Wearable Technology

Health Monitoring in the Home of the Future

Infrastructure and Usage Models for Wearable Sensors That Measure Health Data in the Daily Environments of the Users

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Advancements in sensor technology, wireless communications, and information technology in general give opportunities to new models for providing healthcare and wellness or disease management tools, which enable extended independent living at home and improvement of quality of life for individuals. Today, sensors with a minimal form factor may be made to measure a wide variety of physical parameters. The power consumption of the sensors is coming down, and their production cost is getting cheaper. These trends make it possible to embed sensors in different places or objects at home (e.g., in furniture, electrical appliances, constructions, etc.) or to make them wearable by integrating them into clothing or small apparel items like watches, jewelry, or the like.

Health monitoring in out-of-hospital conditions has been of interest to researchers and healthcare practitioners for a long time. Recording of physiological and psychological variables in real-life conditions could be especially useful in management of chronic disorders or health problems; e.g., for high blood pressure, diabetes, anorexia nervosa, chronic pain, or severe obesity. Furthermore, real-life long-term monitoring of health could be useful for measurement of treatment effects at home, in situations where the subjects live their daily life.

Most of the research for health monitoring in out-of-hospital conditions has concentrated on health monitoring at home. Most studies do not provide data about the usefulness of the approach but report initiatives taken to build systems for home monitoring. For example, Ogawa and coworkers developed a fully automated system for monitoring physiological data in the home [1], [2], and Celler et al. developed a remote monitoring system of health status of elderly at home [3]. In these approaches the measurements are mostly based on embedded sensors in the home furnishings and structures. However, together with the advances in electronics and communication technology, approaches based on wearable sensors have been introduced. Wearable health sensors have been developed and embedded within a form factor of, for example, a ring [4] or a wristwatch [5]. By combining these wearable sensors with measurement devices embedded in home surroundings, advanced multiparametric health monitoring may be achieved [6]-[9].

With these developments, we are able *to measure* many variables from individuals in their own environment, during daily activities, and potentially to observe deviations in health status from the norm in early phases or to automatically alert paramedics in emergency cases such as falls in elderly. However, to achieve this, much more than just sensors and measures are needed—a complete health monitoring system is required. In this article we focus on analysis of what other enabling technology is required for this vision to be realized, what are the requirements for the technology, and what kind of applications would be potentially beneficial to the users. We approach the subject from different perspectives: from a user's perspective, from a data communication perspective, from a software perspective, and, finally, from a system integration perspective.

Models of Use

The use of wearable sensors to measure health or wellness status of an individual is most attractive in out-of-hospital conditions; i.e., when individuals are in their own environment. Yet, one can distinguish two main models of use.

Wellness and Disease Management

In *wellness* or *disease management* the individual is actively participating in the management process. For example, a diabetic subject may be monitoring her blood glucose values, store these results in a database, and receive feedback; e.g., on the success of a diet to improve the blood glucose balance [10]. Or, a person may have a target of losing weight and hence monitors his/her weight on a regular basis and receives feedback on weight trend to allow early detection of success or problems in the weight management program [7], [9].

In this model it is the individual who is actively willing to receive feedback regarding his/her wellness or disease status and to participate in his/her own care. The role of a caregiver in this model is often even secondary to that of the individual. In the management of chronic diseases such as diabetes, hypertension, or asthma, it is the degree of involvement of the individual in the care process that is critical to the success of the treatment. The role of the physician is to support and advise the individual in his/her daily activities affecting the management of the disease. In the case of wellness management (e.g., fitness management by heart-rate-controlled jogging, weight management) there may or may not exist a "personal trainer" who is involved in

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the management process in a similar way: to support and advise and to give feedback—in short, to motivate.

The active involvement of the individual in the process of wellness or disease management has also some consequences for the role and acceptance of the technology. Most importantly, it is the individual in this model who is the primary "consumer" of the measurement data, and hence the feedback should be given to the user, in an understandable form, when and how the user wants it. This feedback is the main element to maintain user motivation to continue to use some technical devices such as wearable measurement devices (e.g., heart-rate monitors [11]), which unavoidably cause some (though sometimes minimal) inconvenience to the subject while used. On the other hand, while subjects in this model may be very motivated and often technically skilled, they may be ready to face even quite challenging technical setups. For example, using an exercise diary and follow-up program, the user needs to transfer the data from a heart-rate monitor wrist unit to the computer and run and use a special program, [11]—not something you may assume less computer-savvy people do eagerly when undergoing treatment for, for example, congestive heart failure.

Another central feature in the wellness and disease management approach is related to the value of a single measurement. The management process is a continuous and long-term process in which the most important role of monitoring is to provide follow-up data to observe long-term trends in the wellness or health status. Hence, the value of a single, isolated measurement is low and the added value comes from combining single data elements into trends. This notion has several consequences. First, the measurement data does (usually) not need to be transferred in real time to the permanent data storage and analyzed further, but the data may be buffered (e.g., in the sensor itself or in some intermediate storage) and transferred when convenient (e.g., when network connection is established). Second, the value of one single measurement alone is not very critical (in contrast to, for example, monitoring of vital signs in the hospital, or cases where alarms should be generated), and some number of bad or missing data may be tolerated without sacrificing the overall value of the monitoring significantly.

Especially in wellness management, the devices and data are usually purchased and owned by the individual, and minimal linking of data to an electronic patient record is required. On the other hand, in the case of disease management, the role of the healthcare system is increasing and needs to be taken into account. In the latter case, the data may be owned by the individual who gives the healthcare system access to the data, or the opposite may be true—in this case secure sharing the data with trusted parties is essential.

Independent Living and Remote Monitoring

The other main use model is the concept of remote monitoring, which is often related to another concept: independent living. In this model the main (and often only) consumer for the measurement data is the caregiver, and the individual is not interested in or capable of interpreting the measurements. For example, the health and wellness status of an elderly subject living alone might be remotely monitored to detect possible deterioration in the subject's health status, or to detect sudden problems such as falls or sudden health hazards [12]. The sensors for this purpose might be either embedded in the subject's home environment [12], [13] or they might be wearable [14]—yet the subject does not receive the feedback on the data, but it is the caregiver who receives both the long-term trend data and possible automatic alarms in the case of a sudden need of help. Another example is telemonitoring for ECG [15], in which the patient carries a portable ECG monitor. In this case, if the patient feels

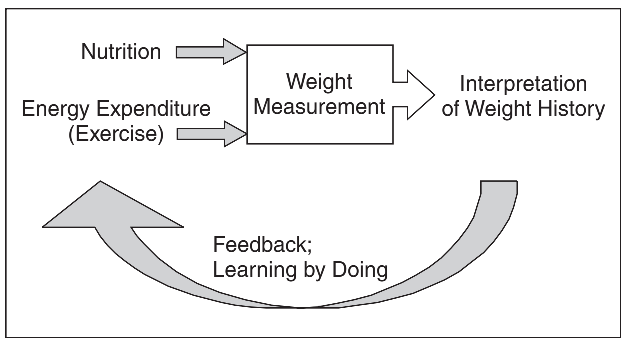

Fig. 1. The basic tenet of a *behavioral feedback model* is that, in trying to obtain a certain goal, a person will adapt her behavior in a structural manner on the basis of learning from earlier experiences. The picture shows the model applied in the case of weight control. The weight changes result from the balance between nutritional input and energy expenditure, which are both practically impossible to monitor with a necessary accuracy over long periods. However, the end result, the weight, is easily measured even daily over longer periods. The system provides feedback to the user relating to her past and present weight, and by following up the changes in her weight the user is able to make a mental model of the effects of her lifestyle (including nutrition and physical activity) on her weight. The monitoring keeps her aware of even slow changes in her weight, and the mental model allows her to manage her weight successfully.

heart-related symptoms, by using the device, he/she may send the ECG to the care center for review and judgement of whether immediate help is needed or not.

In this model the role of an individual is rather a role of a patient and is much less active than in the wellness and disease management process described above. This has many implications for the system design. First, the ease and automation of use of the technical devices, such as measurement devices, is strongly emphasized, as the subjects using them may have limited technical skills, compromised capabilities to attach wearable sensors on a daily basis, and/or reluctance to accept any new technical devices in their home or to be worn on their body. Second, since independent living may be strongly dependent on the monitoring system, the subject may be highly motivated to accept the possible inconvenience due to the usage of the system. Third, as the system is often used to generate alarms in case of health hazards, the reliability of the system functions, including measurement, data transfer, and interpretation, is essential, and any problems in this area may dramatically reduce the acceptance of the system. Fourth, as the individual is primarily interested in continuing life as normally as possible, the unobtrusiveness of the system becomes important. Means to provide feedback to the user (both in terms of data processing and presentation utilities) can be very simple, however, or in some cases even nonexistent.

In this use model the data and necessary devices are typically owned by the service provider or caregiver that is responsible for the care of the subject. Furthermore, to provide appropriate service, the system needs to support the actual service provision; e.g., home health care.

User Requirements for Wearable Sensors

When more and more sensors and measurement devices are integrated in the daily living environment of the ordinary users, certain implementation issues become essential:

- *Reliability, robustness, and durability*. The environments in which the sensors need to operate vary, and the users are nonspecialists not necessarily aware of the technical limits of usage (despite the fact that they may be described in the user's manual). Hence, the sensors should provide reliable results under a wide range of operational environments, they should be robust against external disturbances (physical, electrical, electro-magnetical, etc.), and they should not get easily broken even if the instructions for usage are violated.
- *Look/unobtrusiveness*. The sensors are integrated into the everyday life of the users. Hence, they should either fit by their look to the individual's preferences, or they should "disappear"; i.e., be as unobtrusive as possible. Which option is more preferable depends on the application: while in the wellness management application a trendy wrist-worn heart-rate monitor may be appreciated as a kind of a status symbol, but in the case of independent living a wrist-worn alarm device that looks too much like a technical aid may be regarded as a stigmatizing element for an elderly person.
- *User identification*. While especially wearable devices are often personal and hence their results may be associated with a specific user, this is not true in all cases. For example, a single heart-rate monitor might be used by many persons. This requires some method for identification of the user in order to associate the measurement data with a right person.
- *Communication*. The sensors and measurement devices should be capable of transferring their measurement results to some central data storage preferably fully automatically, or at least so easily that it does not pose a burden to the user. The appropriate level of ease depends on the application, but the simple added value principle should be followed; i.e., the value experienced by the user should exceed the effort needed to use the system.
- *Zero maintenance and fault recovery*. As more and more sensors and devices are embedded in our environment, ease of maintenance becomes essential. An important issue in the case of health monitoring is self-calibration; i.e., finding ways to guarantee that the sensor performance does not deteriorate over time. An issue is the battery life of the sensors and measurement devices—a user should not need to worry about constantly changing or recharging batteries for the multitude of sensors and devices at home. Finally, if something in the system goes wrong, there should be automated methods for assuring a proper fault recovery of the system without complex re-installations and other procedures.

Wearable or Environmental Sensors

The sensors measuring the wellbeing of a human may be either wearable or integrated to the environment. Wearable sensors may be attached to clothes [16], jewelry (e.g., rings [4]), wristwatches [17], etc., or they may be separately wearable (e.g., Polar Electro's heart-rate monitor requires wearing a chest belt). Environmental sensors may be embedded in the house [1], [2], [12], [13], furniture [18], car, etc., but they still measure the human being. Commonly used separate measurement devices such as personal scales, blood pressure meters, etc., fall in between these categories as these devices are often portable and hence not integrated into the environment, but they are not wearable either.

Although wearable sensors have recently been attracting more interest than the environmental sensors, both approaches have advantages and disadvantages. For wearable sensors, the main advantages are 1) possibility to measure many physiological parameters not otherwise accessible, 2) inherent support for mobility, and 3) support for continuous measurement. The disadvantages include 1) limitations in form factor, power consumption, processing power, and communications; 2) potential obtrusiveness; and 3) high demands for durability of materials etc. For environmental sensors the main advantages are related to less severe limitations with respect to power consumption, form factor, processing power, and communications means, while the disadvantages include 1) need for user identification, 2) limited possibilities for continuous monitoring, and 3) limited access to physiological parameters.

Despite the pros and cons, the list above suggests increasing employment of wearable sensors in health and wellness monitoring. The optimal solutions for multiparametric health monitoring lie in combination of embedded and wearable sensors. In a practical solution some parameters are monitored continuously with wearable sensors (e.g., user activity, heart rate) while environmental sensors are used to record other parameters (body weight, body temperature, even ECG [1], [2]).

Automatic processing of the sensor data becomes essential when health monitoring is applied in long-term conditions; i.e., over months or years.

The decision on which sensors to use depends on the application and its needs.

Home Infrastructure for Wearable Sensors

Wearable (or environmental, ambient) sensors provide the basis of the health or wellness monitoring system. They provide the interface between the real world (human beings and their physiology) and the digital world (computers interpreting the data and providing feedback to the users or information to the caregivers). However, there are also other enabling technologies required in a real implementation of a health monitoring system. In short, we need technology to 1) transfer the measurement results from a sensor to a central storage, 2) to (semi)automatically process and interpret the measurement data in order to generate possible alarms and/or generate easy to interpret presentations, and 3) to (automatically) provide results and/or feedback to the user and/or caregiver in a preferred form and in a preferred time and location. In the following we aim to summarize this technology. We will especially concentrate on the first point, as it involves various challenging technical issues to be solved.

A simplified schematic illustration of the system is provided in Figure 2.

Sensors

The main task of the sensors is to provide an interface between the physical and the digital worlds. In the case of health monitoring these parameters are either directly or indirectly related to the wellbeing of the user. Whether wearable or environmental, there are many technical requirements for the sensors, both due to user requirements as well as to other practical considerations, as listed above.

Communications and Networking

An inherent property for wearable sensors is their mobility. Hence, optimally, they should be able to communicate their measurement data wirelessly. While the wireless network coverage is usually not always available, the communication should support of an ad hoc nature; i.e., the data transfer from wearable sensors should occur automatically whenever the sensor arrives into the wireless network coverage. This implies that the sensor should be able to buffer the measurement data until it is successfully transferred further. Given the low-power demand, this problem requires specific designs.

The most simple and currently most often applied method is based on manual download; i.e., the user needs to download the data from the wearable sensors to a computer. The download mechanism may be either based on wired communications (e.g., serial cable) or short-range wireless mechanisms (e.g., inductive or sonic link used by Polar Electro heart-rate meters [11]). This design suits to fitness management or other such uses where there is no need for online monitoring and where the user is both highly motivated and competent in using the necessary technology.

The simplest wireless connection design is based on unidirectional radio frequency transmission of data. In this design a wearable sensor sends the measurement data immediately after the measurement and the receiving end receives the data whenever the sensor is within the network coverage and there are no transmission errors. The advantages of this design lie in its simplicity (e.g., only unidirectional radio interface, minimal memory, and minimal intelligence are required for the sensor) and minimal delay in transmission. It is well suited in applications where the network coverage may be assumed to be present for most of the time (e.g., in home monitoring [14]) and where some missing data due to transmission failures may be tolerated.

The most advanced design for sensor communication is based on wireless bidirectional radio frequency communication with ad hoc characteristics. In this design, the sensor connects to the network (in simplest case just a base station) in an ad hoc manner, and the data transfer is acknowledged by the receiving end to make the process fault tolerant. The communication may be initiated by either by the sensor (i.e., the sensor tries to send the data as soon as it has it) or by the server

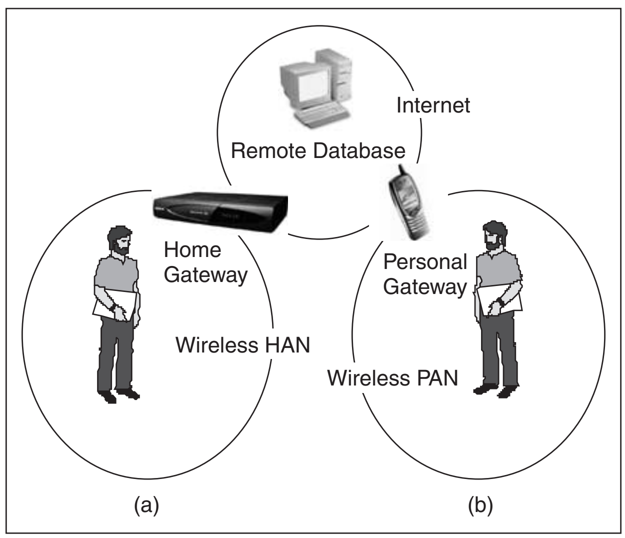

Fig. 2. Two different models for transferring data from wearable sensors to a central data storage. In the first model (a), there is a home network, to which the sensors connect and which is used in communication. In the other model (b), a mobile device (e.g., a mobile phone) acts as a personal gateway to which the wearable sensor connects and which then transfers the data further to the central data storage by using a cellular network.

While the main application domain of health monitoring is often the home, the research is closely related to the concepts of smart home and home networking.

(i.e., the server or base station is regularly polling the sensor for new data). The main advantage of the former option is that it supports immediate sending of essential information; i.e., the transmission delay is minimized. The most important advantage of the latter option is the minimization of the power consumption of the wearable device [19].

Different technical solutions to implement the above designs have been introduced, ranging from nonstandard custom solutions [11], [14], [19] to standards such as IEEE 802.11 (also known as WLAN) and Bluetooth. These solutions may be used to implement a personal area network (PAN) or home area network (HAN) (Figure 2). In general there is a tradeoff between these options. While the standard solutions such as Bluetooth provide better support for interfacing with generic platforms, built-in discovery and networking mechanisms, ready solutions for data integrity protection and security and privacy issues, etc., they often suffer from a large complexity overhead for simple sensor solutions (in terms of requirements for power consumption, processing power, discovery time, and price). Hence, the nonstandard solutions will probably continue their dominance in sensor communications until new initiatives, such as IEEE 802.15, potentially provide standardized solutions for low-speed communications such as sensor networking [20].

Middleware and Software Issues

Middleware for health monitoring comprises both hardware and software—its aim is to provide a platform to which the sensors send their data and where the data is processed further, stored, and presented, or from where the data are further transmitted for central storage. As home networking, and more generically, ubiquitous computing environments are emerging, the health monitoring systems would also need, in order to be affordable and cost-efficient, to support generic platforms (i.e., to interoperate or coexist with other platforms) such as home automation platforms [7], [9]. This is especially true with middleware, networking technology, and user interface devices used for the user feedback.

As the potential architectures for providing the middleware vary enormously, we will not try to describe the options here. Rather we briefly introduce two main models for implementation as suggested in Figure 2.

The first option in Figure 2 is based on usage of a PAN and a mobile personal gateway, which serves as a server for wearable sensors, receives data from the sensors, and then stores it or sends it over a wireless global area network (e.g., GSM network) to a central storage. The necessary capabilities of the gateway are a PAN support (e.g., Bluetooth or some custom solution), connectivity to global area networks, and software to support sensor communications, data management, and data storage. This option is currently in a research phase but is becoming a practical option with the introduction of mobile devices (e.g., mobile phones, PDAs) with in-built Bluetooth capabilities, mobile telephony, and open interfaces for third-party software developers. Important developments in this area are IPv6 and mobile IPv6, which allow mobile terminals to have IP addresses and stay continuously online. The network settings need not be reconfigured each time the terminal moves to a new location. Also, security features will be improved, since IPv6 connections always use the IPSec (IP Security) protocol.

The second option is based on the local networking (e.g., home networking) concept. In this concept the near environment is equipped with a server (e.g., a home server) and a local area network, to which the wearable or ambient sensors may connect to using potentially various different mechanisms; e.g., WLAN, Bluetooth, custom wireless solutions [7], [9], [14], [19], X-10, serial cables, infrared, etc. Compared to the PAN-based solution, this concept offers much more degrees of freedom to implement intelligent features, thanks to less severe restrictions for power consumption and available processing power and storage capacity. The technology and software issues for health monitoring and other intelligent applications based on an ad hoc LAN concept is being explored in many initiatives, including Universal Plug&Play [21], Open Service Gateway initiative [22], Jini [23], Salutation [24], etc. In these concepts, wearable health-monitoring sensors may be considered as ad hoc networked (mobile) devices, which provide a service to the network (e.g., access to health data). A health-monitoring application residing in the network (e.g., running on a home or remote server) receives the data dynamically and takes the necessary actions such as storing, processing, alarming, and giving feedback. The framework provides support for dynamic updates of the sensor or other software as well as management of their mobility.

Data Processing and Feedback

Automatic processing of the sensor data becomes essential when health monitoring is applied in long-term conditions; i.e., over months or years. The processing should detect and compensate for or reject errors, extract specific features from the monitored parameters (including, e.g., long-term trends), and provide necessary alarms. As this kind of (ultra-) long-term monitoring system has not been previously available, there are only few references available about specific problems related to processing of such data [6], [25]. In the future, development of automated and robust screening and analysis methods for this kind of data will become an interesting branch of biomedical signal processing.

In addition to data processing, presentation of long-term health data becomes important. Different presentations are required depending on whether the feedback of the data is given to the user [7], [9] or to a healthcare professional [26], and also depending on the user interface device on which the feedback is provided.

A Wireless Wellness Monitor

In the wireless wellness monitor (WWM) project we aimed to develop a prototype for a home supporting ubiquitous computing applications for wellness management and home automation. The main emphasis was on building a home network where multiple simple household and health monitoring devices are connected and implementing realistic applications, which can be used either with or without a specific information appliance.

Our prototype for a ubiquitous computing-enabled home is based on the IP-based home network and an OSGi [22] compliant home server. Different non-IP peripherals join the network via a device proxy, to which they can connect using any proprietary method; e.g., a RS232 or a SoapBox wireless interface [19]. The applications run on a home server (centralized intelligence model) as OSGi bundles. The user interface (UI) appliances are essentially Java-enabled HTML browsers, which allow the user access to different services at home through a home portal. The UI information appliances in the prototype are a PDA (Compaq iPaq 3850 equipped with a WLAN card) or a TV with a wireless mouse. The main difference between these UIs is that while the former is a personal and mobile device, many persons may use the latter, stationary device.

The prototype includes two different types of health sensors. The wearable sensor is a wrist-worn device, which provides a signal quantifying the wearer's physical activity (Figure 3) [14]. It is connected to the home network wirelessly by a proprietary radio frequency protocol. The ambient sensor is a personal scale, which measures the person's weight when the person steps on the scale. The system recognizes the person on the scale through the use of radio-frequency ID tags (RFID tags), which each user is wearing. The scale is connected to the home network via a serial connection. The other home-automation-related appliances included lights, a coffee maker, movement detectors (for a burglary alarm), and a Web camera.

The health applications include automatic weight and activity monitoring. The weight monitoring application includes automatic weighing (the weight was automatically measured and stored to the person's health database whenever she steps on the scale) and automatic feedback (a weight trend curve is provided to the user automatically after each measurement whenever the user opened a UI on the system). The activity monitoring allows detection of the circadian rhythm [5] as well as potential automatic identification of sudden health hazards such as falls in the elderly (Figure 4).

The WWM project suggests that ambient intelligence (or home networking and ubiquitous computing) with wearable and embedded sensors would allow minimization of the user efforts and maximize user compliance with the health monitoring. This is achieved by two approaches. First, the measurements are made as easy and automatic as possible (no need for user logging or other efforts for data measurement

Fig. 3. IST Vivago® WristCare [14] is a wrist-worn online activity monitoring device, which is designed to be used as an automatic personal alarm system for the elderly and chronically ill. The device continually sends information about the user's activity level via radio frequency transmission. It automatically signals for help if, for example, a period of extreme passivity is recognized. The device provides an activity signal, which is constructed from the measured force change at the unit's movement sensor. The sensor is sensitive enough to record muscle movements inside the wrist in addition to the hand movements.

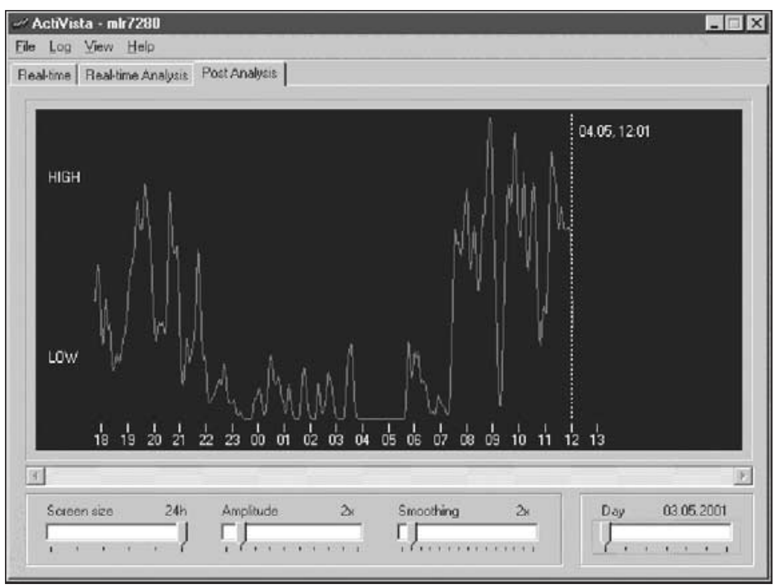

Fig. 4. An excerpt of the activity signal from IST Vivago® WristCare from an elderly subject. The x-axis indicates time (in hours) and the y-axis indicates relative activity. A clear circadian rhythm may be detected. The subject goes to bed around 10 p.m. and sleeps (although somewhat restlessly) until around 3:45 a.m. Then she wakes up and decides to get up to go to the bathroom. However, as she gets up from the bed she falls and loses her consciousness. At 5 a.m. the system alarms for unusual passivity and the help arrives at 5:30 a.m. The alarm delay is necessary to minimize faulty alarms and is kept to a minimum by adapting it to the user's typical daily pattern of activity. The example illustrates how simple long-term wearable monitoring may provide valuable information about slow changes in circadian rhythm or even sudden changes in health status (in this case a fall and following unconsciousness).

Health monitoring seems a very promising application for the smart home. First of all, there is a clear need to provide tools to support independent living.

and storage), minimizing the daily time required for monitoring. Second, clear and intuitive feedback is automatically provided to the user to his/her preferred device, whenever and wherever they want, aiming to keep the user motivated to use the system.

In addition, the WWM project studied how simple health-monitoring devices may be networked at home and how smart health management and home automation applications may actually be implemented in the home networking infrastructure. When considering wellness management, the most important appliances are not computers in a traditional sense. Devices such as scales or blood pressure monitors are specifically designed for one purpose—they provide a natural, physical UI, and provide no or little processing power and memory. Networking and using these devices as automatically as possible poses a special challenge. In our concept we made a few assumptions regarding these appliances for the near future:

- They will continue to have no or little processing power and memory, and hence they will not be capable to run any applications. This means that the applications using them will need to run somewhere else; e.g., in the home server.
- Their connection mechanisms will be nonideal from the networking point of view; i.e., we may not assume that all the appliances would use the same physical mechanism or a similar protocol for networking. This means that the concept will need to have various different interfaces, and it will need to have a mechanism for running device drivers for each device. Furthermore, automatic device discovery may not always be supported.

In the future, wireless (especially radio frequency) technology will be needed and will dominate in small, portable, possibly battery-operated devices, while devices that are stationary, do not require much bandwidth, and/or have a higher power consumption may use powerline communications.

Discussion

In this article we have discussed health monitoring as a potential application field for wearable sensors. We have presented some usage models for health monitoring and discussed the technical requirements for the health-monitoring system based on wearable and ambient sensors, which measure health-related data in daily environments of the users or patients. The presentation is by no means complete, but it aims to give an idea of the system-level issues to be considered for real applications. The technology in this area is rapidly developing, and without doubt we will evidence emergence of these applications in the coming years in the market. This will, in addition to technological developments, require healthcare providers to update their practices and organization of work in order to draw the maximal benefit from the potential faster discharge from hospitals after a care period, extended independent living for elderly and special groups, and improved care balance for some chronically ill patients in out-of-hospital conditions.

To be affordable and cost-efficient, health monitoring needs to support usage of generic platforms. For example, the sensor communications might support generic PAN or HAN technologies such as Bluetooth or ZigBee, the gateways used might run on generic hardware such as a mobile phone or PDA (personal gateway) or digital TV (home gateway), and the user interfaces and the feedback might be provided on these platforms, too. While the main application domain of health monitoring is often the home, the research is closely related to the concepts of smart home and home networking. In fact, technologically, health monitoring and home automation have many features in common:

- There is a requirement for networking traditionally noncomputational low-cost objects that have their main function in the physical rather than in the information space, such as scales, beds, white goods, etc.
- As a result, the user interaction should naturally be primarily through the physical world rather than through information appliances.
- The needed communications bandwidth is relatively low.
- The type of communications is characteristically messaging rather than real-time-communications oriented.

Applications for home automation, including control of HPAC (heating, plumping, air-conditioning), fire and burglary alarms, control of lights and other electrical appliances, have already emerged on the market and allow remote management and receive alarms through, for example, an ordinary mobile phone. However, they are usually implemented on proprietary platforms where there are little possibilities to update or install new applications and where interaction with other systems is poor or nonexisting. The automatic (intelligent) features are usually limited, and user interfaces do not necessarily support natural interaction and intuition.

Health monitoring seems a very promising application for the smart home. First of all, there is a clear need to provide tools to support independent living, especially for the elderly. These tools should include not only means to monitor health status but also to compensate possible functional impairments (e.g., remote control of different electric appliances and doors), add security (fire and burglary alarms forwarded to caregiver, automatic protection mechanisms for electric appliances such as iron and oven), and provide improved communication means. Hence, there is a need for several technical aids simultaneously, giving potential advantages for their integration onto the same platform. Second, due to high costs of the institutional living of the elderly, there would be a clear motivation for society to support purchasing of these kinds of systems if the evidence for prolonged independent living would be provided.

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