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Health "Smart" Home: Information Technology for Patients at Home

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ABSTRACT

This article reviews the emerging concept of health "Smart" homes (HSH) and its potential through the use of telemedical information systems and communication technologies. HSH systems provide health care services for people with special needs who wish to remain independent and living in their own home. The large diversity of needs in a home-based patient population requires complex technology. Meeting these needs technically requires the use of a distributed approach and the combination of many hardware and software techniques. We also describe the wide scope of new information, communication, and data-acquisition technologies used in home health care. We offer an introduction to the HSH concept in terms of technical, economic, and human requirements. Examples of HSH projects are presented, including a short description of our own smart home and telehealthcare information system project.

INTRODUCTION

Due to technological developments and the joint effect of both new social and economic needs and constraints, telemedicine is expanding rapidly through a variety of applications, which range from telepresence, teleconsulting and diagnosis, and telemonitoring to real-time medical imaging, telesurgery, and distance medical education. All these directions of research and development aim at improving patients' health through technology. However, these systems must also balance patients' health needs with technology. Building an efficient system should consider a patient-centered approach, rather than focusing on technology.[1] Indeed, the patients' needs emerge from the difficulties and risks encountered at home in their daily living. Rather than focusing solely on the patient's health concerns, we must consider the patient as a living human being in a social and geographic environment. This patient-centered approach to telemedicine has been widely applied in the remote health care field, thus taking advantage of developments in both telecare and so-called smart homes and the combination of these two.[2] The development of the Health "smart" Home (HSH) concept presented here is supported by several driving forces acting at three levels: an economic trend to contain health costs; a growing wish on the part of patients to stay at home while under medical supervision; and the rapid progress of technology that provides the

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means for home health care service capable of meeting the patient's economic and social needs.

The concept of HSH emerged from a combination of three research areas—medicine, domotics (home-based automatic and remote control devices), and information systems—and represents one of the most promising ways to develop patient-centered telemedicine and telecare services. The smart room concept was developed earlier in the domains of domotics,[3,4] robotics, and artificial intelligence,[5] and was later extended to the fields of telemedicine and telecare. Home health care includes two main categories of services—remote advice and remote medical assistance—implemented using various devices and new information and communication technologies. As stressed by Tang and Venables,[2] "smart homes and telecare are natural companions": the smart aspects of the home make it possible to provide an effective telecare service. Conversely, the proliferation of telecare services consistently leads to the development of smart homes, since the private home is considered to be the most convenient place for patients' follow-up and supervision. Thus, HSH projects have two inseparable but distinct general objectives—a patient-centered (individual care) and a healthcare-centered (public health) objective—precisely defined by Williams et al. as the objectives of their CarerNet project:

Patient-centered objective: To improve and enhance the quality of life of the elderly and the disadvantaged by the utilisation of technology in support of their ability to function independently within their local environment.

Healthcare-centered objective: To increase the efficiency of care services through the use of technology to provide care to clients within their local environment.[6]

This article will clarify the definition of the HSH and describe its emergence within the more general context of telecare. Insight into the economic, social, and technical requirements for building telecare applications and the wide range of technologies involved will be examined, as well as the key factors guiding continuous development of the HSH concept. A few representative examples of HSH projects are briefly described, including a short description of our own HSH project.

THE HEALTH SMART HOME CONCEPT

What is a health smart home?

A Health Smart Home can be briefly defined as a smart home: a home equipped with special electronics to enable the remote control of automated devices specifically designed for remote health care. Such a residence is equipped with automatic devices and various sensors to ensure the safety of the patient at home and the supervision of their health status; is linked to a local intelligence unit (LIU) responsible for sensor data analysis and the detection of critical or suspicious situations; and is connected to a remote control center (RCC). The RCC ensures response in case of emergency and the interface between the patient at home and a set of people involved in the health care process (Fig. 1) such as alarm response operators, doctors, nurses, emergency specialists, social workers, family or voluntary caregivers and helpers, technicians, and system administrators. According to local health policy, the RCC can be of different types, such as a specialized emergency unit in a local hospital, or installations and facilities managed by a private healthcare provider, or even a specific service in a reference university hospital (such as hospital at home services in France). The RCC ensures both technical support for hardware and software maintenance and human support for emergency calls, possibly allowing direct contact between patients and caregivers.[7–9] In addition to the control of emergency cases, the HSH supports a wide range of capabilities for medical and social purposes, as described below. Powerful web-based information and communication software supports the communication channels between the LIU and RCC and between patients and caregivers.

Typical HSH patient profiles include disabled and elderly people living alone; elderly couples, one or both of whom are affected with a degenerative disease (such as Parkinson's or

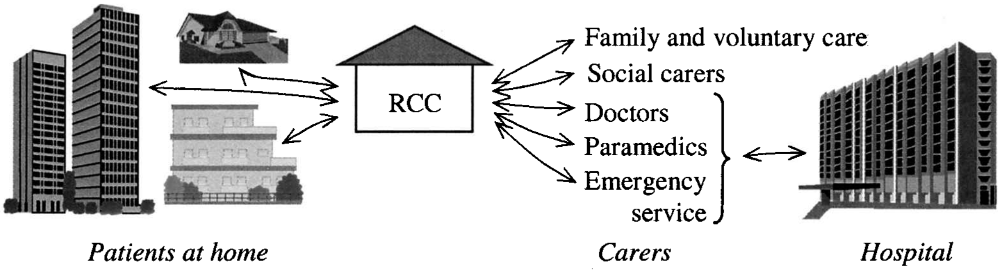

FIG. 1. Overall view of sites and people involved in a smart home for healthcare.

Alzheimer's); people who have been subject to loss of autonomy, exposed to risks of accidents, or needing a precise daily medical follow-up; patients with chronic disease; pregnant women concerned about their health or a possible risk of miscarriage or early delivery; among others. The HSH system is committed to improving the quality of life and the safety of all these patients at risk through the innovative use of advanced technologies such as smart sensors, information technologies, and web-based community services. The home may be a citizen's private home or individual homes or units within a healthcare institution.

A characteristic features of the HSH is the use of an integrated approach, generally adopted in the new generation of telecare systems.[10] In contrast with the fragmented approach currently implemented with individual telecare devices working independently, the extended HSH concept proposes a holistic approach to remote care by making the following assumptions:

Even for a basic installation, there will be a number of devices required at home, some of them smart sensors endowed with local firmware intelligence. (Firmware is programing that is inserted into programmable read-only memory (ROM), thus becoming a permanent part of a computer device.) A typical example of smart sensors is the fall detector.[11] Some devices can be of therapeutic type, such as reminders or glucose sensors for following up the efficacy of insulin treatment.

These devices are connected to a common local area network (LAN)—sometimes a field bus—that can be of wired, wireless, or mixed type. For instance Williams et al. define the HomeLAN as part of their CarerNet architecture[6] (see below). Noury et al.[13] use the CAN bus (wired) mixed with radio frequency portions (wireless) when required (e.g., for body worn or movable sensors). Elger and Furugren[14] and Bonner[15] use the European Installation Bus for its reliability.

The output of the devices constitutes the input of a high-performance health information system (HIS).[16] The HIS provides multihome and multicaregiver management, and is based on advanced software technology for reliability and interoperability (Internet, unified modelling language [UML], Corba, extensible markup language [XML], etc.). The HIS must be endowed with a decision-support layer that includes local, remote, or distributed software intelligence. Such software intelligence generally includes real-time signal analysis for alarm raising, telemonitoring facility, mean or long-term patient data analysis for medical trend surveys, and data-mining and modeling of the patient's evolution to detect changes in functional health status.[17] In order to avoid manual data typing, the system can also be connected to the central patient file management to provide access to the relevant patient data repository. These data are stored in one of the following locations: within a hospital database, in a telecare provider's management system, or in a general practitioner's (GP) medical management system.

Smart homes generally make extensive use of automatic devices such as motion-sensing devices for automatic lighting control, motorized locks (especially for the entrance door), door and window openers, motorized blinds and curtains, among others.[14] These devices might be considered gadgets for any homeowner on a high income who can afford to buy them. However, such devices are of great importance for elderly and disabled people, and any in-home patient.[18] Considering the prevalence of neurological and cognitive disorders in the elderly, it may be useful to add some automatic systems to detect smoke, inflammable gas, misuse of microwave oven, or bath-water temperature that is too high or too low.[19] In private homes, integrating a burglar alarm system into the global architecture may not add very much to the cost and should increase significantly the feeling of residents' security. Smart homes can also be endowed with closed-loop control, such as in the MIDAS project,[19,20] which utilizes a flood-detector unit that turns off the bathroom faucets whenever an excessive level of moisture is detected. Such local control systems should ease and lighten the remote control operated by the RCC, by accelerating resolution of the problem, but should not aim to replace the human presence in the RCC by full automation.

The basic functions of such intelligent environments are generally controlled by computer systems, including graphic user interface. For instance, the SmartBo experimental house for mobility-impaired people, visually, and hearing-impaired people, and people with cognitive disabilities[14] provides the nonvisually impaired with a bird's-eye view of the whole apartment. This allows the users, through a simple click, to enter a room and see the state of any controllable device (windows, faucet, stove, door lock, etc.). However, the achievement of a smart home is inversely proportional to the common visitor's visual impression: there should not be many visible differences from any other home. "A home environment is not to be encumbered by ugly cables and boxes."[14] The Edinvar,[15] University of Grenoble,[21] and SmartBo[14] demonstration apartments reflect this simplicity.

HSH intend to play a key role in the coming creation of a global telemedical information society[22] and may extend to an integrated hospital information system beyond the hospital.[23] Five main types of constraints and conditions govern the use of HSH:

Ethical: their use must take place under strictly controlled medicine and ethics.

Economical: they must be cost-effective from the viewpoint of both patients and society (e.g., the investment in domotics for medical purposes would represent a realistic ratio—less than 10%—of the total home investment.

Technological: the in-home apparatus (sensors, computers, connections, communication) must be perfectly suited to the patient's needs, as unintrusive as possible, and ensure their safety and privacy. Obviously, it must be completely secure, and be regularly and precisely controlled.

Psychosocial: The new technology must be accepted and easily used by all HSH participants.

Public health oriented: information about the medical state of all the HSHs connected to the same network can be collected and analyzed to trigger population alarms in case of emergent disease (seasonal or not, such as influenza, bronchiolitis, or air pollution-related).

HSH APPLICATIONS

To date HSH development can be broadly segregated into two kinds of practice: the social practice of telesurveillance for safety purposes; and the medical practice of remote monitoring for medical supervision purposes.

Social alarm systems

The term "social alarm system" (or safety-alarm system)[8,24] refers to any basic device at home that provides a way to raise alarms automatically sent via a phone call to an RCC that can provide assistance.[25] Doughty et al.[10] suggest the classification of telecare systems into three generations of systems whereas Williams et al. organized them into only two generations.[6] In both classifications, social alarm systems are in the first generation. The most common example of this early generation of systems is the small portable alarm trigger, in the form of a pendant press-button or a watch, which disabled and elderly people operate in case of a fall, sickness, intrusion of strangers, or other emergency.

Although the portable press-button holds a leading market position among the first telecare systems, home sensors and detectors have recently become more prevalent, tend to be smarter, and are more easily commercially available. Recent technological progress has contributed decisively to the development of more efficient social alarm systems and services. Whatever type of alarm device is in use, in case of emergency the response is the same: the remote operator opens a speech link from the RCC to the person at home, tries to verify and evaluate the situation, consults a database gathering useful information about the subscriber (phone number, address, relevant medical features, relatives to contact, etc.), and triggers a medical or social emergency response, if required, by dispatching relevant information to the appropriate agencies. Support services can call for emergency healthcare, ambulance, home nurse, GP, police, fire fighters, and so forth. The RCC uses mainly electronic devices: RCC operators process telephone calls, make speech contact, and consult a subscriber database. They must provide secure and reliable 24 hour communication. The person at home is generally only expected to pay a subscription fee for the service and line charges for any electronic devices.

Social alarm systems have increased in use and success due to their easy installation, operation, and low maintenance requirements. They also have become less expensive as the market expands, and as private telecare service providers (TSP) have become more numerous in Western countries. However, this market expansion is limited to simple alarm handling: systems based on this principle are built upon simple detectors/triggers and a phone communication network. They are not designed to handle more sophisticated applications such as web-based community care or epidemiological survey. Whatever their current and future success, safety-alarm systems are intended to be progressively replaced by more automatic systems[24] such as HSH.

Remote monitoring

The remote (or tele-) monitoring of human physiological data falls into Doughty et al.'s second generation of telecare for the elderly, which includes all intelligent home-monitoring systems.[10] This generation uses sensors and software to monitor data related to the patient, automatically detect critical situations, and then raise an alarm to be sent directly to the RCC. These systems have been developed over several decades and for a wide range of medical purposes[26] such as medical exploration,[11,27,28] emergency handling,[7] elder care,[10,29,30] and chronic-disease monitoring.[17,26,30,31]

Among medical research specialties concerned with this generation of telecare, space medicine has been a proven leader in the domain of remote monitoring and intelligent devices[32] and has been a precursor for HSH achievement. Since 1961, the US National Aeronautics and Space Administration (NASA) has created protocols to predict medical risks, protect health, and provide medical support to space missions. Biosensors have long since been developed to capture and monitor biosignals (Projects Mercury [1961–1963] and Gemini [1965–1966]). Extensive data have been collected over 40 years of missions. Project Apollo (1968–1972) in particular included an in-depth analysis of three distinct monitoring areas: external environment, internal spacecraft environment, and crew biosignals. Highly developed medical facilities, which largely override in-home patients' needs, have been implemented in the form of the In-flight Medical Support System (IMSS). This system was a dedicated rack in the Skylab module (1973) that encompassed raising several alarms, as well as therapeutic and diagnostic capabilities. An unprecedented communications network for data monitoring for medical purpose grew during the Apollo–Soyuz Test Project. More recently the Tracking and Data Relay Satellite System (TDRSS) allows real-time biomedical information transmission from NASA Shuttle crews to mission control. The Operational Bio-instrumentation System allows remote follow-up of the heart rate and rhythm, respiration, and temperature as a test of astronauts during extravehicular activities. Nowadays, the International Space Station (ISS) is intended as a test for space travels whose crews will require advanced interactive and autonomous medical capabilities.

Until now, the remote monitoring of personal and environmental data has been particularly beneficial to space medicine, and since the early 1970s NASA itself has been involved in many ground-based civilian telemedicine applications.[32,33] Although similarities between patients at home and astronauts in spacecrafts may not seem initially obvious, the technologies used in data acquisition, transmission, and analysis for the monitoring of spacecraft habitats and in a patient's home care are similar. Therefore, they can be adapted to meet the specific requirements of the terrestrial context. As in the case of social alarm systems, remote monitoring systems are more and more often included into the general context of smart homes.

DRIVING FORCES FOR HSH

The marriage between smart homes and telecare owes its success to the combination of several driving forces that can be broadly categorized into three areas: medicoeconomy, people's wishes, and a joint venture in advanced technologies created with a group of researchers from the domains of bio- and microsensors on the one hand, and information and communication technologies (ICT) on the other.

The medicoeconomical environment

Tapscott[34] (mentioned by Tang and Venables[2]) stressed that the home has played an increasing role in the healthcare extended enterprise and become a privileged place for personal care and cure. The increasing average life expectancy constitutes the main burden of public health costs. Increasingly, elderly people who have experienced a second serious fall move into a residential or nursing home. A UK Audit Commission reports that "more than half of hospital beds are filled by people over 75 who could be looked after in their own homes."[2]

Several industrialized countries have conducted estimates of cost savings associated with the development of home care systems. In England, significant research from the Royal Commission on Long Term Care reported that the average weekly cost for private residential care was 45% less than for full-time residential care provided by local authorities. The research stressed that a greater proportion of care should be provided at patients' own homes.[2] Several scientific surveys on community nurse activity report that an important percentage of in-home visits by medical staff could be replaced by adequate remote communication with patients (e.g., 15% reported by Wooton et al.,[35] see also ref.[36]). Such an observation has encouraged Tang and Venables[2] to evaluate the cost of a 20-seat telecare service center which could meet many patients' needs through telephone contact alone. They have included in their study the costs associated with the construction of a new building to house the call center, heating, and the hiring of new technical staff. Their evaluation reflects a reduction in spending of £1 million compared with the current need for encounters with patients in their homes.

M. Tsuji et al.[37] conducted a thorough theoretical estimation of the economic effects of telehomecare for the elderly in terms of hospital cost-savings. They based their study on data provided by the *Annual Report of Medical Care for the Aged* published by the Japanese Ministry of Health and Welfare, and the *Population Projection for Japan* provided by the Japanese National Institute of Population and Social Security Research. They have estimated the impact of telehomecare systems on hospitalization costs for the aged from 2000 to 2050. The results feature a reduction of US$ 252 million (0.214% of hospitalization costs of elderly people) by 2010, US$ 2,842 million (1.287%) by 2020, and US$ 25.7 billion by 2050 (7.4%).

Besides theoretical economic studies, examples showing the interest of maintaining at home people with a loss of autonomy abound in the specialized literature and various reports. Significant time and energy could be saved if new communication technologies were properly applied in the context of connections among patients, nurses, doctors, and family or voluntary carers. The benefits most often mentioned are reduced anxiety, reduced hospital admissions, reduced length of stay in hospitals, earlier discharges from hospitals, delayed entry into nursing homes, and reduced need for nursing care at home.[9]

The patient's interests

The patient's desire to stay at home while being medically monitored continuously is the second most important driving force in favor of telecare services at home.[2] HSH contribute to this current trend towards taking into consideration the patient's needs and wishes, in addition to their specific medical needs. Patients are taking a growing interest in treatment options and outcomes relevant to their own health status.[38] HSH are intended to provide access to this information through health status monitoring options, electronic patient records with protected access, and selected medical web sites containing valuable medical information. Currently such aids are available as interactive web pages and videos, computer programs, and printed materials. In the case of sensory-impaired patients, the communication can be established through new information channels such as epidermal pressure, tongue excitation and others.

If they were merely techniques for maintaining people at home to save costs and time, such techniques would probably encounter difficulties in being accepted. Patients could feel isolated, as if they were nothing but an undesirable burden, left without proper medical care but a few smart sensors linked to an artificial-intelligence-based software. On the contrary, HSH may help families relieve the stress and burden of caring for aging parents, thereby restoring or enhancing the relationship between patients and their relatives. The development of appliances well suited to homecare is a move towards community care as an efficient alternative to hospital, nursing, and residential home care for elderly and disabled people.

Advanced technologies

The scientific and technological progress in areas of both sensors and ICT is itself a driving force in the sustained development of HSH. At the present time, homes can potentially be instrumented with sensors for a wide range of biosignals and environmental data acquisition, and network-linked to an appropriate system for automatic alarm raising. The enhancement of sensors, monitoring, and alarm technologies combined with the development and popularization of communication technologies lead naturally to the implementation of an integrated technology in response to the simultaneous growing needs for citizens' telecare. Internet/intranet networks, because they are unprecedented powerful means of multimedia communication, have become a necessary component of communication chains for telecare applications. An increasing number of Internet-based medical systems have been reported.[21,39–42] Although no sound business model for homecare systems has been detailed, the outcomes of scientific and technological progresses tend to be quickly commercially available, thanks to the growing number of start-up companies that have stemmed from institutional research teams.

PILOT PROJECTS AND DEMONSTRATION ROOMS AND APARTMENTS

Driven by these new medicoeconomical, social, and technological forces, a number of pilot smart homes and intelligent telemonitoring systems for medical or rehabilitation purpose have been established. These projects share common features and goals, as well as having unique features. Most of them have entailed the implementation of test-beds or demonstration houses, apartments, or rooms. What follows is a brief and noncritical overview of some of the projects, surveys, and pilot homes published in the scientific literature. The scope and diversity of this research area make difficult any attempt at exhaustiveness; furthermore, demonstration rooms exhibited for commercial purposes only are not described here.

CarerNet[6,43] is a generic systems architecture developed in United Kingdom. The research addresses the system level of the concept of telecare integration. The authors used an adaptation of the controlled requirements expression (CORE) methodology to formalize ideas. That led to the design of a whole system model based on a user-centered approach to requirements for monitoring devices and intelligent software. The CarerNet model involves seven major system components: client; local or home environment; public communication network; formal or statutory care provider; voluntary or informal care provider; emergency services; and service providers. Each component has its specific needs and requirements, which are integrated into the global system model. The intelligent components of the system are intended to provide powerful information-processing capabilities throughout the system, and are distributed among both local and remote nodes according to requirements. The whole model has been designed with the intent of providing a firm foundation for the development of the prototype system described in the next paragraph.

The Modular Intelligence Domiciliary Alarm System (MIDAS) is a prototype second-generation telecare system especially designed for elderly and disabled people.[19,20] The authors introduce this prototype as an implementation of the CarerNet's general model. A prominent feature is its ability to detect quickly deviations from a gold standard of daily living activity, and to "derive an assessment of the client's condition or status at all times."[20] A number of smart, nonintrusive sensors, along with assistive technologies such as speech-based warning or reminders, are connected to a local intelligence unit capable of processing data in real time. Detection of emergencies is performed via a rule-based system that analyzes sequences of events by considering the time spent in specific locations.

The Citizen Health System (CHS)[44] is a generic architecture part of an international project based in Greece aimed at promoting the use of information technology in home health care on a European and transatlantic scale. It has three general objectives: information technology-related objectives, quality of health care, and economic and business objectives. The system, designed to respond to home healthcare needs, is built around two main units: the clinical center unit and the home care unit. The former is devoted to the coordination of home care services. It is intended to be deployed in a hospital or ambulatory care center. The latter is deployed in the patient's home, and includes networked sensors and wireless transmissions. The system is firmly grounded into the component-based or object-oriented approach to software development. For interoperability purposes medical standards such as SCP-ECG and DICOM are used, and the software design is based on advanced Internet-based tools. The wide range of advanced technologies used also includes wireless application protocol [WAP]-enabled wireless devices, such as mobile phones and personal digital assistants, to allow patients to transfer data via the remote center to their electronic patient record. Doctors can obtain updated information on their patients and send them medical advice or educational messages, or request a complete examination if necessary.

In 1995, Rodriguez et al.[45] from Spain reported on a home telecare management system as part of the European Prototype for Integrated Care (EPIC) project, funded by the European Union (EU). The project arose due to concerns about the increase in early hospital discharges and the expectation of a better quality of life for elderly and disabled people at home. Their telecare system was developed in two parts: a subsystem for the patient's home and a central service center. The home telecare service center provides two services: remote monitoring of vital signs, including blood pressure and electrocardiographic (ECG) measurements, over public telephone lines and the management of three types of alarms: active alarms, generated by the patient using their alarm unit or a pendant button (portable alarm unit); automatic alarms, generated by the alarm unit itself; and passive alarms, generated by different emergency detectors installed in the patient's house. The system has been tested in Belfast, Northern Ireland, and the outcomes reflected the high acceptability of the system in terms of efficiency, effectiveness, helpfulness, control, and education.

The VITAL-HOME project (http://www.biomed.ntua.gr/vital_home/), conducted by the Institute of Communication and Computer Systems at the National Technical University of Athens (ICCS-NTUA), concerns biosignal monitoring of patients. It aims to validate and demonstrate the use of both VITAL (Vital Signs Information Representation) and DICOM Supplement 30 standards to codify the medical procedure and the vital signs information exchange. The demonstration is performed by developing a realistic, small-scale implementation of a telemedicine platform for home care monitoring, permitting the acquisition, encoding, transmission, decoding, and visualization of patient biosignals/waveforms and medical data.

The Home Asthma Telemonitoring (HAT)[46] is an Internet-based home asthma telemonitoring system in the United States that provides patients with continuous individualized help in the daily routine of asthma self-care. This system allows early recognition of potentially dangerous situations: health care providers are notified for timely intervention if certain clinical conditions occur. In addition, testing the HAT system showed a reliable reciprocal exchange of all relevant information between a physician and the asthma patient in home settings. Lung function test results collected during home asthma telemonitoring were comparable to those collected under the supervision of trained professionals, and a higher patient compliance with asthma action plans compared to that for patients in standard care was shown. The system has been designed to conform to principles underlying the patient-centered model of health care.[1] It has been achieved by means of a multidisciplinary approach to chronic disease management, and was guided by state-of-the-art knowledge about the educational, behavioral, cognitive, and organizational components of asthma self-care process.

In Japan, Ogawa et al.[28,47] developed a fully automated, noninvasive biosignal data acquisition and monitoring system to demonstrate the feasibility of long-term measurement of physiological functions at home without disturbing the patient's normal routine. The system consists of three instrument points distributed within the home and connected to a computer equipped with simple data collection and analysis software without any mechanism for alarm raising. The instruments are an electrocardiography monitor placed in the bathtub for measuring heart function during bathing, a temperature sensor in the bed for measuring body temperature, and a weight sensor fitted to the toilet and used as a weight scale. The system was successfully tested for 1 week with a healthy subject in laboratory-based facilities.

Celler et al.[17,48,49] have designed a pilot project to test whether the functional health status of the elderly at home can be assessed remotely by continuous analysis of data gathered from a number of physically distributed instrument points within the home. Ten sites have been equipped with remote devices systems and volunteers selected from outpatients from a local aged care community hospital. The functional health status of the elderly participant can be estimated from a total of 18 sensors, selected according to their ability to deliver parameters of daily living sensitive to changes in health status. That includes environmental and behavioral sensors such as infrared sensors to estimate the mobility around the house, ambient condition sensors, and other various sensors to monitor the use of household resources (operation of the stove, opening of the refrigerator, etc.). All of them are interconnected using Echelon LONWORKS technology, and data are automatically transmitted over the telephone system to a monitoring and supervisory center. The participant's health status is assessed from data collected by sensors and using statistical distributions of the probability of events occurring in the home at any particular time of the day. Outcomes are compared with a reference standard defined using established methods of functional health status assessment (computerized handheld questionnaires, daily logs, and weekly interviews). Due to the success of the first experiments, Celler et al. planned to investigate a number of other analysis techniques from statistics, information systems, and artificial intelligence such as hidden Markov models, time sequence analysis, or temporal logic, to develop individualized templates of activity around the home.[49]

Peeters[24] presented a thorough survey of design criteria for automatic safety alarm systems for elderly people as a preliminary step toward the realization of a prototype system. The author emphasized several interrelated features, including flexibility: the system should be adaptable to actual user needs; acceptability: the system should not be imposed, but be sufficiently attractive, secure, and helpful to be demanded by elderly people; ethical concern: the system and its whole sociomedical context of use should be driven by a concern for privacy and confidentiality. Besides these general guidelines, Peeters drew up a thorough inventory of sensors, system functionalities, observable activities to be monitored, and other items, with a special emphasis on the functionality of a measurement device for activities of daily living (ADL meter), based on Celler's works.

Lind et al.[50] reported early experience in Sweden in the development of a home health care application based on emerging Java technologies and applied to the follow-up of diabetic patients. Their application satisfies the Open Services Gateway initiative (OSGi) specification (www.osgi.org). They based their design approach on discussions with professional caregivers and IT organizations in Östergötland County Council in Sweden, and on rigorous security guidelines provided by the Swedish Secure IT within Health Care project (SITHC). They argue that what is needed to support a constantly changing home health care environment is not a large monolithic application with many functions, but a flexible toolkit that can be configured in many ways. To develop this toolkit they chose Java technology because of its wealth of facilities, such as reuse of components from different platforms, Java-enabled telephones, personal digital assistant, home gateways running OSGi, and clients and servers running Linux, Mac, Windows, Solaris, and other operating systems. The authors address issues inherent in component-based and networked systems such as security, synchronization, and network reliability and latency. The system is still under development, although the authors developed a prototype application that uses a combination of blood glucose meters linked to personal computer (PC) applications and a simple WAP-based mobile telephone interface to enter all complementary data (meals, insulin intake, extensive physical work, infections, fever, etc). On request, the system can send the collected data to a health care provider such as a diabetes clinic, which, in turn, provides healthcare support.

Roth et al.[7] reported the Shahal experience conducted by a healthcare company in Israel that provides user-friendly emergency and preventive homecare telemedicine services to over 40,000 patients with cardiac, pulmonary, and hypertensive disorders. It operates an RCC with a staff of physicians and coronary care unit nurses for 24 hour medical telemonitoring, along with a fleet of ambulances (mobile intensive care units), which provide emergency and preventive home care services. The home apparatus includes a cardiac device that enables the transmission of a complete 12-lead ECG for remote, real-time diagnosis of arrhythmia, ischemia, and myocardial infarct; a home care station that enables hands-free two-way voice communication and automatic transmission of data between home and the RCC; (c) devices for automatic measurement and transmission of heart rate and blood pressure values; relevant respiratory data for pulmonary testing and data to authorize remote unlocking of a door for an arriving emergency crew. The Shahal experience is one of the most representative large-scale safety-alarm system carried out in the world.

The SmartBo (meaning "smart living") project[14] is centered on a two-room ground-floor demonstration apartment of 78 m^2, operated by the Swedish Handicap Institute. The flat is located in a five-story building in a Stockholm suburb, and was built for a cooperative housing association for senior citizens. The project focuses on ICT and assistive devices and solutions for mobility-impaired people, visually and hearing-impaired people, and people with cognitive disabilities (dementia, developmental disability, brain injury). It aims to demonstrate that people with mild to severe disabilities can supervise many functions in an ordinary home. To reveal and analyze the problems encountered in daily life, the authors created scenarios in which fictional individuals with different impairments would live a rich and independent life in the apartment. The results were discussed with disabled people and approved. The installations selected to meet the needs of the users fall into two categories: equipment relevant to all users (such as systems enabling the user to control lighting, windows, doors, locks, water outlets, electrical power, and stove), and those specific to each group of patients with a specific diagnosis or even to each disabled individual. They strove to optimize accessibility for people with a wide range of disabilities (e.g., visual and tactile signaling devices, a text-enlargement program, a speech synthesizer and a Braille display for visually impaired, blind, or deaf–blind people). In other words, the SmartBo demonstrator anticipates an ideal smart home inside an ideal community housing, with facilities for relaxation, hobbies, work, and study.

Assisted Interactive Dwelling House[15] is a smart technology demonstrator and evaluation site promoted by the Edinvar (Edinburgh, UK) Housing Association that has been conceived with objectives similar to SmartBo. However, the author expresses a particular concern about ethical issues raised by remote monitoring of people’s daily living at home.

Van Berlo[4] presented another representative smart model house for senior citizen located at Eindhoven (The Netherlands). This house was built according to the specifications of the Dutch Senior Citizens Label, a uniform consumer label made up with 71 requirements (of which 31 are mandatory) developed to serve as a minimum guarantee for the quality of life housing. Before the building started, a panel of elderly people was consulted and expressed their wishes. They mentioned two main priorities to focus on: maximal safety and security (including automatically switching on a burglar alarm when leaving the apartment, automatically depicting on TV someone who rings the bell at the entrance, several automatic lights, several panic buttons that switch on lights and switch off equipment), and maximal comfort with minimal expenses (including optimal processing of temperature, automatic regulation of lighting and heating, remote control of several functions). The project uses a variety of telematics applications within the house, along with many kinds of information technology applications to exchange information between senior citizens and care providers and among care and service providers. This experience suggests a rational approach to the widespread introduction of smart home technology in normal housing.

As a step forward in the real deployment of in-home care, Sueda et al.[51] have designed the Smart House in Tokushima. This house, remodeled from a standard wooden house in order to decrease construction costs, accommodates an elderly couple, a parent with senile dementia, and two students. It is built around several key design concepts: a barrier-free environment, secured lifelines in case of a natural disaster, and preinstalled hollow pipes to hold many signal lines. The studies conducted on this research house aim to develop not only assistive devices but also total life systems for in-house care. The Smart House in Tokushima is also one of the 15 Welfare Techno Houses built across Japan in the context of the project of same name (http://www.rethinkinghouse-building.org/). The concept of this project was launched in 1995 as a collaboration between the Japanese Agency of Industrial Science and Technology, under the auspices of the Ministry of International Trade and Industry (MITI), and the New Energy and Technology Development Organisations (NEDO), with the external help of several private companies that donated equipment. These demonstration and research houses were constructed for the purpose of identifying and promoting the barrier-free design concepts for assistive technologies in housing.

Chan et al.[52,53] have designed and tested a smart room for elderly people at Toulouse and at Grenoble, France. Their related project, PROSAFE (http://www.laas.fr/PROSAFE/), was developed with two objectives: providing a system to detect any abnormal behavior of a monitored patient that can be interpreted as an accident, a fall, or running away for instance; and collecting representative data on patient’s nocturnal and daily activity. The experimental room, made up of a main area and a bathroom, has been designed to accommodate patients with Alzheimer’s disease. It is equipped with a set of infrared motion sensors connected to either a wireless or a wired network. The system’s global architecture is compatible with devices for emergency calls used by the medical staff. The system is designed for monitoring patients in real time, including automatic recognition of their activity and release of alarms if an exceptional situation is detected. It also allows postprocessing of data to provide complementary information on the patient’s behavior, such as agitation during sleeping hours, or the distribution of specific activities over a day (getting up, going out, toilet usage, and leisure time). The detection of alarming situations is based on a finite automaton that represents displacements of the patient and the medical staff within the room. The states of this automaton correspond to the set of areas covered by the sensors. The first experiments conducted with patients have provided some representative measurements of hospitalized patients' activity, especially regarding nocturnal wandering.

The main objective of the TIISSAD project[54] is the definition of a generic, modular, and open architecture for intelligent remote monitoring systems of at-home patients, adaptable for those with different medical conditions. The project stems from different experiences developed for some years in France by various partners involved in the follow-up of elderly people, heart disease, and kidney disease patients. It encompasses the definition of a global architecture, the definition of standard components to construct interoperable systems, the specification of a home care station, the analysis and comparison of modeling techniques for intelligent assistants, data models and automatic human–machine interface design. UML use cases structures are used for capturing the user needs and various UML graphics depict the functionalities needed. XML is recommended for data and action representation, and is considered useful for data reuse and interoperability of subsystems.

Noury, Rialle, and colleagues[11,13,21,55] from the TIMC-IMAG laboratory in Grenoble, France, are currently studying possible responses to the increasing and often pressing need to maintain at home people due to loss of autonomy or exposure to risks of health problems or injury. To this end, a test-bed for HSH has been designed and evaluated at the University Hospital Centre of Grenoble. The project features networked sensors in a fully equipped apartment measuring about 50 m^2 composed of living room, bedroom, kitchen with dining area, toilets, shower, and a corridor equipped with all furniture needed in everyday life. The home telecare system is supported by an advanced information and communication system based on object-oriented modeling and Internet-related technologies including UML modeling, Java programming, and XML data representation and transmission. The sensors installed in the flat include passive infrared movement detectors and magnetic door contacts used to locate the patients and assess their activity of daily living (ADL), microphones for the detection of abnormal sounds and the recognition of help calls,[56,57] various other environmental sensors (such as inside temperature sensor), a multifunctional body-worn sensor especially designed for fall or emergency detection, and assessment of ADL,[11] and various physiological sensors (such as oxymeter, tensiometer, bathroom scale). All these sensors are connected, wirelessly and through a CAN bus, to a software agent hosted on a PC at the patient's home to perform signal analysis and detection of critical situations. This module communicates, either via modem or cable network, with an RCC responsible for collecting and interpreting alerts, and transferring appropriate messages to the personnel concerned. The central objective of the project is to provide medical, social, and voluntary caregivers with a user-friendly and powerful information and communication tool to make the patient-centered and cooperative work of caring for people at home easier. It also maintains respect for the patient's privacy and ensures the confidentiality of medical information. To this end, the system offers a series of functions such as user profiles and access rights management, electronic entry of doctor's notes and prescription orders after patient visits, medical records management, and recording events that occurred. Thanks to n-tier software architecture, the system is accessible from anywhere for people issued with their own personal username/password pair. The system is being developed in the form of a signed Java applet invoked from any web browser, or a stand-alone Java application. Rialle et al.[58] had previously presented a study on detecting falls and sickness of hospitalized elderly people living in a smart room, and the first steps of an experiment. The system implemented four main functions: perception of patient and environment through sensors, reasoning from perceived events and patient clinical findings, action by alarm triggering and message sending to medical staff, and adaptation to various patient profiles, sensors layouts, home fixtures, and architecture. In the early 1990s, Noury et al.,[31] developed a complete home telecare system with a Videotex server accessible through a specially designed embedded handheld computer, called the Biomaster, which automatically accessed the medical database through the Minitel. The idea was to build up a medical database of the patient from the accumulation of various data gathered at home, either physiological or medical reports.

The TIMC-IMAG laboratory is involved in identification of crucial findings for main functions necessary to autonomy, choice of suited sensors, integration of the findings into composite criteria (data fusion, classification, and scoring), study of functional activity measures and statistical distributions and comparison to canonical patient profiles, determination of alarm thresholds and identification of outlier data assigning abnormal behaviors when compared to statistical models of normality, automatic assignment of subjects into one of the precomputed classes (obtained by automatic classification methods), realization of metrological environments (for measurement) acceptable by the elderly (such as intelligent room, bed, vest, rolling chair, etc., for continuous monitoring), realization of communication channels implementing efficient and noninvasive telemetry, display of aggregated data at the patient's home (numerical TV), at the doctor's home (using a specialized 'Smart Card'), and at the hospital or care center, selection of sensitive channels able to give to sensory-impaired people an information feedback (including tactile or lingual sensors and activators), and study of the acceptability and the efficiency of the medical surveillance system.

CONCLUSION

Remote health care for patients has been a great source of interest to many researchers for several years. Medicoeconomic, social, and technical driving forces have encouraged them to conduct studies in this area: politicians and health professionals from several countries are looking for new ways to contain health costs, patients wish to remain living independently at their own home while under medical supervision, and progress in information and communication technologies has led to an attempt to expand their scope of application.

The complex issue of monitoring patients at home encompasses several areas of research, which represent different viewpoints and deal with matters beyond their shared interest in improving the patient's daily living: new information and communication technologies are investigated to define the best architecture and devices to connect efficiently all participants in the care process; medical help, for instance, to determine which physiological and environmental parameters are relevant to assess the health status of patients, detect any suspicious situation, and provide them with the best medical care; domotics, which are automatic and remotely controlled devices that could be installed in the home to ensure an easy and secure way of living for patients; sensor technologies are reviewed to determine the most appropriate sensors for obtaining parameters representative of the patient's situation at home; data fusion, signal processing, and pattern recognition techniques are used to analyze the data from sensors and extract relevant information about the situation of the patient at home; and sociology and ethics explore how to monitor patients while remaining unobtrusive, and protecting their privacy and the confidentiality of their medical data. However, despite their different backgrounds and views, all the research results agreed to focus the development of health care services through telemedicine on patient's needs. Politicians, companies, and investors, for their part, have pointed out the need for systems that can be implemented at low costs.

At the moment, attempts to design remote care systems for patients are various and scattered. Nevertheless, we can differentiate projects mainly focused on improving the daily life of patients using various automatic devices, specific equipments, and basic alarms, from projects more concerned with the global assessment of patients' health status and the development of a global information system to extend patient care beyond the hospital. Obviously, these two types of projects are highly correlated and investigate complementary aspects of the same, larger, issue. The notion of the Health Smart Home is intended to incorporate all these different views into an overall concept of remote health care.

All recent projects concerning the remote care of patients aim eventually at improving the care and comfort of patients. Beyond this joint primary objective, each of them brings its own concepts and principles. There is still no real trend towards a consensus in standardized concepts, definitions, or techniques. In the near future, because of the real need for remote care systems, projects in this research area may have to be developed around specific requirements and key concepts unanimously adopted by representatives of every community involved in the remote care process.

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