likely to play an increasing important role in weight-reduction programs. Sleep data will be used to provide insights into the affects that lifestyle choices and behaviors are having on an individual's weight gain or loss. The next section looks in more detail at current sleep-sensing approaches.

Another approach to measuring caloric burn is based on indirect calorimetry. The technique is recommended by the World Health Organization, American Dietetic Association, and the American College of Sports Medicine for the treatment of obesity and the management of weight. As previously described, portable calorimeters are now available that provide accurate metabolism tracking which has utility in weight management applications. Inertial sensing approaches can have some difficulty with determining context, that is, running on a flat surface or running up a 20 percent incline. In-direct calorimetry provides insight to exactly how hard the body is working, or not, as the case may be. The disadvantage of portable calorimeters is that the measurements are not continuous and offer only snapshots in time. However, they do provide a means to accurately establish a baseline of how many calories you burn.

The other side of the equation in weight and obesity management is determining how many calories you are consuming. This is extremely challenging to achieve with any degree of accuracy because of the variety of variables that must be considered. However, most of the products available do provide some form of capability within their web portals to input your food intake. You can generally select the foods from a prepopulated database with accompanying calorie values. Or you can add your own meal information based on ingredient selection and quantity. Although this approach is imperfect, the process can be useful to making people understand how much food they are consuming without their full realization.

Sleep

Increasing evidence shows the impact of sleep on overall health, wellness, and even weight control. The measurement of sleep, and particularly the quality of sleep, is challenging. The gold standard method for measuring sleep is polysomnography (PSG). This method measures variables including EKG/ECG, electroencephalogram, oxygen saturation levels, and breathing patterns. Despite its accuracy, the method has a number of distinct disadvantages. First, it requires a significant number of electrodes to be attached to the subject. This is often uncomfortable for the patient, disturbing their sleep. It also requires the subject to stay overnight in a specialist sleep clinic, which is expensive and takes subjects from their normal environment, which again may influence the data. However, the data collected can be used for sleep staging determination, which is important in calculating the ratio between REM and non-REM sleep. REM sleep should account for about 20–25 percent of total sleep in most adults. Poor sleeping patterns and poor sleep quality have a variety of issues associated with them:

- Impaired memory and thought processes
- Depression
- Decreased immune response
- Fatigue
- Increased pain
- Weight gain
- Loss of creativity

Apart from the impacts on health, sleep disturbances may also be early indicators for poor health and functional deficits, especially in older adults. Sleep complaints are particularly prevalent in the over-65 age group, with more than 50 percent reporting issues including getting less sleep, frequent awakenings, waking up too early, and sleeping and napping during the day (Miles et al., 1980).

Given the significance of sleep in the matrix of health and well-being and the limitations of PSG, there has been a growing interest in the application of sensor technologies for home monitoring of sleep. Early devices used actigraphy, which is comprised of a dual-axis accelerometer worn in a wristwatch-like device. Data from the sensor is stored locally on the device and downloaded to a PC for analysis after each night's sleep. Analysis of the data reports motion over a predefined epoch length, as shown in Figure 10-6. The upper graph shows both the times and the magnitude of any individual activity measured. The lower timeline (in red) shows the cumulative activity for a given period of time. Low levels of activities may be associated with non-REM phases, while periods of high activity may indicate that the subject is awake. Estimates of sleep-to-wake stages are made using regression-based algorithms. The approach is good at identifying patterns of sleep disturbance; the data cannot be used for sleep staging, which is required for the measurement of sleep quality. But this limitation can be addressed in part through the use of either a respiration or EKG/ECG sensor to estimate the REM and non-REM sleep stages.

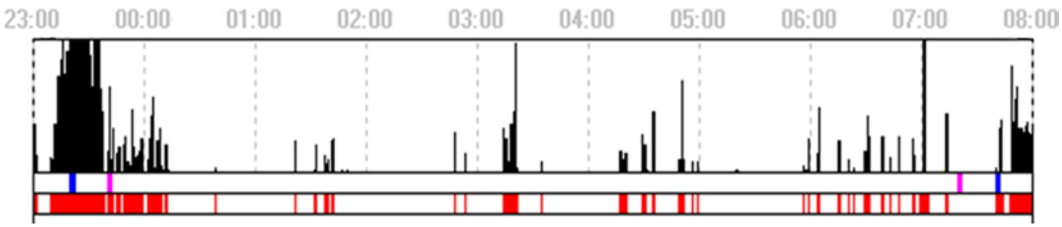

Figure 10-6. *Acitgraphy sensor data from a nine-hour sleeping period*

Although actigraphy sleep data can be useful, it requires the subject to remember to wear the sensor each night. Noncontact methods have the advantage of being able to operate without subject involvement. Sensing approaches include load cells (Austin et al., 2012), radar-based technologies (Vasu et al., 2011), force sensitive resistors (Lokavee et al., 2012), and wireless inertial sensors (McDowell et al., 2012). Walsh et al. has demonstrated the use of an under-mattress pressure sensor, as shown in Figure 10-7, which uses 24 fiber-optic sensors embedded into a mat to detect body position and movement during sleep. A home-based study of elderly subjects demonstrated accurate temporal resolution of activity monitoring in bed that was correlated with activity data captured using an actigraphy watch (Walsh et al., 2008).

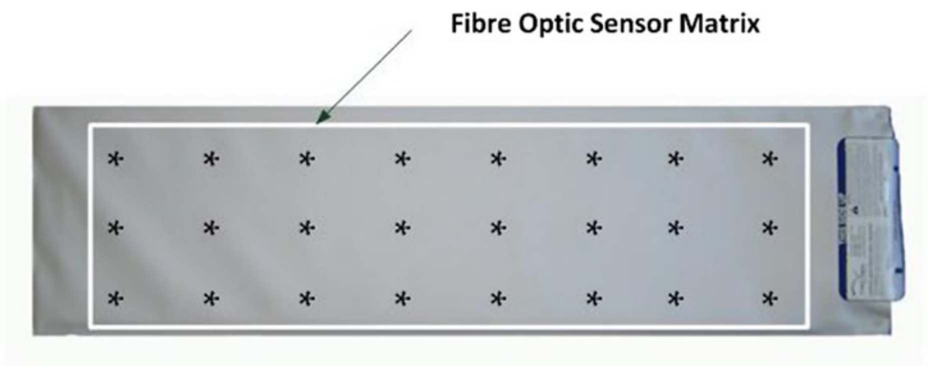

Figure 10-7. *Under-mattress pressure sensor*

The consumer-focused Zeo sleep monitoring system took a PSG-type approach to sleep monitoring by tracking brain activity. The systems comprised a lightweight wireless headband that was worn during sleep. The data from the headband was streamed either to a bedside display or to a smartphone. The aggregated data was sent to a web portal for online analysis. The web portal had a number of other features including a sleep journal that was designed to identify the links between lifestyle influences and sleep quality. The system features a SmartWake capability that looks for a “natural awakening point”—that is, a light point in your sleep to help you wake up without feeling groggy. Unfortunately, the company closed down in early 2013 because of financial difficulties (Dolan, 2013). Apps, such as Sleep Cycle Alarm (Maciek-Drejak-Labs, 2013), use the smartphone’s integrated accelerometer as actigraphy to monitor quality of sleep. The smartphone is placed on the person’s mattress, and the user calibrates it to detect motion. The app claims to be able to detect REM and non-REM sleep by indirectly measuring how much the person is moving while they sleep. The user can set an alarm to wake them when they enter a period of light sleep rather than waking them from a deep sleep.

Baby Sleep Monitoring

Anxious parents have always worried about the well-being of young babies while they sleep. Incidences of cot deaths reported in the media only heighten those anxieties. As a result, there is significant interest in sensor technologies that can monitor a child when sleeping. The most common approach simply monitors for sounds that indicate whether the child is asleep or not, and monitors the temperature in the child’s environment. However, more sophisticated sensors have emerged that can monitor the baby via contact or noncontact modes.

One approach is to place a pressure sensitive mat under the baby’s mattress. The AnglecareAC401 sensor system shown in Figure 10-8, for example, has an under-mattress sensor that provides continual monitoring of a baby’s movements while they sleep. An alarm sounds to alert parents if no movement is detected for 20 seconds. The system also features sound monitoring to augment the motion sensing capabilities. Additionally, the system has room temperature monitoring with upper and lower temperature alerts. Collectively, these sensing capabilities give parents a degree of reassurance, particularly those who are concerned by sudden infant death syndrome (SIDS).

Figure 10-8. *The Anglecare under-mattress movement and sleep sensor for use with babies (image used with permission from ANGELCARE)*

The pressure of the baby lying on the mattress over the sensor is typically measured using either piezoresistance or optical sensing. In a piezoresistance sensor, changes in electrical resistivity relate to applied pressure, which varies during the breathing cycle or as the baby moves. In the fiber-optic approach, a transmission fiber and receiver fiber are enclosed in a cell structure. When pressure is applied to the cell, it is distorted, which affects the amount of light collected by the receiver fiber in proportion to the amount of applied pressure. The sensors in the mat are connected to an aggregation unit, which processes the sensor readings. Lack of detectable respiration in a defined period or a low respiration rate (>10 breaths per minute) triggers an audio alarm alerting the parents.

The second type of sensing is body-worn. These sensors clip onto the baby's clothing or diaper. These sensors use an inertial sensing approach to monitor movement of the chest or stomach area. Many of the available products feature a built-in tactile stimulator that is generally triggered if no movement is detected for 15–20 seconds. If the sensor does not detect movement after use of tactile stimulation, an alert is generated. Correct attachment to the body is important to prevent false positive alerts, which can be challenging with babies. The key advantage of this sensing approach is its mobility in comparison to under-mattress sensing. Under-mattress sensing is often tied to a specific mattress type and thickness for optimal performance.

A number of baby monitoring approaches have been investigated in the research domain, including a sensory vest that features EKG/ECG, respiration, moisture, and temperature sensing integrated into a baby's vest (Linti et al., 2006). A more recent smart clothing approach is the Exmobaby suit, which features a thermometer, heart rate monitor, and movement sensor built into the fabric. The suit also features a moisture sensor that is used to indicate when the baby requires changing. A Zigbee transmitter pod attaches securely to the suit and is used to stream the sensor data to a receiving PC. An application on the PC processes the data and sends information to a web site. Users can connect to the Web via smartphone app. The web site also generates SMS and e-mail alerts as required (Waugh, 2012). Other reported approaches include pulse oximetry monitoring (Rimet et al., 2007), wireless audio sensing (Al-Dasoqi et al., 2010), and UWB radar sensing (Ziganshin et al., 2010).

Sleep Apnea

Sleep-related complaints include insomnia, restless leg syndrome, snoring, parasomnias, and sleep apnea. Incidences of sleep apnea are relatively common and affect men more than women. Studies in the United Kingdom have estimated that about 4 percent of middle-aged men and 2 percent of middle-aged women suffer from the condition. Left untreated, the condition has the potential to cause high blood pressure, heart attacks, stroke, obesity, and type 2 diabetes (NHS, 2012). In addition, sleep apnea causes daytime sleepiness that can result in accidents, lost productivity, and other issues. The condition is commonly associated with being overweight.

Sleep Apnea Syndrome describes the cessation of respiration during sleep. The most common kind of sleep apnea is called Obstructive Sleep Apnea Syndrome (OSA), which is defined as a total blockage of the airway for 10 seconds or more. Polysomnography is the gold standard used as the diagnostic test to identify OSA; however, in 2008, the FDA approved home monitoring as a tool for diagnosing sleep apnea. Home sleep monitoring utilizes a variety of sensors, including the following:

- Airflow (pressure-based)
- Blood oxygen saturation (pulse oximetry, normally at 0.1 percent resolution)
- Heart rate (EKG/ECG)
- Respiration effort (respiratory inductive plethysmography)

In addition, it is strongly recommended that the following parameters are monitored:

- Temperature-based airflow (thermistor)
- Snoring patterns (acoustic microphone)

- Muscle activity (EMG)
- Head movement/position (inertial sensing)
- Body position (inertial sensing, supine or nonsupine sleep positioning)

It has been reported than home sensor platforms can deliver comparable accuracy to PSG. For example, the Ares Unicoder system from Watermark Medical has a reported correlation of 0.96 with PSG when recorded concurrently and 0.88 for home-based monitoring when compared to PSG (Westbrook et al., 2005). Other home monitoring solutions include the Stardust II Sleep Recorder (www.stardust2.respironics.eu) and Alice PDx portable sleep diagnostic system (www.alicepdx.respironics.eu) from Philips, SleepView from Cleveland Medical Devices (www.clevemed.com/SleepView/overview.shtml), and AccuSom from NovaSom (www.novasom.com).

When mild sleep apnea is diagnosed, treatment is normally based around lifestyle changes including losing weight, cessation of smoking, and limiting alcohol consumption. In moderate to severe cases, continuous positive airway pressure (CPAP) machines are used to treat sleep apnea. This involves using a mask worn over your nose that delivers a continuous supply of compressed air. The compressed air prevents the airway in the throat from closing. Sensing plays a key role in the operation of these machines. Precision MEMS pressure sensors monitor the instantaneous pressure at the output of the machine and inside the breathing mask. This data is used to dynamically adjust the air pressure in order to maintain a set value required by the prescribed therapy. This increases the accuracy and sensitivity for individual CPAP users. Pressure data can in some cases be used to identify the need for specialized therapy. In addition to pressure measurement, the CPAP machines may also capture data on the duration of the therapeutic episodes each night, leak rate, pressure settings, pauses in breathing, and periods of shallow breathing. This data can be used by clinicians to modify or refine the therapy for each patient.

Posture Monitoring

Back pain is a prevalent problem among adults, with 80 percent of people experiencing lower back pain sometime during their lives and with 20 to 30 percent experiencing it at any given time (Virutal Health Care Team, 2012). The American Academy of Pain Medicine reports that back pain in workers in the 40–65 age bracket costs employers an estimated $7.4 billion a year in the United States alone. There are also indications that the prevalence of back pain is increasing. The reasons for this increase are unclear, but factors such as obesity and increased numbers of people in desk-based jobs may be a factor (UNC School of Medicine). Frequently, back pain can be successfully addressed with a combination of exercise, nonsurgical treatment, and alternative therapies. For some chronic back pain sufferers, implantable neurostimulation devices that deliver mild electrical signals to the epidural space near the spine may also provide a solution. Poor posture has been identified as a significant contributor to back pain issues. It is important to maintain the spine in a strong and stable position through healthy posture. Stooping or slouching deviates the spine from its three natural curves (cervical, thoracic, and lumbar). As a result, the back muscles and ligaments are overextended as they struggle to maintain postural balance which leads to back pain, headaches, and other related problems.

Inertial sensing is also playing a role in intervention, particularly with posture monitoring applications, as shown in Figure 10-9. Already a number of products, such as Lumoback, are available that can monitor and improve posture. The Lumoback sensor is worn around the lower back provides vibro-tactical feedback when the wearer slouches. The sensor connects via Bluetooth Smart, to a smartphone app that delivers real-time posture tracking. The sensors provide tracking of pelvic tilt alignment and slouch due to the lower back position, leaning forward, leaning backward, or incorrect balancing of weight to one side (Lasky, 2013).

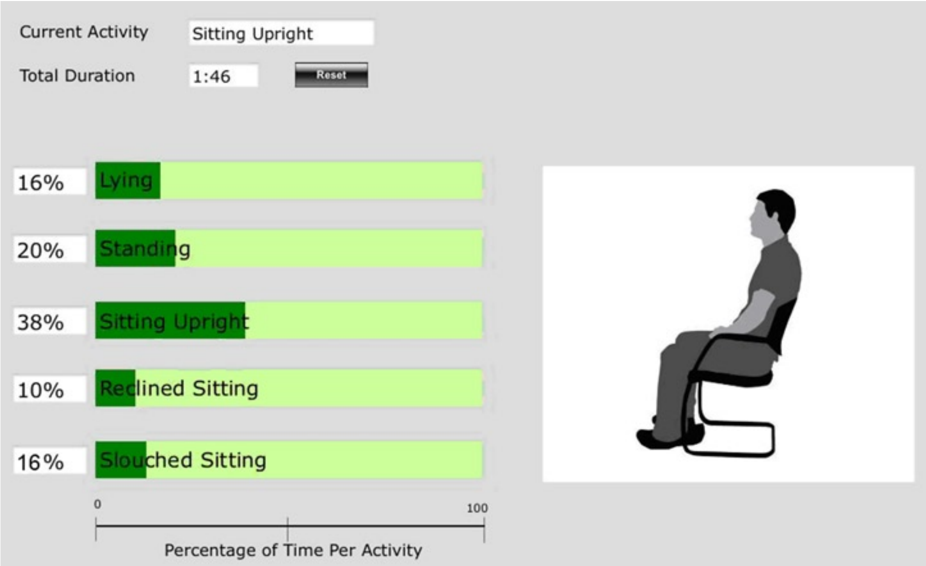

Figure 10-9. *Posture monitoring and classification using inertial sensors*

The Philips ErgoSensor monitor uses an optical CMOS camera to determine distance from the screen and neck angle while sitting. The screen provides a warning when your posture is not ergonomically correct (Chang, 2012). Other approaches to posture monitoring reported in the literature include smart clothing featuring integrated accelerometers and gyroscopes (Wong et al., 2008), force-sensitive resistors (FSRs) embedded into shoes (Sazonov et al., 2011), and piezoelectric eTextile cushions (Wenyao et al., 2011).

Personal Safety

Sensors are being applied to make our lives safer. Sensors can notify us of potentially dangerous conditions in our homes, such as the presence of smoke or carbon monoxide. They can also help to secure our homes and notify us of potential break-ins or intruders. They can even detect when we've experienced an accident. When an accident, such as a fall, occurs sensors can be used to identify that a dangerous event is occurring and trigger preventative measures to protect us from injury. Sensors can also be used proactively to determine whether we are in satisfactory physical condition to engage in routine daily activities. Older adults may test their balance to ensure they are sufficiently stable before leaving the house or walking around their garden. For adults who like to socialize with an alcoholic drink at home or outside the home, testing of your blood-alcohol level before driving may be of enormous benefit for obvious reasons.

Home Safety Monitoring

Home safety monitoring embraces various sensing functions, ranging from traditional home security monitoring to ambient environment monitoring to health-related event detection and response. PIR motion sensors can detect motion in rooms, and magnetic or vibration sensors are attached to windows and doors to detect tampering. These sensors can be augmented with video surveillance to provide continuous monitoring or motion activated monitoring via PIR sensing. Home security systems are now being augmented with "smart" features that allow people to monitor their home remotely. Monitoring can include access to real-time video streams and the ability to receive alerts such as SMS messaging if an issue, such as an intrusion, is detected. The capabilities of these smart security systems are being further enhanced with home automation features or domotics (automated controls for homes), such as light and HVAC (heating, ventilation, and air conditioning) control. Additional sensing capabilities, such as water and flood monitoring, can also be included to increase the home owner's peace of mind when they are away. These systems are natural extensions of the Internet of Things approach (see Chapter 5), where all sensors and devices around us are connected in some manner to deliver intelligent applications. In the United States, AT&T has recently launched its Digital Life home security and automation product, which features sensing capabilities for water and flood monitoring, carbon monoxide and smoke detection, and glass breakage (AT&T, 2013).

The use of smoke alarms as shown in Figure 10-10 in the home has been common practice for many years—their installation is a legal requirement in many countries. As described in Chapter 2, smoke detectors come in two types: ionization detectors and photoelectric detectors. For carbon monoxide detection, semiconductor or electrochemical sensors are normally used for residential applications. They can be either battery powered or powered by the home's electrical mains. Mains-powered devices typically feature a battery backup to ensure that during a mains power outage there is no loss of monitoring.

Figure 10-10. *A home smoke alarm*

Safety Monitoring and Falls Detection

Another key element of wellness is personal safety, which can be of particular concern for older adults, especially in their own homes. Falls-related injuries, which commonly occur in the home, are the single biggest cause of injury-related death in older adults. It is estimated that falls-related injuries cost approximately $30 billion annually in the United States. The use of notifications systems for older adults to alert support services in the case of an emergency such as a fall has been common practice for many years. These systems often take the form of stand-alone units, simple pendants, or wristbands with a help button. Activation of the button notifies a remote monitoring service that there is an issue. Examples of product offerings include AlertOne (`www.alert-1.com`), LifeStation (`www1.lifestation.com`), and Bay Alarm Medical (`www.bayalarmmedical.com`). Emergency monitoring can also form part of an overall home monitoring service, including additional services such as security and ambient sensing as provided by products like Life Alert Classic from Life Alert Emergency Response, Inc. (`www.lifealert.com`).

Falls detection devices are another common home safety application and often build upon an extended medical alert service. This form of product is commonly known as mobile personal emergency response (M-PERS). The detection devices are based on single or multiple inertial sensors (e.g., accelerometers and gyroscopes). Using multiple inertial sensors reduces the false positive rate and improves sensitivity. The sensor modules are worn on the wrist or waist or as a pendant. The modules feature an emergency response button, which is wirelessly connected to a base station in home. Once triggered, the base station can send an alert to a monitoring center. More sophisticated devices have integrated GSM modules, which automatically send an alert when a fall is detected. Alternatively, the sensor can automatically notify the in-home base station that a fall has occurred, which then notifies the call center. The call center contacts the wearer to assess the level of urgency. If an emergency is determined or there is no response, the call center notifies the emergency services and alerts designated caregivers and family. This form of approach has the advantage of being able to operate even when the fall results in the person losing consciousness. Some devices also feature GPS tracking, which is useful if the fall occurs outside the home.

The development of falls detection sensing technology remains an area of active research. Approaches reported in literature include inertial sensors embedded in a custom-designed vest (Bourke et al., 2008) and an inertial sensor embedded into a cane (Lan et al., 2009). Smartphones have also attracted attention as potential falls detection devices because of their integrated inertial sensors. Tacconi et al. report the use of data from a tri-axial accelerometer embedded in an Android smartphone to detect falls and to deliver the Timed Get Up and Go test (Tacconi et al., 2011). This test is a common clinical test to determine falls risk because of gait and balance issues. A key limitation of the approach outlined is the requirement that the smartphone must be worn on the waist, which may not be practical for everyday use as a falls detector, particularly for women. Yavuz et al. also report the use of a smartphone for falls detection. They also utilize the GPS functionality of the smartphone with Google Maps to provide information on the location of the fall. This information is provided together with notification of the fall event to caregivers through various notification mechanisms such as SMS, e-mail, and Twitter (Yavuz et al., 2010). The BuddyGuard from MPOWER Labs is a commercial product that takes a similar approach. The app running on an iPhone provides a number of personal protection services including falls detection. The app automatically senses when a fall followed by a 5G stop occurs using the phone's built-in accelerometer. An emergency alert is triggered within five seconds if users do not respond to a warning notification displayed by the application. The alert transmits the faller's location to friends and family via e-mail, automated phone call, and text message (PR Newswire, 2011).

While there have been various efforts to determine falls risk in older adults (see Chapter 8), other efforts have focused on preventing or reducing the severity of injury when a fall occurs. A common research approach is the use of body-worn air bags such as the jacket system developed by Tamura at Chiba University in Japan. The system comprises both an accelerometer and gyroscope that are used to trigger airbag deployment when acceleration and angular velocity thresholds are exceeded (Tamura et al., 2009). A similar approach using airbags has also been reported in the research literature (Guangyi et al., 2009, Fukaya et al., 2008). There are still considerable practical obstacles that must be addressed before such devices could be considered usable in the general population.

Alcohol Monitoring

We are all aware of the issues associated with driving impairment and the consumption of alcohol (ethanol). In many countries, the legal drink limits are falling. As a result, a single drink may potentially place you over the legal drink/drive limit. Both roadside and bench-top systems have been used by law enforcement agencies for many years. A more recent development has been the use of personal alcohol monitoring sensors, some of which are small enough to attach to car keys. In France, it has been a legal requirement since July 2012 to carry a breathalyzer kit in your car. This is likely to be replicated in many other countries before too long. There are three major types of breath alcohol testing devices commonly available, which are based on different detection principles:

- Chemistry (based on a chemical reaction between alcohol and other chemicals that produces a visible color change)
- Infrared (IR) spectroscopy (intoxilyzer)
- Sensor (fuel cell or semiconductor sensor)

For personal use, semiconductor sensors are the most common because of their low cost and ease of integration into an electronic device. Commercially available personal breathalyzers can cost as little as $20. In a semiconductor alcohol sensor, a bead of metal oxide is heated to around 300 °C. A voltage is applied to produce a small standing current. When alcohol in the breath is exposed to the bead, it changes its resistivity, resulting in a change in the standing current. Semiconductor sensors exhibit a number of problems:

- Nonalcohol specific response. The sensors can react to other volatile organic compounds such as hairspray and breath acetone.
- Relatively short working life.
- Sensor saturation.
- Drift. The sensor can exhibit variation in response that normally increases with age.
- Nonlinear response. Sensors have a narrower and reduced linear range of alcohol measurements in comparison to fuel cells.

Fuel cell devices are generally regarded as the gold standard for field sobriety testing and are used extensively by law enforcement agencies. In fuel-cell devices, the breath sample is exposed to dual platinum electrodes in the cell. Any ethanol in the breath sample is oxidized to acetic acid at the anode, which generates an electrical current. The current generated is proportional to the concentration of ethanol in the breath sample. Fuel cells have a number of key advantages over the semiconductor sensors. They have very high specificity and sensitive for ethanol. The alcohol measurement cannot be influenced by endogenous substances such as acetone (produced by diabetics) or by ambient environmental gases such as carbon monoxide or toluene. The sensors normally have an operational lifespan of more than five years.

Recently fuel cell devices have entered the mainstream consumer market at an affordable price point. As with so many other application domains described in this book, breathalyzer sensors are now being integrated with smartphones. The BACtrak, shown in Figure 10-11, is a fuel cell (Xtend electrochemical fuel cell) breathalyzer that provides accurate blood alcohol content (BAC) measurement in the 0.000–0.400 percent range. (Generally the legal limit in the United States for alcohol intoxication is 0.08 percent, whereas in Europe it is generally 0.05 percent.) The sensor connects to an Android or iOS smartphone via Bluetooth (v4.0). The BACtrak features an internal air pump designed to ensure precise and consistent results. The supporting software offers a number of social media features, including the ability to share results privately via text message or publicly via social media or to simply delete the data. Other features include the ability to share photos, notes, and drink logs. The data provided allows users to gain insight into their drinking habits and to learn how their body processes alcohol (Ferro, 2013). The Alcohoot from an Israeli startup company also utilizes a fuel-cell sensor targeted at the consumer market. It attaches to either an Android or iOS smartphone via the audio port. The supporting software app automatically calls a cab if the reported result is higher than the legal limit (Ferenstein, 2013).

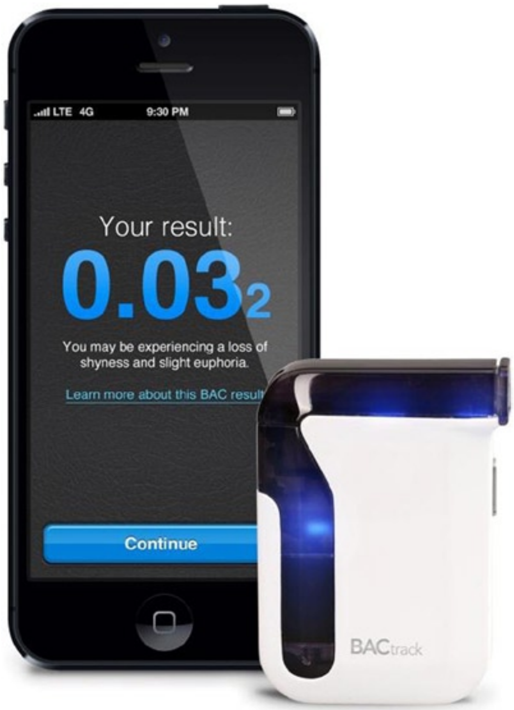

Figure 10-11. *BACtrack Fuel Cell personal breathalyzer (image used with permission from BACtrack)*

The Future of Sensor-Based Wellness, Fitness, and Lifestyle Applications

We are now entering an age where wellness is being embraced as a means to proactively manage health and well-being. As we have seen in this chapter, sensor technologies are playing a pivotal role in enabling us to understand our wellness and the factors influencing it. Sensors can help us identify behaviors such as sedentary lifestyle choices, overeating, poor sleeping patterns, and engaging in unsafe behaviors that will negatively impact on our well-being.

Both discrete and integrated sensors found in mobile devices will continue to be used for wellness-orientated applications. These applications will utilize either active or passive modes, or a combination of both. For active use scenarios, we wear a particular sensor for the duration of a particular activity, such as running or walking. This form of use currently dominates our interactions with fitness and activity sensors. In the future, most interactions with sensors will be passive. We are already seeing this approach starting to emerge with some of the commercial activity sensing products. They are designed to be worn all the time with minimal physical impact on the wearer. This passive approach to sensing will be reflected in opportunistic sensing, which will emerge as we carry our smartphone, wear certain pieces of clothing, or drive to work.

Although the integration of sensing capabilities in smartphones continues to increase, physical limitations in the form factor of smartphones will ensure that discrete sensors will continue to be used for specialized usages. For example, integration into clothing, particularly for sports-related activities, is one such case. We are also likely to see acceleration in the use of smart or eTextiles, where the garment itself acts as the sensor. The evolution of smart clothing will make sensing almost transparent to the user and will move from initial specialist applications for high-performance sport, and so on, to being commonly use in our daily lives.

Pervasive connectivity will be a key enabler. The trend of sensor integration with smartphones is becoming more and more ubiquitous. The vast majority of sensors for fitness and wellness-oriented applications now come with free smartphone apps. These apps provide local aggregation of the sensor data, processing, visualization, and connectivity to web-based portals hosted on the cloud. The future will be very much about a data-driven society. We will increasingly socialize our personal wellness data to achieve a variety of goals: group support to maintain current endeavors, expert analysis and opinion, and affirmation from friends and family. Socializing this data is also likely to have unforeseen consequences in the future. Tracking our levels of food and drink intake on a weekly basis and sharing that data via social media may attract unwanted interest from service providers we might need to engage in the future, such as insurance companies. While many people currently share personal wellness–related data without much thought of privacy concerns, the social norms of the future may change sharing behaviors. The Facebook generation has grown up sharing their personal information with little consideration for the consequences. The sharing of wellness-related data is an unknown quantity for the vast majority of people. Opinions and views are likely to have an age-related perspective in the short term. However, as the wellness domain evolves and matures, people will have to weigh the potential benefits of data sharing against the actual or perceived risks. Technology developments will certainly allow us to enforce better fine-grained control over our data in the future; however, ultimately we will have to make conscious decisions on what we share, with whom, and for what purposes. We are likely to see people's actions and opinions evolve over time as we build our collective social knowledge on best practices relating to personal wellness data sharing.

Sensing will also enable us to actively monitor both the physical and ambient environments in our homes from wherever we may be located at a given time. We already have home security systems and stand-alone smoke and carbon monoxide detectors. The future will bring us smart integrated systems that proactively monitor, manage, enable remote dynamic management, and proactively communicate with us. Our homes will leverage the drive toward the Internet of Things in ways that make meaningful and practical impacts on our lives.

We are also likely to see greater synergies between our personal physiological well-being and the environmental conditions that impact our well-being. Our physical environment will adjust to us, whether it is the temperature in the bedroom to ensure it is optimal for a good night's sleep, whether it is waking us at exactly the right time during our sleep cycle to ensure we wake refreshed, or whether it is turning on the lights automatically at night for trips to the bathroom. The future will be about managing our wellness in a seamless, almost invisible manner, allowing us to remain healthy and active and socializing that fact among friends, family, and peers. Sensors, mobile devices, and ubiquitous connectivity are already playing a vital role in making this future happen.

Summary

This chapter looked at how sensors are being increasingly adopted across a wide range of sporting and physical activities. Many of these sensors utilize the same sensing principles and measure many of the same parameters as healthcare sensors. Adoption of these technologies is increasing as people become more proactive in engaging with physical activities. Users are also increasingly interested in sharing their activity online among peers, friends, and families. We have also seen how sensor technology is being integrated into clothing and how this is advantageous for applications that require a precise location on the body. Sensors that are integrated into or attached to sports equipment, such as bikes or golf clubs, are becoming more widely available. Technologies used in the sports and fitness domains are also being used to support individuals in weight management programs by providing them with constant data on how they are performing. Throughout this chapter we have seen the importance of sensor integration with smartphones to provide processing and visualization of data—and as a platform for remote connectivity to enable sharing of data on the Web. Finally, we looked at how sensors can be used in the home to protect us by identifying hazards or by proactively securing assistance when an accident such as a fall has occurred.

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