TOPICAL REVIEW

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TOPICAL REVIEW

Home geriatric physiological measurements

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Abstract

In an ageing society, the elderly can be monitored with numerous physiological, physical and passive devices. Sensors can be installed in the home for continuous mobility assistance and unobtrusive disease prevention. This review presents several modern sensors, which improve the quality of life and assist the elderly, disabled people and their caregivers. The main concept of geriatric sensors is that they are capable of providing assistance without limiting or disturbing the subject’s daily routine, giving him or her greater comfort, pleasure and well-being. Furthermore, this review includes associated technologies of wearable/implantable monitoring systems and the ‘smart-house’ project. This review concludes by discussing future challenges of the future aged society.

Keywords: elderly, monitoring, unawareness, wearable devices, home care

(Some figures may appear in colour only in the online journal)

1. Introduction

It is necessary to take steps to improve the quality of life of elderly people in an ageing society. Many elderly people want to remain active and independent for as long as possible. Seniors want to age in their own homes and avoid moving to institutions or nursing homes. The physiological condition of elderly and disabled people can be monitored with numerous intelligent devices. Sensors can be installed in the home for continuous mobility assistance and unobtrusive disease prevention. Modern sensor-equipped homes, or smart homes, not only assist people with reduced physical function but also help resolve the social isolation that such people face. Sensors are capable of providing assistance without limiting or disturbing the resident’s daily routine, providing greater comfort, pleasure and improved overall well-being. It is necessary to monitor physiological parameters such as blood pressure (BP) and body weight to maintain a healthy condition. Automated physiological- and behaviour-monitoring
systems capable of functioning without disturbing the individual’s activities of daily living have been developed by several researchers. Such systems have been expanded based on a concept of providing sequential clinical examinations. Health condition and daily activities can be monitored in the home in two different ways. One candidate approach involves monitoring physiological parameters, such as BP, electrocardiogram (ECG) and body weight. The other approach entails the use of physical sensors that can detect water or electricity usage. This review presents various physiological and behaviour sensors in smart homes, as well as the associated technologies of wearable/implantable monitoring systems.

Although the evidence has not demonstrated a strong correlation between such sensors and health performance, several research trials have been conducted. In this review, we present recent developments in geriatric sensors, including behavioural-monitoring and integrated sensors.

2. Physiological monitoring

A non-intrusive physiological-monitoring system capable of operating without disturbing the activities of daily living was reviewed. Monitoring must not disturb daily activities. This section discusses the monitoring of activities of daily living, such as sleeping, bathing and excretion (Tamura et al 1998, 2007). The monitoring devices are installed in the home, and the subjects automatically obtain their own physiological measurements such as pulse rate and body weight.

2.1. Bedroom

Sleeping conditions are important to improve quality of life in elderly people. Sleep apnoea is a common disorder among elderly individuals. Nocturnal polysomnography (PSG) has been used to achieve precise diagnoses, but a simple portable screening device (a portable monitor, PM) can be used as a home monitor. Several comparative studies have been conducted assessing the value of PM and PSG in evaluating sleep disorders (ATS/AASM/ACCP/ERS Committee 2011, ATS/ACCP/AASM Taskforce Steering Committee 2004, Portable Monitoring Task Force of the American Academy of Sleep Medicine 2007, Flemons et al 2003). Even a seven-channel recording device that includes EEG, EOG, chin EMG, ECG or heart rate, airflow, respiratory effort and oxygen saturation showed insufficient evidence for evaluating obstructive sleep apnoea (Portable Monitoring Task Force of the American Academy of Sleep Medicine 2007). At a minimum, a PM must record airflow, respiratory effort and blood oxygenation.

Sleeping conditions can be monitored in several ways. The main concept is that body movements during sleep, as well as estimated sleep conditions, pulse rate and respiratory rate, must be measured without requiring the attachment of sensors or transducers to the body. The simplest way to achieve these goals is through image processing. A camera is installed on the ceiling and focused on the bed. Differences between pairs of images are recorded, and body and chest movements can be observed. Fibre-grating and optical flow methods are available for application of such methods. However, these methods suffer inevitably from privacy problems.

The fibre-grating system utilizes a fibre-grating vision sensor to obtain three-dimensional information about the person on the bed. A visual sensor installed above the bed monitors respiration and roll-over movements in a non-restrictive manner without the privacy concerns associated with other methods. This system can detect respiration patterns within an average of four consecutive respiration cycles (Aoki et al 2003a, 2003b).
A spatiotemporal local optimization method has been applied to determine the optical flow of image sequences (Nakajima et al 1997, 1996). Optical flow can be used to visualize the apparent velocity field of the motion of the entire body, including chest movement associated with respiration and postural changes. A study was conducted on postural changes under sleeping conditions by measuring pulse and respiration rates using digitized image sequences obtained with a video camera. A transient increase in the pulse rate reflected the magnitude of physical activity. Two candidate parameters were proposed for evaluating respiratory and physical activities based on the experimental results. The average-squared motion velocities reflected the magnitude of physical activity. The representative field-averaged component showed a waveform with periodic fluctuation corresponding to that of respiration obtained with a nasal thermistor. To further evaluate the system, five subjects at a nursing home were tested. The system evaluated 99.4% of subject movements during a total monitoring time of 61 h. The waveform was flat when the subject was out of camera view. This system has the potential not only for evaluating postural changes and respiratory rate but also for monitoring sleeping patterns (Nakajima et al 1997).

Another method involves the use of pressure-sensitive transducers. Body movements during sleep can be measured without attaching sensors and transducers to the body by using a pressure-sensitive sheet (BioMatt; VTT Electronics, Tampere, Finland), which consists of a pressure-sensitive film 50 μm thick that can be installed under the mattress. This film is quite sensitive and detects not only body motion but also respiration and pulse rate. Therefore, it can be used as a sleep monitor to detect insomnia and sleep disorders and as a patient monitor to detect sleep apnoea, heart dysfunction and even coughing and teeth grinding (Nakajima et al 2001, Salmi et al 1986, 1988, Sjoholm et al 1992). A similar device that has been also commercialized is shown in figure 1. Photoplethysmography (PPG) is also a candidate to monitor the pulse rate through a mattress (Wong et al 2010). A contactless PPG
signal was captured from the subject’s back and was sufficient to provide accurate pulse-rate measurements.

Some special ECG recording equipment can be used in the home, allowing the ECG to be recorded automatically during sleep. An ECG can be recorded from a pillow, sheets, or beneath the leg using electroconductive textiles (Ishijima 1993). As a contact between a textile electrode and the skin is not always secure, large artefacts can occur with body movement. In our estimation, 70–80% of ECGs during sleep can be monitored (figure 2).

Capacitive sensing, which is capable of detecting and alternating electrical potential through an inserted thin insulator, is also available (Ueno et al 2007) and has been used to measure electrocardiographic potential from the dorsal surface of the body through commonly available cloth with a subject in the supine position. Despite the gain attenuation in the higher frequency region, this method is useful for ECG health monitoring. This method yields a stable ECG from a subject at rest for at least 7 h, and long-term measurements show no significant adverse effect on signal quality. The input capacitance of the device was assumed to be the dominant factor involved in gain attenuation in the high-frequency region and should be reduced for diagnostic use.


A microwave antenna has been used to measure respiration (Uenoyama et al 2006). A non-contact respiratory-monitoring system comprised of a 1215 MHz microwave radar and
Figure 3. Electrocardiogram (ECG) monitoring in the bathtub. The photo on the left shows the electrode arrangement in the bathtub, and the figure on the right shows typical ECG signals.

An antenna box attached to the ceiling has been tested on healthy and elderly volunteers. Respiratory rates of subjects measured using this system correlated with rates measured using respiration sensors \( (r = 0.97, P < 0.001 \) for healthy volunteers, \( r = 0.98, P < 0.0001 \) for elderly volunteers). This system monitors subtle changes in respiratory rate and respiratory rate increases caused by disorders such as pneumonia.

Body motion during sleep can also be monitored using a thermistor array installed on the surface of the bed at waist or thigh height (Tamura et al. 1999, Lu et al. 1999). Changes in temperature indicate body movement and sleep condition.

2.2. Bathroom

2.2.1. Bathtub. An ECG can be recorded during bathing. If electrodes are installed on the inner wall of the bathtub (figure 3), an ECG can be recorded through the water (Ishijima and Togawa 1989, Tamura et al. 1997). The amplitude of the ECG signal depends on the water conductivity. If conductivity is high, the water makes a short circuit with the body, which serves as the voltage source, and, consequently, the amplitude is reduced. However, if water conductivity is low, the signal amplitude remains at levels similar to those taken on the skin surface. Fortunately, the electrical conductivity of ordinary tap water is of the order of \( 10^{-2} \) S m\(^{-1}\), which is within the acceptable range for measurements using a conventional ECG amplifier. However, such ECG signals cannot be used for diagnostic purposes because of signal attenuation at lower frequencies. Clinically, signals obtained from surface electrodes with standards leads can be acceptable. Furthermore, the increase in ST segment is one of the criteria for a diagnosis but an attenuated signal would not be clearly detected.

A two-year study of long-term monitoring by stress ECG during bathing has been reported (Ishijima and Togawa 1999). The results revealed prominent events and biological
rhythms, periodic by month and monotonic by age. It was suggested that unobtrusive vital-sign monitoring can be used to generate long-term health data, which can be used to predict possible disorders, resulting in appropriate preventive health-care treatment.

PPG during bathing has also been proposed. A PPG signal can be obtained from a waterproof probe attached to the bottom surface of the bathtub inner wall. The PPG signals are filtered with a low-pass filter, and the respiration components are extracted. PPG signals have been measured during bathing in ten healthy male subjects, and respiratory signals were obtained from the PPG signals (Ogawa and Tamura 1999).

Furthermore, pulse transit time (PTT) has been measured simultaneously by PPG and ECG. PTT was measured using the R-wave of the ECG as a time reference. PTT was also measured between the carotid and femoral pulses. The speed at which this arterial pressure wave travels is directly proportional to BP. PTT values and a non-invasive measurement of BP were compared and PTT was found to be inversely proportional to BP (Geddes et al. 1981). Absolute values of PTT cannot be extrapolated as absolute values of BP at a given time point, but PTT can predict changes in BP over short periods. PTT is high correlated when it is utilized as a surrogate semi-quantitative monitor of abrupt BP changes (Naschitz et al. 2004). During bathing, peripheral blood flow is uniquely determined and seems to be a good indicator of BP.

As tub bathing is not a common custom in the western world, Ishijima (2007) attempted to monitor an ECG signal during a shower. A mesh screen of silver wires was enclosed in a handheld shower nozzle, which functioned as a negative electrode for an instrumentation amplifier. The hose to the faucet was made up of electrically non-conductive material. The positive electrode is installed on the part of the floor on which one foot of the subject rests or on a stool on which a subject sits while taking the shower. The other part of the floor or of the stool adjacent to the positive electrode is used for the neutral terminal of the amplifier. The wall is made up of electrically conductive material. Both the faucet and the wall are connected to the ECG acquisition system ground. An ECG taken during the shower while the subject was sitting on a stool was found to be stable. However, the ECG acquired while the subject was standing was contaminated by the electromyogram. However, the QRS complex on the ECG waveform was still legible even with the contamination. In this review, the shower impedance between the nozzle and the body was approximately 1.5 MΩ at 10 Hz with a distance of 8 cm under a water flow rate of 13.5 l min⁻¹. A level metre to detect the surface level of the water was used in an attempt to monitor sudden drowning in the bathtub, but its accuracy was insufficient.

2.2.2 Weight scale. Treatment guidelines for heart failure emphasize daily weight monitoring (Goldberg et al. 2003). Body weight is an important health index, but long-term monitoring is sometimes troublesome. A wireless body weight scale is in the market. Weight, body fat and body mass index are displayed and saved. Significant seasonal changes were observed in our web-based one-year body-weight-monitoring study (Tamura et al. 2010). Long-term body-weight monitoring is easy using a wireless device and may be effective for home health care. Furthermore, a ballistocardiogram (BCG) has been used for constraint-free monitoring of BP and cardiac contraction (Shin et al. 2009). BP has been estimated by cuffless measurement based on ECG and BCG values. BCG can be non-invasively measured using a common electronic weighing scale. ECG was measured using three different methods: on the chest using Ag/AgCl electrodes, on the hands using dry electrodes and on the feet using dry electrodes. A time-interval parameter, which is defined as the time difference between the ECG R-peak and the BCG J-peak, was used as a BP-correlated parameter for evaluating and estimating beat-to-beat BP. A systolic BP (SBP)-estimating equation was established for each
subject using linear regression analysis. In the case of a foot-delivered ECG, an ensemble-average technique synchronized at the BCG J-peak point was applied to extract the ECG signal from the feet. The performance of the proposed method was evaluated using Finapres, a non-invasive BP measurement system, as a reference BP signal, and a scatter plot was used to determine the regression line between the reference values and the estimated BPs. A moving-window averaging technique was applied to remove the high-frequency noise in the R–J intervals and to enhance the accuracy of the SBP estimate. The estimated SBP was reliably similar to the measured SBP, which makes the proposed method suitable for use in a home health-care system to monitor BP on a weighing scale at the same time as weight is measured.

A BCG also measures the reaction of the body to cardiac ejection forces and is an effective, non-invasive means of evaluating cardiovascular function (Inan et al 2009). A simple, robust method has been attempted for acquiring high-quality, repeatable BCG signals from a modified, commercially available weight scale. Measured BCG waveforms for all subjects qualitatively matched values in the existing literature and physiological expectations in terms of timing and IJ amplitude. Additionally, the BCG IJ amplitude correlated with diastolic filling time for a subject with premature atrial contractions. This method could allow patients at home to monitor trends in cardiovascular health.

2.2.3. Toilet. Toilet sensors can be used to monitor both urinary volume and urinary content (Yamakoshi 2000). Body weight and weight of urine and faeces together with BCG as an index of cardiac function have been monitored using specialized weight scales. The system consists of a weight-measuring platform (WMP) with four load sensors and a unit for data processing, display and storage. A platform is placed on the floor adjacent to the toilet bowl. The unit also supports the toilet seat so that total body weight can be determined by load sensors with the subject either in the standing position or sitting on the seat. The prototype WMP had a weight resolution of about 5 gf, so these data could be automatically determined accurately and processed appropriately (figure 4). The possibility of evaluating cardiac function from a BCG was also examined. However, the experimental errors in the measured blood acceleration were large, as the mass of the accelerating blood is small compared with the mass of the body and table. Thus, it was not useful as a diagnostic tool. However, modern signal-processing
techniques have allowed these experimental errors to be greatly reduced, and BCG can be used in a medical context. A record of the body’s recoil caused by cardiac contraction, the ejection of blood into the aorta and ventricular filling forces can be obtained, and BCG monitoring can easily provide clinically useful cardiac indices.

BP measurements have also been attempted using sensors built into a toilet seat (Kim et al 2006). ECG was measured with copper-coated electrodes, and PPG was measured using a specially designed toilet-seat apparatus. Non-intrusively measured PTTs were compared with those measured by the standard method, and the results were correlated. An equation was used to estimate BP from the measured PTT during a training period for each individual. Estimated BPs were compared with measured values in a series of experiments. Estimated BP was similar to the measured value within a tolerable error range for each individual. This method has also been used for long-term monitoring, and the results indicated the value of this method for continuous home BP monitoring.

Furthermore, a fully automated ‘non-restrictive’ BP-monitoring system for home health care has been developed (Tanaka et al 2005, 2006). A BP measurement system based on the volume-oscillometric principle has been built into a toilet seat. A reflectance-type photoplethysmographic sensor was installed in an appropriate position on the toilet seat and was automatically lifted and lowered using a newly designed helicoid-type actuator. SBP and mean BP were obtained using the arterial-volume pulsation signal obtained by the sensor. However, errors due to gravitational force and the peripheral measurement location increase if the measurement site is changed from the upper arm. Simultaneous measurements were conducted using two types of commercially available BP monitors (upper arm and wrist) to evaluate the accuracy of the BP measurements. Simultaneous measurements using an invasive technique via catheterization of the right brachial artery were also conducted. This toilet-embedded system, which requires no cumbersome procedures, such as cuff setting or proper positioning of the measurement site, appears to be a useful means for long-term home health-care monitoring.

Chemical analysis of urine components is also available and provides important diagnostic information for clinicians (Karube and Yokoyama 1993). Urinary glucose and ketene levels can be used as indicators of diabetes, and urinary protein as an indicator of kidney disease. However, the only tool available for such testing is the urine test strip. No fully automated urine test system is available, but there have been some attempts to monitor urine components at home with minimal disturbance. The instrument shown in figure 5 can be installed in a toilet and measures urinary glucose level after a button is pushed (TOTO, Tokyo, Japan). The urine collector protrudes, collects urine automatically from the urine stream and analyses urinary glucose level within 1 min using an enzyme glucose sensor. The sensor must be replaced every 4 months, and the calibration solution must be replenished every three months. This system is useful for monitoring urinary glucose levels in patients with diabetes.

2.3. Living room

Individuals are generally relaxed in the living room, so heart rate is relatively stable. ECG measurements without direct conductive skin contact have been attempted with a subject sitting on a chair wearing normal clothes (Lim et al 2006). Measurements were made using electrodes attached to the back of a chair, with high-input impedance amplifiers mounted on the electrodes and a large ground plane placed on the chair seat. ECGs were obtained by this method with subjects wearing several types of clothing and compared to those obtained by the conventional method using Ag–AgCl electrodes. Motion artefacts caused by normal
3. Behavioural sensors

It is useful to monitor the status of elderly individuals during daily routines in their own homes. In addition to physiological sensors, physical sensors such as pyroelectric and magnetic sensors can be used to evaluate indoor activities. This section discusses the possibility of remote monitoring of daily routine behaviour.

A number of attempts have been made to monitor daily activities without attaching devices to the body. Infrared sensors can be installed in the home and used to detect infrared radiation from the body, so that the presence or absence of a subject can be monitored; this allows an estimation of daily activity in the home, at least for subjects living alone. Other simple sensors such as photo-interrupters, electric touch sensors and magnetic switches can also be used to detect activities of daily living (Celler et al 1995, Yamaguchi et al 1998, Suzuki et al 2001, 2004, Ohta et al 2002, 2006). The use of room lights, air conditioning, water taps and electrical appliances, such as the refrigerator, TV, or microwave oven, can be detected and used as information related to daily living. Habits and health conditions have been correlated with these data to some extent, but further studies are required to provide stronger correlations between sensor output and daily health condition.

For example, one- and two-year studies involving daily behavioural monitoring were performed with elderly women living alone in a rural area of northern Japan. Sensors were installed, including infrared sensors to detect human movement, magnetic switches to detect the opening and closing of doors, watt metres embedded in wall sockets to detect the use of household appliances, a flame detector to detect the use of the stove and a CO₂ sensor to detect the presence of the subject in a room by monitoring expired carbon dioxide. An industrial networking system was introduced into each house to combine data from the various sensors,
and the sensor outputs were recorded on a personal computer located in each house. Data were automatically transferred every day to another site via the internet using CATV. Monitoring was fully automatic and did not require the placement of any sensors on the subjects or any operation by the subjects. Information on several daily behaviour patterns such as the number of doors opened, sleep duration, absences from the house, use of the stove and time spent watching television were clearly identified either from a single sensor output or by combining the outputs from several sensors (Suzuki et al 2001). Additionally, the total counts from all sensor outputs matched the concurrently acquired data for physical activity obtained with a pedometer (Suzuki et al 2004). Further examination of the data allowed an evaluation of some additional daily behaviours such as spiritual practice (in the form of Japanese Buddhism) and tending plants. Such monitoring can contribute to the maintenance of health in elderly people.

A simple network system can be applied to evaluate daily activities (Tsukamoto et al 2008). An installed box was designed as a passive-monitoring system in which data were gathered from a number of physically distributed sensor points within the house, linked using the main electrical wiring as the communications medium and then transmitted automatically using either the RS232 wireless (i.e. ratio frequency) protocol or via a TCP/IP interface across the internet to a monitoring and supervisory centre. Moreover, applying frequency and rank-order statistics to monitor mobility changes in the elderly individuals in their home has also been proposed (Tsukamoto et al 2008).

Smart homes are a good alternative to allow elderly people and those with disabilities to lead independent lives. Numerous intelligent devices embedded within the home environment can provide the resident with both movement assistance and 24 h health monitoring. Modern home-installed systems tend to be not only physically versatile in functionality but also human friendly; that is, they perform their functions without disturbing the user and without causing pain, inconvenience, or restriction of movement and may provide both comfort and pleasure (figures 6 and 7).

The main concern with such systems is evaluation; strong evidence is needed to support the utility of these systems. An algorithm for a health-diagnosis system for elderly people that uses image processing has been developed. This algorithm reconstructs monochrome images from data regarding the time a subject watches TV and calculates the index for diagnosing the subject’s health condition from the entropy of the image (Nambu et al 2005). When this algorithm was applied to data obtained over 7 months, the results showed relatively good
correspondence with the subject’s health condition. It is assumed that this method can be used for diagnosis of not only the subject’s physical but also his or her mental health. As a result of this trial, the algorithm was considered effective. Additionally, this method is economical because the algorithm requires only simple data acquired from simple sensors. In the future, automatic diagnoses will become available using this algorithm. Further development of a practical system of this sort will help reduce total medical expenses.

4. Smart home

A smart home was originally developed by computer researchers to create an automated computer interface with networks (Helal et al. 2005). It appeared to be an ‘intelligent’ home because the computer systems monitored many aspects of daily living. For example, the refrigerator inventoried its contents, suggested menus, recommended healthy alternatives and ordered groceries. Smart-home systems may even clean rooms and water plants. There are many smart-home projects running all over the world, but networking and home automation have been most often attempted.

However, in this review, we focus on the smart home as a monitor of physiological and related parameters and as a means to improve quality of life, or what Rialle et al. (2002), (2001) called ‘health-smart homes’. Demiris and Hensel (2008) critically reviewed the smart-house application. They classified applications into six categories. Physiological monitoring includes collecting and analysing data obtained during daily activities by installing the above-described physiological sensors. Functional monitoring refers to data collection and analysis obtained from behaviour sensors. The monitoring targets are general activities of daily living including motion, gait and energy consumption. Emergencies such as falls are also monitored by emergency-detection sensors. Other functions are safety, security social interaction and cognitive and sensory assistance in the home. The ideas for physiological and functional monitoring were mostly presented in the previous section (Chan et al. 2009, Keogh et al. 2010). However, no strong evidence has been found to support the integration of smart-home technologies into health and social care (Martin et al. 2008).
5. Wearable systems

5.1. Ambient monitoring

Ideally, wearable and implantable health systems could be used both indoors and outdoors to monitor physical activities 24 h per day, 7 days a week. Although the power-consumption requirements of the system preclude continuous monitoring 7 days a week, the devices can be used not only for health-evaluation monitoring but also to affect vital functions. The devices should have the potential to greatly enhance comfort and health as well as increase the efficiency of disease prediction and prevention. The system includes sensors and data storage or a wireless transceiver. An example of a watch-type sensor is shown in figure 8. Data are transmitted to a central processing unit to make diagnoses and allow intervention if necessary. Wearable and implantable systems must be easy to operate, small in size and unobtrusive.

The simplest wearable device is a pedometer. From the standpoint of health management, both the physical and the mental health of individuals are reflected in his or her daily physical activities. The amount of daily physical activity can be estimated from the number of steps taken in a day, measured by a pedometer attached to the belt or waistband. A level of 10 000 steps per day or more is recommended for improving physical fitness.

For more precise measurement of physical activity, an accelerometer has been used for classifying behaviour patterns, such as changes in posture, walking or running, which in turn can be used for estimating metabolic rate. Algorithms for calculating energy consumption differ for different pedometers. Each manufacturer uses a different algorithm, and they are not available for public assessment. However, energy is probably evaluated using total body weight and walking time (Wong et al 1981). This measurement involves attaching a device to the body and requires continuous motivation. An accelerometer equipped with a global positioning sensor has been developed and can be used to monitor the distance and speed of daily activity (Tharion et al 2004).

Furthermore, physiological parameters such as ECG, heart rate and pulse rate can be monitored based on wearable technology. Although the moving artefact must be solved, many studies have appeared in conference proceedings and journals (e.g. Augustyniak 2011), and devices such as heart rate and SpO2 monitors are in the market. However, it is difficult to find
The smart shirt (figure 9) is also a candidate for monitoring physiological parameters. Embedding sensors into clothing is popular given the development of miniature sensors and circuits. Sensorized garments (Marculescu et al. 2003, De Rossi et al. 2003, Axisa et al. 2005, Paradiso et al. 2005, Pasquale Scilingo et al. 2005, Celka et al. 2005, Finlay et al. 2008, Yoo et al. 2009, Lee and Chung 2009) and vests (Pandian et al. 2005, Finlay et al. 2008) are available, and physiological and biomechanical parameters can be monitored. The conductive fibre grid and sensors are fully integrated (knitted) into the garment. The garment is a lightweight, machine-washable form-fitting shirt with embedded sensors. Recent advances in wearable sensor technology are reviewed in Bonato (2003), Rutherford (2010). Most recently, a disposable patch sensor was attempted for home use (Yoo et al. 2010).

5.2. Fall detection and prevention

Falls and fall-induced injuries are major public-health problems among the elderly population. The ‘early’ detection of a fall has consequently raised the interest of researchers. It is also an interesting scientific problem because it is an ill-defined process. Many methods and programs to prevent such injuries already exist, including regular exercise, vitamin D and calcium supplementation, withdrawal of psychotropic medication, environmental hazards assessment and modification, hip protectors and multi-factorial preventive programs for simultaneous assessment and reduction of many of the predisposing and situational risk factors. This section updates and summarizes the medical devices for preventing falls and consequent injuries in the elderly.

5.2.1. Fall detection. Two main fall-detection technologies have been proposed from an engineering perspective; one uses wearable motion sensors, such as accelerometers and gyro sensors, and the other uses image processing with a camera installed in the room. However, these recent developments have not yet come to fruition.

(a) Wearable motion sensor. Automated fall detectors have been developed to support independent living and safety. These detectors are mostly based on body-attached accelerometers. Most of the reported fall-detection applications are prototypes or applications for research purposes. Fall-detection algorithms detect different phases of a fall event: (1)
motion before impact based on high velocity (Lindemann et al 2005, Bourke et al 2008) and fast postural changes or free falls (Noury et al 2008, Bourke et al 2007), and (2) the impact itself based on high acceleration (Bourke et al 2007, Karantonis et al 2006), a rapid change in acceleration and end posture (Bourke and Lyons 2008, Dinh et al 2009) or reduced general activity after the impact (Noury et al 2008). In earlier studies, Kangas et al found that detecting a fall with a waist-worn triaxial accelerometer was sufficient and required quite simple algorithms (Kangas et al 2008, 2009).

(b) Image analysis. Indirect monitoring systems have also been developed with automatically triggered alarms and appropriate responses, even when the person is incapacitated. One such system is the smart inactivity monitor using array-based detectors (Simbad), which is based on a low-cost, array-based infrared sensor. An analysis of user needs provides a detailed functional specification for the system. A field trial of a prototype and user research indicated that Simbad significantly enhances the functionality and effectiveness of existing monitoring systems and community alarm systems (Sixsmith and Johnson 2004).

A digital camera has also been installed in the ceiling to detect falls. The potential use of a vision-based system provides safety and security in homes of the elderly (Lee and Mihailidis 2005, Nyan et al 2006).

The ethical aspects of implementing such technology are also important. In particular, these technologies should be used only where end users or their caregivers understand the technology and can provide informed consent.

Further technical developments, such as miniaturization, smart sensors and improvements with regard to signal processing can be expected.

Evidence-based applications need to be developed and available before this new technology will be implemented on a large scale in the home environment or for routine use in health-care settings.

5.3. Fall prevention

A wearable airbag has been developed that incorporates a fall-detection system using both acceleration and angular velocity signals to trigger airbag inflation (figure 10) (Tamura et al 2009). The fall-detection algorithm was devised using a thresholding technique with an accelerometer and gyro sensor. A quite simple algorithm would be sufficient for fall detection. Since intentional falls with older people are ethically questionable, 16 younger subjects mimicked falls and their acceleration waveforms were monitored. Then, we developed a fall-detection algorithm that could detect signals 300 ms before the fall. This signal was used as a trigger to inflate an airbag to a capacity of 2.4 L.

The system consists of a wearable acceleration and angular velocity monitor and an airbag. Ease of use and low power were considered in the design. The system was built and tested successfully, and results indicated high accuracy for detecting a fall.

Although the proposed system can help to prevent fall-related injuries, further development is needed to miniaturize the inflation system.

Preventing falls and injuries is difficult because they are complex events caused by a combination of intrinsic impairments and disabilities with or without accompanying environmental conditions. The algorithm for fall detection for several environments and the subject’s physical condition were rather troublesome; however, a combination of accelerometers and angular velocity sensors and signal-processing technology can provide more accurate and precise fall detection.
6. Further challenges

Many devices are still in the prototype stage but will soon make the transition from research to viable commercial products. We propose a list of future challenges that must be overcome by researchers. Resolving the following problems will facilitate practical, sustainable and successful home health care among the general public.

The most important points to be addressed are user needs, acceptability and satisfaction. Elderly and disabled people have a clear need for this type of technology. Furthermore, a subject’s immediate surroundings, including his or her families and neighbours, voluntary activities and organizations are also important. Fulfilling the needs of users is a major challenge in research and development.

Second, we must focus on the reliability and efficiency of the sensor system and data-processing software.

Third, we need to address the standardization of information and communication systems. Ease of use and cost are the most important criteria for smart-home applications. The ideal network media are wireless, i.e. radio, IR, ultrasound and microwaves. This choice offers several advantages, including mobility of components, ease of installation and simplicity of reconfiguration. Additionally, the interface must be standardized between institutional use and home health care. For example, the principle of body impedance analysis differs among device manufacturers, so values differ for different devices. This creates confusion among customers, who may then feel that the devices are unreliable, leading patients to discontinue their use. Pedometers, which use either a mechanical pendulum or a multi-axial accelerometer, suffer from similar problems. Manufacturers should briefly mention the limitations and reliability of such devices, although many customers will find this information difficult to understand.

The fourth point involves legal and ethical issues. Although information and communication technology have improved access to health care, it is important that policy makers enact laws to ensure that citizens have a high quality of care and can anticipate the legal conflicts that could arise between recipients and providers of remote care. Furthermore, some home health-care devices have not been approved by health agencies, such as the FDA. For example, a physician must still measure BP during a clinical examination, even if the
subject measures his or her own BP at home. If the home health-care devices were sufficiently reliable, the physician would be able to trust the BP values obtained at home. Both researchers and industrial developers must consider ways to resolve this problem in the near future.

Additional social problems are associated with implementing smart-home health-monitoring systems, such as insurance coverage for home health-care devices, costs, handling and interface design. The development of home health-care devices must also consider psychological and environmental factors that affect the user. It is also important to ensure privacy protection during data transmission. Finally, we must solve the problems of cost effectiveness and cost sharing. Although these systems are effective, it is necessary to determine whether the client will have to share operating costs. Such sophisticated network systems are usually operated with government grants, but support ceases after grant termination. It is necessary to evaluate these systems and seek evidence to reduce medical insurance costs.

7. Conclusions

Recent advanced home health-care devices were reviewed. These devices can be used effectively, not only for the elderly and the middle-aged populations, but also as a means to establish home health care and telecare more generally. Telecare and telemedicine are now commonly used options for monitoring patients with chronic diseases and elderly individuals living alone. The devices are placed in the patient’s homes and data are transmitted to the hospital or a health care provider, who can check a patient’s condition remotely.

In the future, preventative medicine will play an important role in medical diagnosis. We hope that it will be possible to develop more sophisticated, high-quality home health-care devices. The final goal of smart-home monitoring should follow the four Ps: prediction, prevention, personalization and participation.

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