In the spotlight: Bioinstrumentation

Title of the Area: BioInstrumentation

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Introduction

Over the major part of the last century medical instruments based on a variety of principles and technologies were developed for the measurement of physiological variables to aid diagnosis and medical treatment in the hospital as well as in the out-patient clinic. More latterly, however, there has been a growing interest and effort to obtain vital signs during normal daily life to achieve healthcare management at home. In order to realise this goal, it appears necessary to develop automatic means for the acquisition of the required physiological data and to implement this in a non-invasive fashion. It might also be of value to people in their home during daily routines to assist them by monitoring the usage of the home services and facilities in a fully automated manner.

The concept of this human support system, including features aimed at achieving home healthcare, is generally referred to as a "smart home" or "smart house". This has several elements, in particular: i) as far as possible measurements should be made automatically, with only minimal operation required by the subjects; ii) monitoring should be continuous and around the clock; iii) the intended subjects might be elderly, physically or mentally challenged, at risk of illness, but not necessarily having an existing medical condition.

The development of the smart home through modern technological advances has progressed remarkably, and the present “In the spotlight” column focuses on the various topics within this research area and briefly introduces several trials where recent advances have been made.

Progress in the emergence of the smart home

The “smart home” or “smart house” is an intelligent residential environment to subserve inhabitants’ needs and has been considered to be one of the most desirable dwellings of the future [1]. The first clear description of the smart home concept appears to have been presented by M. Weiser in 1991 [2]. The vision was of a place where many computers and electronic devices with wire/wireless communications were installed to support living environments. This work has also been well recognised as possibly the first proposal of “ubiquitous computing” or “pervasive computing”. The author’s concept is neatly encapsulated in the subtitle of the report, as *“Specialized elements of hardware and software, connected by* *wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence.”* This proposal included almost all of the constituent elements of the current smart home trials (and also ubiquitous computing), with the exception of the specific provision of healthcare services. After this key published work, many proposals have been made to create smart homes with modern technologies.

Currently, an important aspect of smart homes under discussion and being developed is the inclusion of healthcare services. Of relevance here is the activity of CENELEC (European Committee for Electro-technical Standardization), which has produced a roadmap for an integrated set of standards for the “smart home[3]”. This roadmap includes several applications of services such as broadband communication, multimedia and entertainment, safety and security, home automation, energy management, and, significantly, telecare and healthcare. With regard to the implementation of smart home designs the recent and on-going advances within information communication technology (ICT) and pervasive computing have yielded new devices with appropriate characteristics [1]: (a) miniature - devices can be blended with or disappear into the environment; (b) communication - devices can communicate with other equipment; (c) autonomy - devices can work autonomously. These characteristics are also ideal for use in smart home healthcare systems, and this review will therefore focus on current technologies of the smart home incorporating healthcare services.

Smart home for healthcare

The concept of healthcare within smart homes often arises from a recognition of the growing importance of the so-called aging society within the community, countries or, indeed, the whole world. A smart home equipped with sensors, actuators, and biomedical instruments may provide a better and more cost-effective living environment for elderly care in a person's own home. This could be achieved in an unrestrained manner, offering better independence, helping to maintain a good health condition as well as preventing social isolation. This system would also have networking means for communication between devices in the home and with a remote center and/or a family living remotely. Chan *et al.* gave a good review of this concept, introducing 13 smart home projects in the USA, the UK and Japan [4]. In addition, it is pertinent that these authors discussed in detail both advantages and disadvantages of the approach. The disadvantages identified by them are as follows: The smart home (i) involves a technology-push type rather than a demand-pull approach, (ii) lacks interchangeability between a healthcare professional person and the system, (iii) has difficulties of acceptance due to social, ethical and legal barriers, (iv) requires considerable time and cost to operate the system, (v) can have privacy problems. It is also pointed out that it is doubtful if the present smart home technologies can truly lead to reduced healthcare costs in the future [5]. Although the above issues are open to debate, further evaluation of these possible disadvantages should be carried out carefully because of the impact on what is a seminal issue with implications for the practical realization of smart homes in the near future.

Bioinstrumentation for the smart home

Biomedical instrumentation constitutes an important, indeed essential element of the smart home [1, 3, 4], as reviewed recently by Ding *et al.* [6]. These authors categorized sensor technologies for the smart home into five types: 1) simple binary sensors (SBSs), 2) video cameras (VCs), 3) radio frequency identification devices (RFID), 4) infrastructure mediated systems (IMSs), and 5) other sensors. Motion detectors, pressure sensors, and contact switches are used as SBSs, indicating the presence of a human or their movement with a single digit ‘1’ or ‘0’. IMSs utilize motion sensors to determine human behavior in the house, these being positioned in such infrastructures as central heating, ventilation, air conditioning and so on. Other sensors used include environmental sensors to detect humidity, temperature, light and barometric pressure, and a microphone or a pneumatic strip installed under the bed linen to detect presence, respiration, cardiac pulse and body movements in the bed.

Skubic *et al.* have reported their efforts to develop smart home-based bioinstrumentation [7]. They investigated the construction of sensor-network systems for monitoring the behavior of elderly people in their own homes situated within the TigerPlace, an aging-in-place community located in Columbia, Missouri, USA [8]. The authors equipped and installed their network systems in 17 apartments and reported the operational monitoring status, which lasted in some cases more than two years [7]. The sensors used in this work were quite standard motion sensors, video sensors, and a bed sensor capable of capturing restlessness in sleep, cardiac pulse and respiration rates. The bed sensor consisted of a hydraulic sensor placed beneath a standard mattress [9].

An appropriate combination of signals obtained from several SBSs is able to give quite effective information about human behavior at home [4, 10, 11]. In general, however, it is difficult to perform a detailed analysis of human behavior due to the lack of standardization or generalization of the analysis methodology, and the use of different sensor positioning in the home, as well as the performance specification of sensors to be used. Recently, Hong *et al.* tried to overcome these problems [12]. They described a general ontology network of human activity using sensors positioned appropriately, giving the ontology-based activity estimation in the kitchen as an example. They also introduced the Dempster–Shafer theory of evidence [13] for addressing uncertainty between human behavior and the sensor outputs, and demonstrated the human activity estimation from the sensor outputs. It is interesting to note that their ontology network approach with the Dempster–Shafer theory has the potential to establish the standardization/generalization of the analyses from outputs of SBSs that are properly placed in the house.

In the sensing systems mentioned above, however, physiological measurement techniques have not been employed successfully to obtain such vital signs as ECG, body temperature and blood pressure. Nevertheless, directly relevant advances in physiological measurement techniques, with apparatus installed in household equipment, have been reported [14-20]. The development of these systems has arisen from the need for healthcare at home and is an independent approach to the smart home-based development. The main focus has been to design systems to monitor physiological variables in a fully automated manner, without the need either to attach any biological sensors to the body or for individuals to carry out any operations, simply using home facilities such as a bed, a bathtub, and a rest room. Similar to the concept of the smart home, the techniques used in the physiological measurement approach do not disturb normal daily activities, and thus the monitoring is done in an unconstrained manner, so-called “non-conscious physiological monitoring”. This means that a subject does not need to be aware of the measurement being made, and the physiological data collected and stored are truly representative of normal daily living. In fact, this concept could also be applicable and useful for patient monitoring in a hospital room [17, 20].

With the non-conscious physiological monitoring system during sleeping the array of sensors incorporated within the bed can collect useful physiological data. This includes the cardiac pulse, respiration and snoring using a flat-type under-pillow sensor with vinyl tubes filled with silicone oil [17-20]. Also derived are a body surface contact-pressure distribution map together with body movements using a bed sheet-type pressure sensor with 2D-distributed multi-pressure elements [20]. For the care of the elderly there is a risk of drowning in the bathtub and a reliable alarm is needed. Therefore the bathtub monitoring system allows the simultaneous detection of the ECG together with respiration signals from electrodes embedded into the wall of the bathtub.

In the toilet monitoring system a highly accurate weighing scale device is installed in the lavatory floor around the toilet bowl. This is able to measure body and excretion weight and urination rate together with the ballistocardiogram (a small body weight change produced by cardiac blood ejection; [14, 15, 21]). Also, a system built into the toilet seat allows the blood pressure to be measured [16, 17, 20]. Just recently, these authors have developed a network system that connects with each facility monitoring system using a LAN (Local Area Network). This network system is also supervised from another site (data server center) v*ia* a public WAN (Wide Area Network) with appropriate security, so as to consolidate individual healthcare information [20].

Summary and future aspects of the smart home

The emergence and recent developments of the smart home have been briefly introduced in this review. Initial developments of smart homes comprised of computer-based housing to support elderly and challenged persons at home during daily living through the automatic monitoring of the usage of home infrastructures. In light of the rapid growth of the aging society, which has created what might be regarded as a longevity crisis, healthcare is also one of the most serious and worldwide issues to address. From this background, the smart home with healthcare management has rapidly been pushed into the spotlight.

Utilizing ICT technologies could also dramatically facilitate this approach, with the prospects of achieving smart home healthcare in an integrated manner [22, 23]. For example, Yuce [24] showed a very promising implementation approach for healthcare monitoring systems using W-BAN (wireless body area network). In addition, the smart home with ICT technologies has strong potential to realize fully a human support system including healthcare both in- and out of the house [18-20, 25], that is, to achieve a ubiquitous bioinstrumentation human support system (u-BHS).

To promote such u-BHS further, the establishment of an appropriate social infrastructure that meets the needs of human life support is urgently needed. Efforts to produce much more human-friendly and universally-accepted u-BHSs, where a number of practical problems still remain, are likely to be resolved through the recent dramatic advances in the integration of microelectronic, micromechanical as well as ICT technologies.

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