# Wireless Sensors for Home Monitoring - A Review

Subhas C. Mukhopadhyay*, Anuroop Gaddam and Gourab S. Gupta

*Institute of Information Sciences and Technology, College of Sciences, Massey University, Palmerston North, New Zealand*

*Received: August 29, 2007; Accepted: September 21, 2007; Revised: November 2, 2007*

**Abstract:** A review of wireless sensors and sensor networks, especially for in-home monitoring of elderly people, has been presented in this paper. The characteristics of various sensors for monitoring applications have been studied. The requirements of the sensor for making a smart sensor network have been investigated. A typical in-house developed system for home monitoring and elder-care application has been presented. A few patents on the sensors for home monitoring have been reviewed.

**Keywords:** Wireless sensor network, radio frequency communication, non-intrusive monitoring system, current sensing, hardware interfacing, elderly care.

## 1. INTRODUCTION

The advancement of science and technology are dependent upon parallel progress in sensing and measurement techniques. The reason for this is obvious. As science and technology move ahead, new phenomena and relationships are discovered and these advances make new types of measurements imperative. New discoveries in this technological world are not of any practical utility unless the results are backed by sensing techniques. Sensory data come from different kinds of sensors of different modalities in distributed locations. Basically a sensor is a device that responds to a physical stimulus, such as thermal energy, electromagnetic energy, acoustic energy, pressure, magnetism, or motion, by producing a signal, usually electrical.

The rapid development of microelectronics, micromechanics, integrated optics and other related technologies has enabled us to develop various kinds of sensors, both wired and wireless, which enable us to sense and measure data more efficiently and accurately. Efficiency relates to the speed of measurement, energy consumed for the measurement and processing resources required.

Wireless sensors have more advantages when compared to wired sensors. They are flexible and can be easily reconfigured. They can be used in places geographically far apart to monitor activities remotely. They also generally consume less power. Wireless sensing units integrate wireless communications and mobile computing with transducers to deliver a sensor platform which is inexpensive to install in numerous applications. Indeed, co-locating computational power and RF communication within the sensor unit itself is a distinct feature of wireless sensing.

## 2. CHARACTERISTICS OF SENSORS

For selecting a sensor, both static and dynamic properties must be considered. These properties play a significant role in the performance of the sensors and the sensor networks. The static characteristics of a sensor are defined as the way a sensor affects the measurement performance due to its inherent features.

The static characteristics of a sensor are its accuracy, error bands, span and zero, resolution of measurement, sensitivity (gain), repeatability, bias and drift, dead band, saturation, hysteresis and linearity.

The dynamic characteristics of a sensor are defined as the capability to handle rapid changes in the input. The following factors affect the input of a sensor, delay (response time), rise time, overshoot and settling time.

When designing a sensor module or a sensor network, not all the characteristics of the sensors are necessarily considered. Depending upon the application and the environmental factors a chosen sub-set of characteristics of the sensors are considered by the designer.

## 3. WIRELESS SENSORS

A wireless sensor is a sensing module which houses one or many transceiver nodes and base stations. It uses a wide range of RF communications techniques. Through software, the sensor may be configured to measure and monitor various physical parameters such as force, temperature, motion etc. Since the wireless sensors employ RF communication, a network of these sensors is considered as a "Wireless Sensor Network". The tasks performed by these wireless sensor networks include measuring the relevant quantities, monitoring and collecting data, assessing and evaluating the information, formulating meaningful user displays, and performing decision-making and alarm functions.

Fig. (**1**) shows the block diagram of a wireless sensor network for monitoring of electrical appliances in a home [1, 2]. The sensing units (SUs) not only have the necessary transducers to monitor an electrical device, they also house the RF transceiver modules to communicate with the central controller unit (CCU). The data communication on the wireless network may follow one of many industry standards or a proprietary protocol.

*Address correspondence to this author at the Institute of Information Sciences and Technology, College of Sciences, Massey University, Palmerston North, New Zealand; Tel: 64 6 350 5799; Fax: 64 6 350 2259; E-mail: S.C.Mukhopadhyay@massey.ac.nz

1874-4761/08 $100.00+.00 

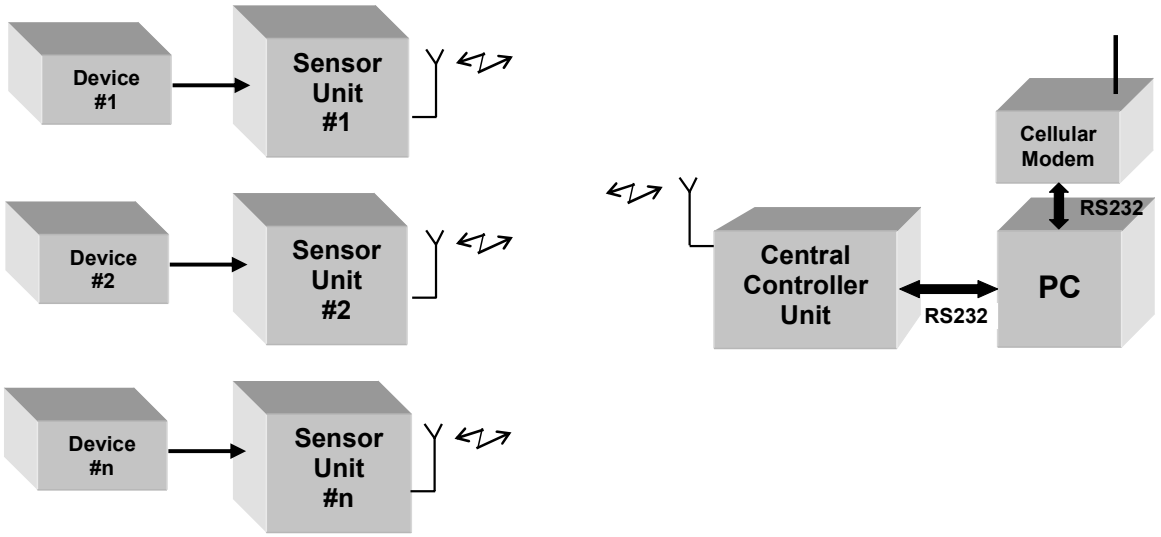


**Fig. (1).** Functional block diagram of a wireless sensor network.

## 4. WIRELESS SENSOR NETWORK CHARACTERISTICS

For measuring and monitoring physical and non-physical activities in a remote area, various types of wireless sensors are generally grouped in a network [3, 4]. Apart from the sensors, the network may incorporate repeater hubs to extend the transmission range of the retrieved data. The network may also incorporate processing units to analyze the data.

The sensor networks employ small, low power devices to do all the tasks. The sensors in the network capture the activity and the collected data is communicated to a remote monitoring centre using wireless data transfer techniques such as Radio Frequency (RF) communication. The size and cost constraints on these types of network result in corresponding constraints being exerted on the resources such as energy, memory, computational speed and bandwidth.

Figure (**2**) shows a typical wireless sensor network [5]. It consists of a Data Acquisition Network (DAN) and a Data Distribution Network (DDN).

In the Data Acquisition Network, the data collected by the sensor nodes are transmitted, using RF channel, to the Base Station Controller (BSC), which in turn is connected to the Management Centre using wired or wireless connection. Some pre-processing of data is often done at the base station which, for a small and simple sensor network, is generally equipped with a microprocessor or microcontroller.

The entire network is monitored and controlled by the Management Centre which is equipped with large storage capacity and computational resources to undertake data analysis and presentation.

As shown in Fig. (**2**), the Base Station provides a gateway to the Data Distribution Network. For distribution of data within the DDN, various kinds of transmission techniques are used, such as Wi-Fi, Bluetooth and Cellular networks (CDMA/GSM). Data may be distributed to remote PCs/ Notebooks, handheld PDAs and cellular phones.

Thus, to build and implement a sensor network, a designer needs to consider several aspects which are discussed in the following sub-sections.

### 4.1. Wi-Fi

Wi-Fi networks use radio technologies IEEE 802.11x standard, which is a standard that uses the 2.4 GHz and 5 GHz bands, to transmit and receive the wireless data [6]. Wi–Fi is useful in implementing ad-hoc wireless networks.

### 4.2. Bluetooth

Bluetooth is an open standard for short-range, low power, and low-cost digital radio wireless communication [7]. Bluetooth is now being used in a wide range of personal products and the technology is readily available in the market. The blue tooth transceiver use unlicensed 2.4 GHz frequency band, with a nominal bandwidth of 1 MHz for each channel. It offers an effective range of 10 meters (32 feet). Bluetooth can indeed be used in wireless sensor network for short range applications.

### 4.3. ZigBee

Zigbee is a relatively new, wireless personal area network technology based on IEEE 802.15.4, with a transmission range of 100+ meters [8]. ZigBee based communication devices consume very little power and hence the battery life of 1000+ days is common. ZigBee has enormous advantages compared to Bluetooth when used in wireless sensor networks. The reasons include more coverage area, less power consumption, and secure networking. ZigBee operates in the industrial, scientific and medical radio bands - 868 MHz in Europe, 915 MHz in the USA and 2.4 GHz in most other countries in the rest of the world.

### 4.4. Network Topology

In any communication network, the message should be transmitted with a prescribed throughput and reliability. This is usually termed as “Quality of Service” (QoS). It can be specified in terms of message delay, bit error rates, packet loss, economic cost of transmission, transmission power, etc. Depending on the QoS, the installation environment, eco-

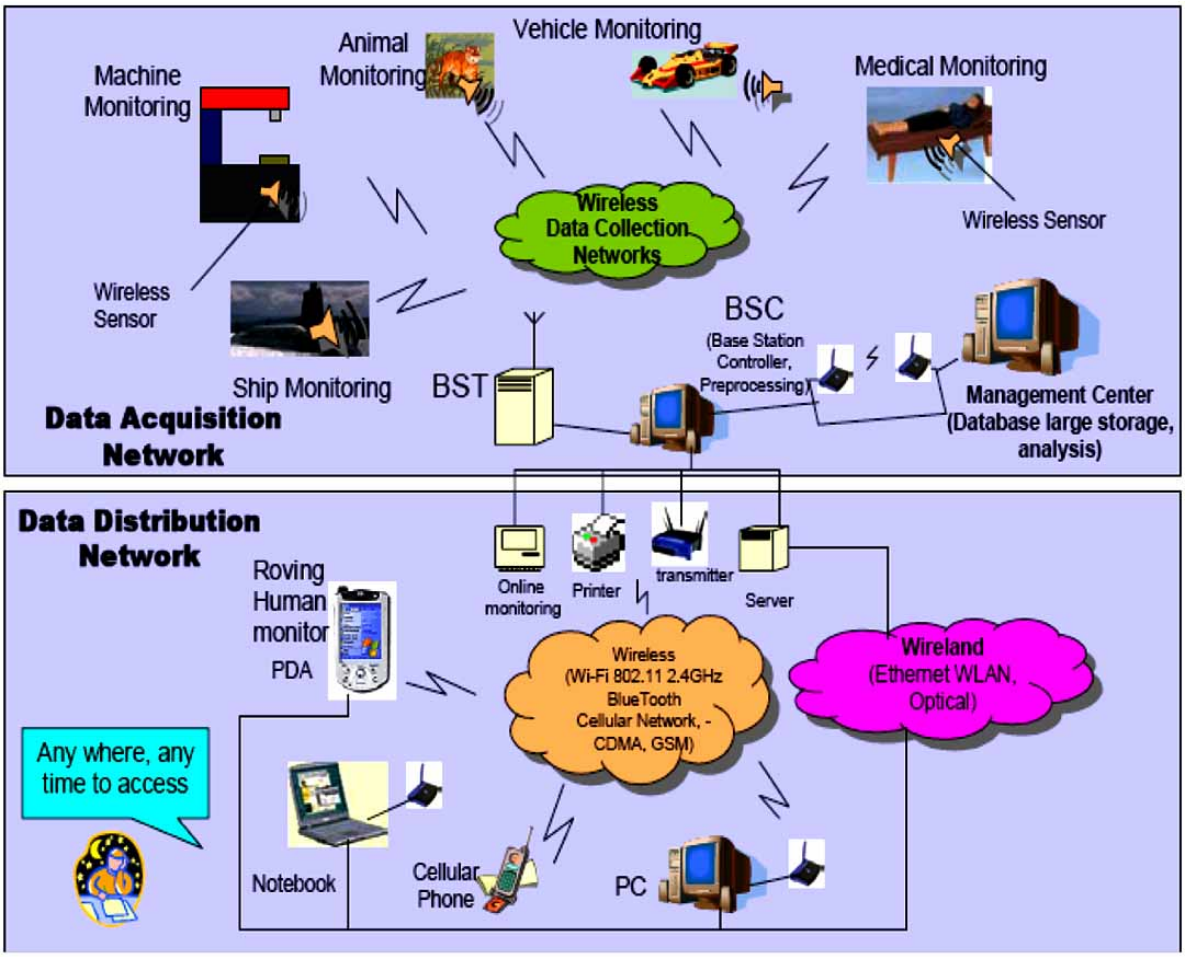


**Fig. (2).** Wireless Sensor Network.

nomic considerations, and the application, one of several basic network topologies such as star, ring bus or tree connection may be used. A communication network consists of nodes, which in our case are sensors, each of which has computing power and can transmit and receive messages over communication links, wireless or cabled.

### 4.5. Communication Protocols and Routing

In a wireless sensor network, one can implement different types of communication protocols and routing techniques. The protocol employed depends on the application in which the sensor is meant to be used. A basic communication pro-tocol consists of packets of data which has a header for identification, data bits and also some special frames to identify and correct errors in transmission. When a sensor node desires to transmit a message, handshaking protocols are implemented with the destination node to improve reliability and ultimately the QoS of the wireless network. This hand shaking protocol makes the sensor node to retransmit messages that were not properly received.

To use the extremely limited resources effectively and efficiently, a new technique called CodeBlue is implemented in wireless networks in order to cope up with the sensor nodes which have limited communication and computation capabilities. The CodeBlue integrates sensor nodes and other wireless devices in the network, thus performing various tasks, such as device discovery - naming, routing, prioritization of critical data, security and tracking device locations. The inventors designed Code Blue for rapidly changing, critical care environments. It acts as an "Information Plane", letting various devices detect each other, report events, and establish communication channels. For medical applications, Code Blue is designed to scale across a wide range of network densities, ranging from sparse clinic and hospital deployments to very dense, ad hoc deployments at a mass casualty site. CodeBlue must also operate on a range of wireless devices, from resource-constrained motes to more powerful PDA and PC-class systems.

The main advantage of this kind of structure is, it incorporates a flexible naming scheme, robust publish and subscribe routing framework; authentication and encryption provisions and handoff. The other services the Code Blue provides to the network are location tracking, in-network filtering and aggregation.

### 4.6. Power Management

Since the wireless sensors are geographically distributed, often in remote sites, the lifetime of the sensor nodes is important. Power generation, power conservation and power management play very important roles in extending the lifetime of the motes. Most of the power is consumed in the process of RF communication since the required trans-

mission power increases as the square of the distance between source and destination. While software power management techniques can greatly decrease the power consumed by RF sensor nodes, TDMA is especially useful for power conservation, since a node can power down between its assigned time slots, waking up in time to receive and transmit messages.

### 4.7. Network Coverage

The coverage area of the sensor is defined as the effective range of the sensor connected to its sensor node. In a network, high coverage makes it robust system and this can be exploited to extend the network lifetime by switching redundant nodes to power-saving and sleep modes.

## 5. APPLICATION OF WIRELESS SENSORS

Wireless sensors are being used in a vast number of fields which include, machine manufacturing, process automation, automotive, aerospace/military/homeland security, and speciality markets which includes Medical monitoring devices, engineering/architectural, R&D, wholesale/retail utilities, and many more [9]. Recent advances in embedded computing systems have led to the emergence of wireless sensor networks, consisting of small, battery-powered "motes" with limited computation and radio communication capabilities. Sensor networks permit data gathering and computation to be deeply embedded in the physical environment. This technology has the potential to impact the delivery and study of resuscitative care by allowing vital signs of a person to be automatically collected and fully integrated into the patient care record and used for real-time triage, correlation with hospital records, and long-term observation.

## 6. A REVIEW OF PATENTS ON SENSORS FOR HOME MONITORING

A lot of invented works have been filed for patents and obtained in different countries. In [10] P. E. Cuddihy et. al., in US7091865 have reported a system and method for determining periods of interest in home of persons living independently. The purpose is to monitor the activities of a resident living independently to distinguish normal activity from unusual activity. The system is based on many sensors, the sensors are distributed around the home to collect data on activity in the home. The sensors have built-in transmitters which are used to transmit the collected data to a central monitoring system to collate all data and saved in a database according to predetermined time slots. The historical activity timelines as well as buffer times are stored in the database which are used to distinguish the activities. If the current activity is outside the range of the historical activity timelines and buffer times, the activity is defined as unusual and an alert is issued. The Fig. (**3**) shows the block diagram representation of the developed system. The sensors include motion sensors, inside door sensors, exterior door sensors, cabinet sensors, kitchen and appliance sensors, hazard and security sensors, and any other sensors suitable for collecting and communicating data regarding activities on-going in the home. The sensors, preferably are wireless sensors capable of wirelessly communicating signals to the communication relay panel. The communication relay panel as shown in Fig. (**3**), communicates the sensor data to the remote monitoring centre either by wired or wireless communication platform. The communication may take place via a wired telephone, wireless telephone, two-way walkie-talkie, pager, cable, the internet or any other wireless communication platform.

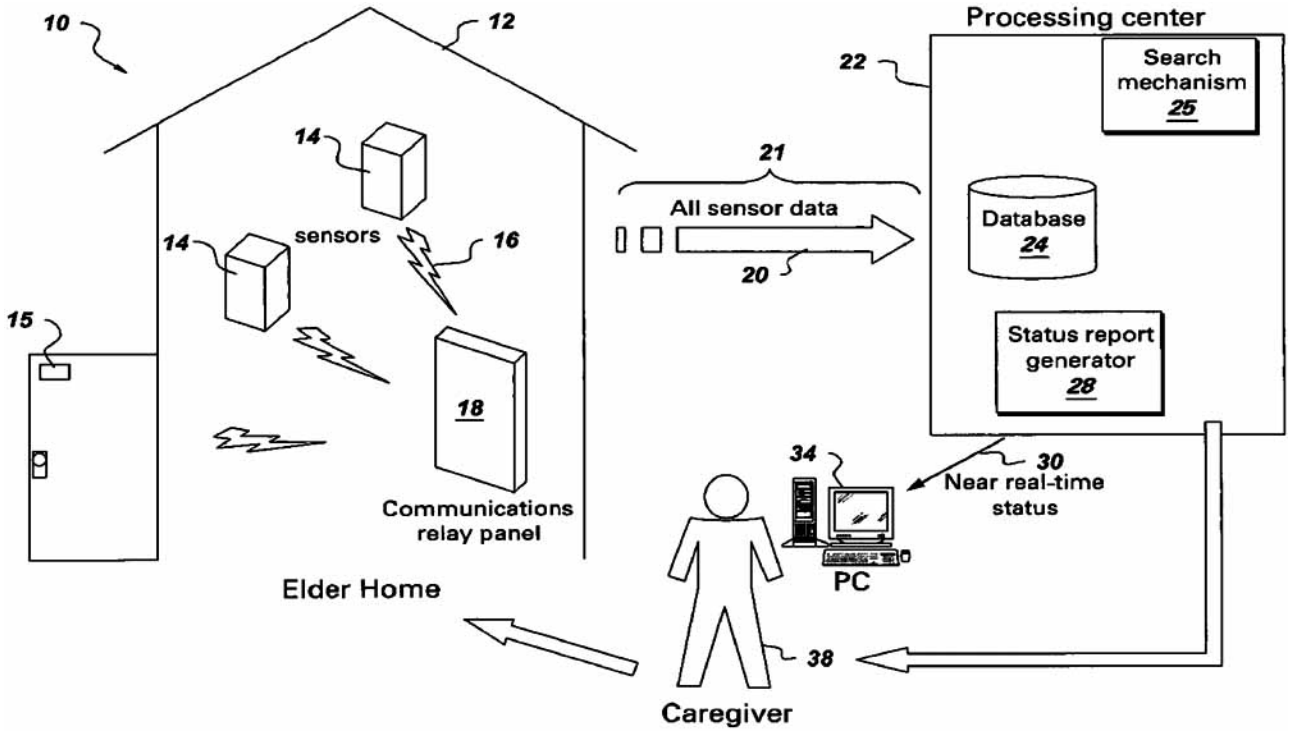


**Fig. (3).** Block diagram representation of the system and method for determining periods of interest in-home of persons living independently [10].

The monitoring centre other than collecting all sensors signals transmitted by the communication relay panel, can do a variety of works such as comparison of data to decide the unusual state and generating a status report. The status report may be accessible to the caregiver if it is required. The monitoring centre can provide the total different activities throughout the day, one of such daily activities is shown in Fig. (**4**) in which the maximum, average, minimum activities are plotted throughout the day.

The invention reported in [11] and [12] relates to a behaviour determining apparatus to investigate whether or not a pattern regarding behaviours of a given subject person and an actual behaviour of that person are substantially identical. The authors have filed and obtained the US patent [13] on the expanded version of their earlier system. The system is based on many sensors installed throughout the home as is shown in Fig. (**5**). The sensors include camera, infrared, in-bed/out-of-bed sensor, air quality sensor, toilet sensor, window open/close detector, TV power on/off detector, refrigerator door open/close detector and so on. The list of the sensors used for this system is shown in Fig. (**6**).

The recording unit collects all sensors data and stored in the system. Based on the stored data a pattern of the behaviour of the person is generated and stored in the system. This pattern is useful to decide whether any activity is unusual. Once the system operates in the normal activity detection mode, the collected data from the sensors are used to check with the stored pattern data whether anything is abnormal. The operation flow chart of the invented system is shown in Fig. (**7**) and a typical response is shown in Fig. (**8**) respectively.

The system described in this invention is a huge one, it needs many sensors, so it will be very expensive. Moreover, the use of camera in a private home will not protect privacy which is a requirement for many people. The communication may be an issue as so many sensors are involved. So in terms of commercialisation the complete version of this invention may not be attractive.

Kiluk has reported a method of an alarm system which is intended for monitoring of apartments for elderly and/or handicapped person in his invention [14]. The energy consumption of the apartment is measured and recorded over a period in a computer. The actual energy consumption of the apartment is compared with the expected energy consumption which is recorded in the computer to generate different degree of alarm level. The block diagram representation of

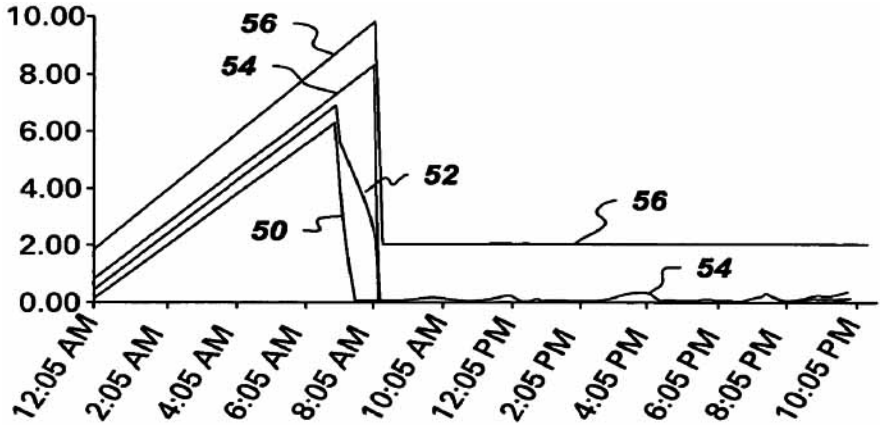


**Fig. (4).** The daily activities on a typical day [10].

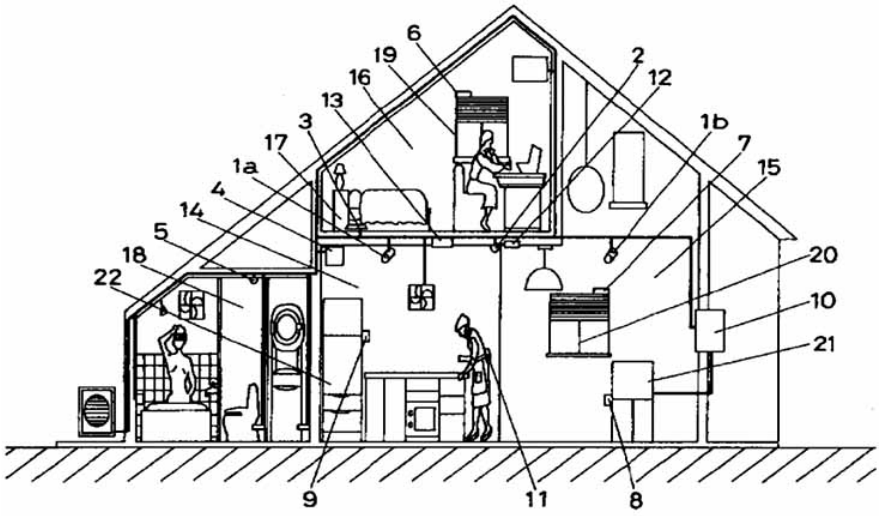


**Fig. (5).** Behavior determining apparatus for home monitoring based on sensors [13].

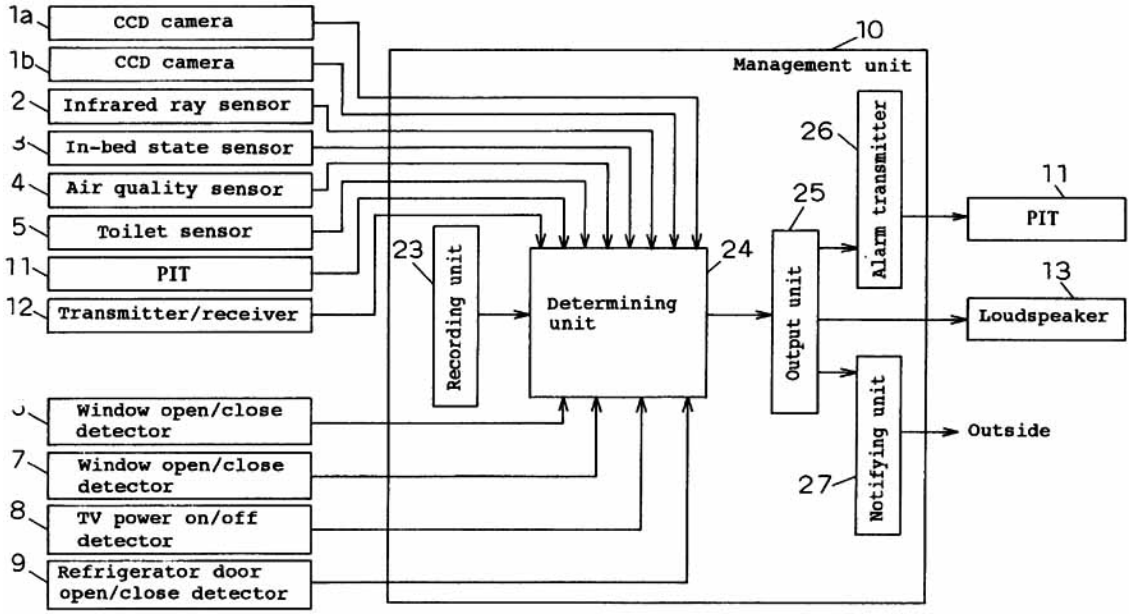


**Fig. (6).** Different sensors used for home monitoring [13].

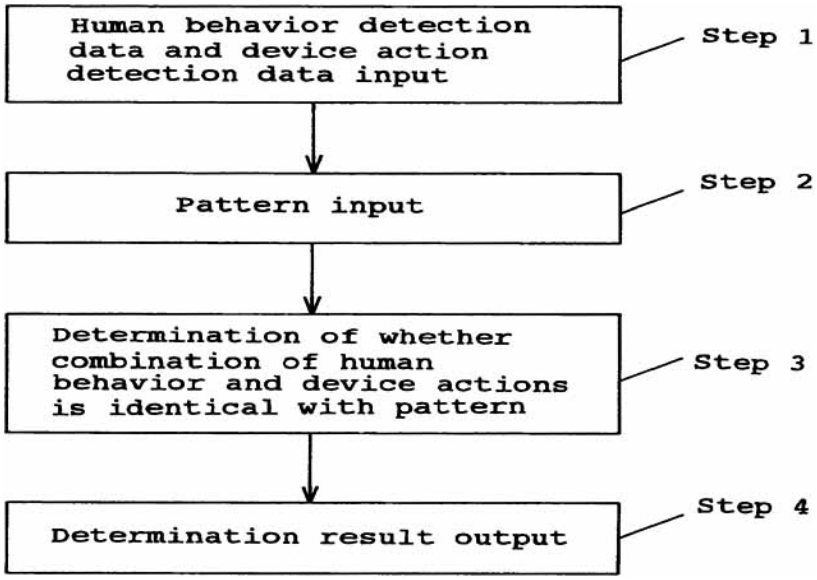


**Fig. (7).** The operation flowchart of the developed system [13].

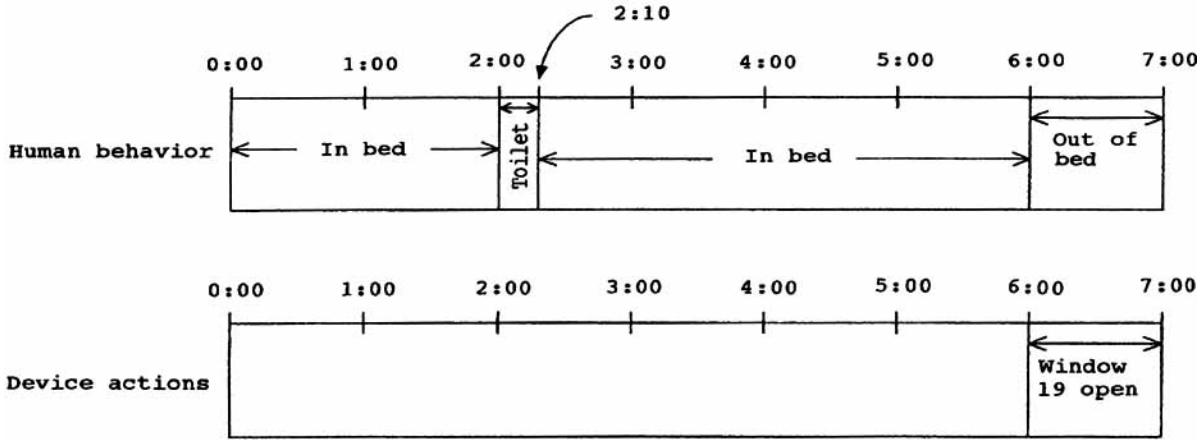


**Fig. (8).** Response of the system with time [4].

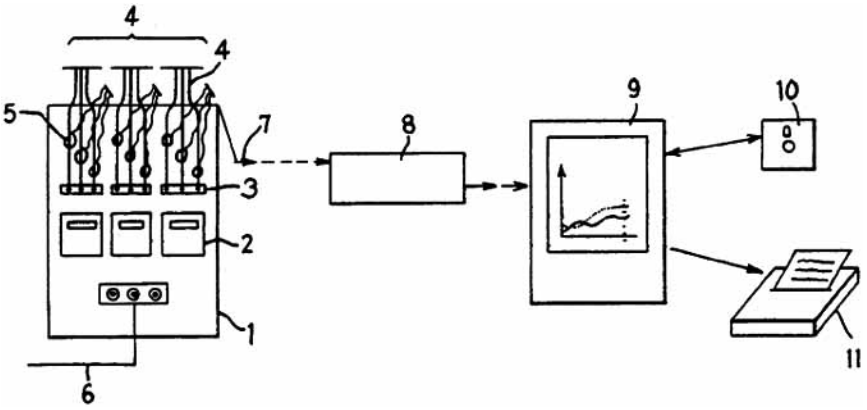


**Fig. (9).** Block diagram representation of the alarm system for monitoring elder people [14].

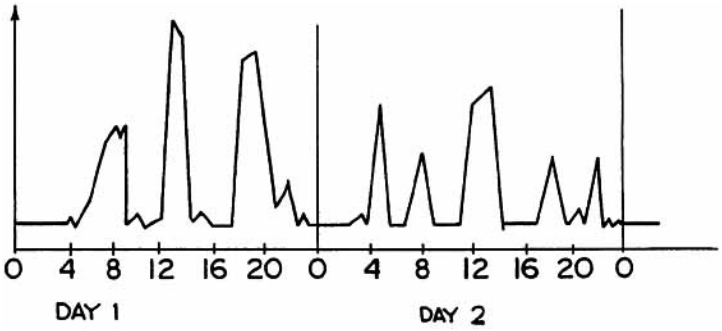


**Fig. (10).** The recorded energy consumption throughout the day [14].

the invented system is shown in Fig. (**9**) and the variation of energy consumption throughout the day over two days is shown in Fig. (**10**) respectively.

In [15], the activities of a user within a selected environment which can be measurement of both physiological and non-physiological parameters are reported. The system is based on many sensors which measure physiological parameters such as blood pressure, heart rate, body temperature, body weight and blood glucose level and non-physiological parameters such as room temperature, ammonia from spilled urine, methane from spoiling food, the presence of smoke, the frequency of electrical usage, the temperature of water flowing from a tap located within the selected environment and the use of selected appliances such as toilet, telephone, stove, microwave, oven , toaster, refrigerator, freezer, dishwater etc. The outputs from all sensors are transmitted to a central receiver system. The receiver around a processor can monitor and check all data to decide whether any abnormal situation has arisen. Depending on the situation an alarm signal may be generated and send to an external user who may be a friend, relative, building staff member or fire department.

D. A. Monroe has reported an invention which is based on multimedia surveillance and monitoring security system for commercial and residential applications [16]. The cameras, used as sensors which are activated by the occurrence of an activating event and upon activation generate a signal. The picture taken by the cameras are converted into a network compatible signal and it is transmitted to a server either by a wired or by wireless transmission. Depending on the situation with the help of GPS (Global Positioning System), the personnel can be alerted and the location of event can be informed. It has been reported that if a wireless LAN (Local Area Network) is used the audio, video and image data can be distributed over a high bandwidth without requirement of a licence. It is possible to interface the surveillance system with a WAN (Wide Area Network) or the internet for providing a worldwide, low cost surveillance system with virtually unlimited geographic application.

The invention reported in [17] relates to a biomechanical monitoring apparatus to be worn by the user to provide information of physiological parameters over a specific period of time. The monitoring apparatus is a fusion of different sensors which are used to measure different physiological parameters of interest.

## 7. CURRENT & FUTURE DEVELOPMENTS

The reported inventions on home monitoring are based on different sensors, collection of sensors data by a central processor, comparison of activities with a standard pattern and detection of unusual or abnormal event. In many situations, the cameras are used for security surveillance which may be appropriate but in home monitoring applications the privacy is not protected. The cost of the complete system may be a critical factor for its universal use. In future, the research should be targeted to develop a low-cost system with the sensors essential to monitor the elder people at home. The time to detect any abnormal or unusual incident should be detected as fast as possible and the message to the caregiver should reach as quickly as practicable.

## 8. CONCLUSIONS

This paper has reviewed different wireless sensors used for home monitoring especially to care elder people. The monitoring system is based on the integration of different sensors which has the capability of transmitting the data via wireless communication. The data are collated by a central processor which saves all data for processing as well as future use. The habit of the life-style of the person under care is stored in the system. The collected data are compared with the stored pattern and depending on the situation the actions are defined as unusual or abnormal. If the system detects any abnormal activity a warning or alarm message can be transmitted to the care-giver. The availability of low-cost wireless sensing system for this type of application has a great potential to save human life especially elder people.

## REFERENCES

[1] Gupta GS, Mukhopadhyay SC, Devlin B, Demidenko S. Design of a Low-cost Physiological Parameter Measurement and Monitoring Device, Proceedings of 2007 IEEE IMTC Conference. Poland, Warsaw 2007; 1(3): 1-6.

[2] Gupta GS, Mukhopadhyay SC, Sutherland M, Demidenko S. Wireless Sensor Network for Selective Activity Monitoring in a home for the Elderly, Proceedings of 2007 IEEE IMTC conference. Poland, Warsaw 2007; 1(3): 1-6.

[3] Callaway E, Gorday P, Hester L, *et al*. Home Networking with IEEE 802.15.4: A Developing Standard for Low-Rate Wireless Personal Area Networks. IEEE Commun Mag 2002; 69-77.

[4] Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. A Survey on Sensor Networks. IEEE Commun Mag 2002; 102-114.

[5] Lewis FL. Wireless Sensors Networks, Smart Environments: Technologies, Protocols, and Applications ed. Cook DJ, Das SK, John Wiley, New York, 2004; 1-18.

[6] IEEE 802.11 Working Group (2007-06-12). *IEEE 802.11-2007: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*. ISBN 0-7381-5656-5659.

[7] http://www.bluetooth.com/bluetooth/

[8] www.zigbee.com

[9] Tang TB, Johannessen EA, Wang L, *et al*. Toward a miniature wireless integrated multisensor microsystem for industrial and biomedical applications. IEEE Sens J 2002; 2 (6): 628-635.

[10] Cuddihy, P.E., Weisenberg, J.M., Ganesh, M., Graichen, C.M.: US20067091865 (**2006**).

[11] Yoshiike, N., Hattori, A., Morinaka, K., Inoue, S., Tanaka, S.: EP1071055A1 (**2001**).

[12] Yoshiike, N., Hattori, A., Morinaka, K., Inoue, S., Tanaka, S.: EP1071055B1 (**2004**).

[13] Yoshiike, N., Hattori, A., Morinaka, K., Inoue, S., Tanaka, S.: US20046796799 (**2004**).

[14] Kiluk, C.: US4990893 (**1991**).

[15] Lane, S.S., Chadbourne, C., Buller, W.T., Steiger, S.A.: US6002994 (**1999**).

[16] Monroe, D.A.: US20056970183 (**2005**).

[17] Davis-Havill, J.R., Walley, J.L.: WO05120348A1 (**2005**).