

# A Novel Approach of Sensors-Based Wearable Systems for Monitoring of Human Movement and Falls

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**Abstract:** *The aim of this paper is to summarize recent developments in the field of wearable sensors and systems that are relevant to the field of rehabilitation. The growing body of work focused on the application of wearable technology to monitor older adults and subjects with chronic conditions in the home and community settings justifies the emphasis of this review paper on summarizing clinical applications of wearable technology currently undergoing assessment rather than describing the development of new wearable sensors and systems. The advancement in the field of wireless technology in recent years has led to a wide variety of applications. Wireless sensor networks have been an active research topic for around a decade now. Moving from early research in military applications, these are now widely deployed in diverse applications including the health monitoring system. Body area sensor network is one of those advanced applications which assist in monitoring of bio medical parameters of a person wearing it. The main purpose of this is to make it possible for a patient needing permanent monitoring yet to be fully mobile. This paper deals with most of the biomedical parameters of a patient like heartbeats, body temperature, glucose levels, respiratory conditions and so on. Body area sensor network basically consists of a set of light weighted sensors which monitor the various health parameters. All these monitored bio-signals are sent to a back-end system at a healthcare centre with the help of radio frequency signals. A healthcare specialist retrieves this data over a reliable wired connection. To increase the freedom of movement of the patient, technologies like Bluetooth and general packet radio switching have been utilized. Global positioning system is used here to track the specific location of a patient. This location provision service makes it possible to locate patients even while they are outside the healthcare centre. This system is cost effective and the results indicate that the system has a very good response time.*

**Keywords:** WSN, BAN, BASN, Radio Frequency, Bio-sensors

## 1. Introduction

The problem with accidental falls among elderly people has massive social and economic impacts. Falls in elderly people are the main cause of admission and extended period of stay in a hospital. It is the sixth cause of death for people over the age of 65, the second for people between 65 and 75, and the first for people over 75. Among people affected by Alzheimer's disease, the probability of a fall increases by a factor of three. Elderly care can be improved by using sensors that monitor the vital signs and activities of patients, and remotely communicate this information to their doctors and caregivers.

For example, sensors installed in homes can alert caregivers when a patient falls. Research teams in universities and industries are developing monitoring technologies for in-home elderly care.

A fall can occur not only when a person is standing, but also while sitting on a chair or lying on a bed during sleep. The consequences of a fall can vary from scrapes to fractures and in some cases lead to death. Even if there are no immediate consequences, the long-wait on the floor for help increases the probability of death from the accident. This underlines the importance of real-time monitoring and detection of a fall to enable first-aid by relatives, paramedics or caregivers as soon as possible. Monitoring the activities of daily living (ADL) is often related to the fall problem and requires a non-intrusive technology such as a wireless sensor network.

Telehealth – the provision of health services involving information, communications, measurement, and monitoring from a distance to patients' homes—is forecast to become a mainstream application. Its intended purpose is to alleviate the expected pressure on healthcare systems and facilitate an improved level of care via long-term follow-up for diagnostic and intervention purposes [3]. Telehealth applications are largely based on the use of sensor technologies [4]. Console-based systems have been at the core of telehealth for many years. Such systems typically include sensors to capture vital physiological measurements (heart rate, electrocardiogram, etc.) and are often equipped with a user viewing screen. In some instances, ubiquitous sensors may be placed around the home or a residential care facility, as in the "smart home" concept [5]. Remote observation of activity can then be conducted with various objectives in mind, including safety monitoring or to ensure proper care. Another application category involves body-fixed sensors that are referred to as wearable sensors (or systems, since in many cases more than one sensor is utilized). Regardless of the specific application, information collected via such telehealth sensors is transmitted over some distance and possibly further analyzed at its destination, before being viewed by predetermined recipients whose role it is to monitor or act upon the data when required.

Technological advancements in the fields of electrical, mechanical and computer engineering, particularly involving microelectromechanical systems (MEMS) have resulted in smaller and cheaper sensors that operate in a wireless manner. Most systems available commercially, or

which are the subject of current research, are enclosed in small cases that can be attached to the body using bands or belts [6]. In the future, an everyday object like a ring may be transformed into a completely unobtrusive sensor for monitoring heart rate and blood oxygen saturation over long durations. Some sensors are small enough to be contained in a patch or a bandage; these may be placed on the skin for collection of various measurements, like galvanic skin resistance or temperature. Another exciting research field involves the development of smart garments, where sensors are woven into real wearable objects, such as shirts and vests [7].

The main area of utilization for wearable sensors is health-related. This can be divided into critical and noncritical applications [6]. The former would include monitoring individuals whose condition might trigger an alarm when help is required (e.g., an epileptic episode; an elderly person falling) or remotely tracking a casualty's vital signs in combat situations.

Noncritical use would encompass long-term monitoring of patients suffering from chronic conditions or of elderly people in their homes for purposes that are not necessarily alert-driven. For example, wearable sensors that quantify physical activity may be used for patients with chronic lung disorders in order to ensure their activity levels are sufficient, as inactivity tends to exacerbate their condition. In relation to possible non-health applications, wearable sensors used for monitoring physical activity can also be used by professional athletes to improve the efficiency of their training. Rescue operations may keep track of an emergency crew's location by using sensor-based wearable systems including global positioning systems. Individuals executing tasks that require high levels of alertness, such as truck drivers or heavy machinery operators, may be monitored to ensure their consciousness [6]. It is therefore evident that the field of wearable sensors for telehealth is both broad and rapidly emerging. This paper focuses on sensor-based wearable systems in relation to ambulatory monitoring and presents an overview of recent developments in the field. Movement monitoring and classification are examined, along with a range of clinical applications of these ambulatory sensor technologies, with particular emphasis on falls detection and falls risk assessment.

## 2. Ambulatory Monitoring:

### A. The Significance of Studying Human Motion

Human motion is a highly complex concept, which depends on and is, in turn, influenced by many factors, including physiological, anatomical, psychological, environmental, and social effects [6]. Movement reduction or modification can stem from various conditions, including stroke, osteoarthritis, and aging. Once mobility is impaired or reduced, a cycle of deterioration is commonly generated, whereby a person's capacity to move is further diminished, mostly due to physical and emotional reasons [8]. This highlights the need for proper and timely interventions that address the specific issues which hinder movement in each individual and provide the necessary encouragement to keep frail and sick people as physically active as possible.

Clearly, to achieve these objectives, we must first be able to monitor and quantify movement, identify reduced or impaired movement, and estimate the value of administered interventions.

Interestingly, though a real fall would never be an intentional or positive event, in the context of ambulatory monitoring, a fall can be regarded as a subcategory of human movement [9]. Its occurrence is related to the same factors that affect movement in general and it often leads to reduced movement and an increased risk for subsequent fall episodes [8]. Monitoring and preventing falls may therefore be possible using similar concepts to those applied to movement monitoring.

### B. Assessment Techniques

The study of human motion and falls employs many techniques, including visual observations, video capture, interviews, diaries, questionnaires, physical measurements, and wearable ambulatory sensors. Self-report tools are simple to administer, but capture partial information and suffer from inherent bias due to inaccurate recall, whether intentional or not. Objective measurements use a variety of physical tools such as force plates, gait mats, and balance testing apparatus.

Such tests are designed to be conducted in a clinical setting, usually in dedicated gait and falls clinics, and are relatively costly and inappropriate for long-term monitoring of large patient cohorts under real-life conditions [10].

Miniature sensors or sensor systems that can be worn on the body offer another means of gathering physical activity and falls data in a way that is suitable for clinical settings but has immense potential for long-term use, especially in the community [11]. Additional advantages related to the use of such wearable ambulatory monitors (WAMs) are: a) capturing objective measurements of everyday or structured movements, including aspects that cannot be obtained by other assessment tools and b) custom-tailored measurements can be developed to enable improved interventions and to quantify their effect over time [12].

### C. Types of Wearable Ambulatory Sensors

*Accelerometers* are used to measure acceleration along a sensitive axis and over a particular range of frequencies. Since they measure acceleration due to gravity and movement, the actual component of movement-related acceleration needs to be separated from the gravitational. The gravitational component is nevertheless useful in defining a subject's postural orientation.

There are several types of accelerometers available based on piezoelectric, piezoresistive, or variable capacitance methods of transduction. They all employ the same principle of operation of a mass that responds to acceleration by causing a spring or an equivalent component to stretch or compress proportionally to the measured acceleration (Hooke's law). Early available accelerometer sensor devices were of a uniaxial design; however, further advances in MEMS technology have led to the availability, at low-cost,

of biaxial and triaxial devices, with their sensitive axes mounted orthogonally to one another.

*Vibrating gyroscopes* measure angular velocity by taking advantage of the Coriolis Effect. MEMS-based gyroscopes use a small vibrating mass within the sensor that undergoes a slight displacement when the gyroscope is rotated. If measured over time, a change of angle in relation to an initial known angle can be detected. These sensors have known limitations, which include output drift over time, output offsets when the device is stationary, and a sensitivity which is limited to a particular range of angular velocities.

*Magnetometers* can be used to measure the orientation of a body segment in relation to the earth's magnetic north, utilizing electromagnetic induction. In order to work effectively, the orientation of the sensitive axis of the device must be aligned with the magnetic field lines; composite devices containing multiple devices on orthogonal axes are now used to compensate for this requirement.

*Goniometers* are fairly rudimentary devices, based on a potentiometric element which is attached to a joint's rotation point to measure joint angle, although more advanced flexible electrogoniometers employ strain gauge elements. These sensors (along with *inclinometers* that are used to measure the slope of an object with respect to gravity using an artificial horizon) are mainly employed in the determination of the range of motion of human body joints.

*Sole pressure sensors* assess the pressure distribution across the planar aspect of the foot by measuring the net ground reaction force. These are often realized using resistive or capacitive-based strain gauges. Such pressure sensors have been incorporated into socks for increased ergonomics.

*Pedometers*, also called step counters, detect human motion and, using specialized software, translate the measurement into a count of the number of steps performed.

In the past, pedometers were based on mechanical switches or pendulums, but nowadays they incorporate MEMS sensors, typically accelerometers.

*Actometers* are usually attached to an individual's extremities in order to measure the magnitude of mechanically produced movements. These sensors are basically a modified version of the mechanism in a self-winding mechanical wrist watch, where the self-winding rotor responds to movement by driving the minute hand. The resulting output is a measurement of "actometer units" per known time period; this enables an estimation of total energy expenditure.

In the context of clinical ambulatory monitoring, it seems that the most commonly used WAMs consist of accelerometers, gyroscopes, or both. Integrated systems that employ accelerometry with a gyroscope and a barometric pressure sensor (for measuring elevation) [13] or a magnetometer have also been explored.

## D. Design and Usability Considerations

On a technical level, the most important factors in designing an ambulatory sensing system are reliability (no random variance in measurements over time), durability, portability, continuous recording, high resolution at the desired frequencies, and an ability to filter the bandwidth as required. Wireless communication is another fundamental feature; in some cases, real-time data processing via embedded intelligence is a must (e.g., in falls detection). On a user interface level, the main considerations are size, weight, ease of use (preferably minimal or no intervention is required), number of sensors, and their location. Cost is clearly a deciding factor as well. Naturally, placing more sensors across the body will generate more collectible data, but it is very likely that compliance and usability will suffer. Conversely, especially in the context of unsupervised home monitoring, the goal is to allow data capture with minimal interference.

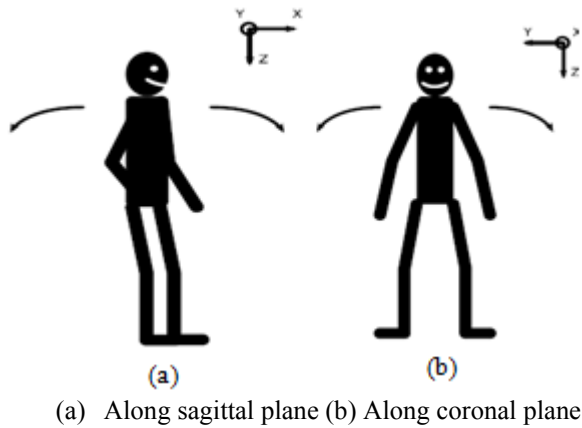
While this is easier to achieve using ubiquitous home sensors, having multiple devices in several body locations is clearly contradictory to this objective. The location of the sensor(s) on the body greatly depends on the type of measurement desired.

For example, the wrist may be an ideal location for monitoring tremors associated with Parkinson's disease, but is considered inadequate for studying patterns of locomotion [6]. Placing a WAM at waist level, or as close as possible to the body's center of mass, is often recommended [16], yet device placement remains a complex decision that is further complicated by issues relating to orientation and measurement artifacts. A fall can be defined in different ways based on the aspects studied. The focus in this study is on the kinematic analysis of the human movements. A suitable definition of a fall is "Unintentionally coming to the ground or some lower level and other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure.

(Gibson et al., 1987). It is always possible to easily re-adapt this definition to address the specific goals a researcher wants to pursue.

In terms of human anatomy, a fall usually occurs along one of two planes, called sagittal and coronal planes. Figure 1(a) shows the sagittal plane that is an X-Z imaginary plane that travels vertically from the top to the bottom of the body, dividing it into left and right portions. In this case a fall along the sagittal plane can occur forward or backward. Figure 1(b) shows the coronal Y-Z plane, which divides the body into dorsal and ventral (back and front) portions.

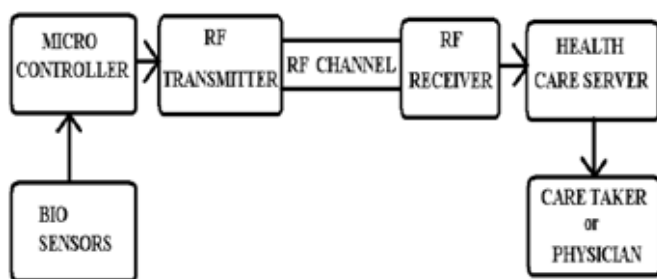
The coronal plane is orthogonal to the sagittal plane and is therefore considered for lateral falls (right or left). Note that if the person is standing without moving, that is, he or she is in a static position, the fall occurs following in the down direction. The sense of x, y and z are usually chosen in order to have positive z-values of the acceleration component when the body is falling.



**Figure 1:** Fall directions

### 3. Health Monitoring System

Wearable health monitoring systems integrated into a telemedicine system are novel information technology that will be able to support early detection of abnormal conditions and prevention of its serious consequences. Many patients can benefit from continuous monitoring as a part of a diagnostic procedure, optimal maintenance of a chronic condition or during supervised recovery from an acute event or surgical procedure. Important limitations for wider acceptance of the existing systems for continuous monitoring are unwieldy wires between sensors and a processing unit, lack of system integration of individual sensors, interference on a wireless communication channel shared by multiple devices, and nonexistent support for massive data collection and knowledge discovery. Traditionally, personal medical monitoring systems have been used only to collect data for off-line processing. Systems with multiple sensors for physical rehabilitation feature unwieldy wires between electrodes and the monitoring system. These wires may limit the patient's activity and level of comfort and thus negatively influence the measured results. The overview of our health monitoring system is as shown in figure 2.



**Figure 2:** Overview of Health Monitoring System

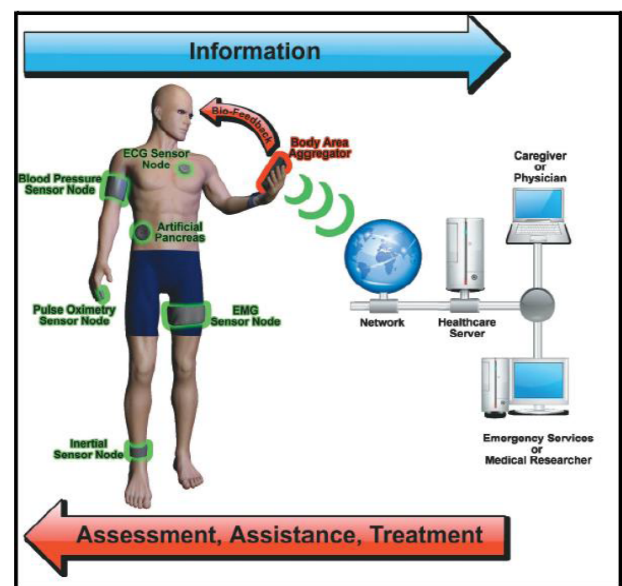
#### A. Bio-Sensors

Wireless BASN can include a number of physiological sensors depending on the end-user application. Information of several sensors can be combined to generate new information such as total energy expenditure. An extensive set of physiological sensors may include the following:

- An ECG (electrocardiogram) sensor for monitoring heart activity

- An EMG (electromyography) sensor for monitoring muscle activity
- An EEG (electroencephalography) sensor for monitoring brain electrical activity
- A blood pressure sensor
- A tilt sensor for monitoring trunk position
- A breathing sensor for monitoring respiration
- Movement sensors used to estimate user's activity
- A "smart sock" sensor or a sensor equipped shoe insole used to delineate phases of individual steps

There are many numbers of sensors in the BASN as shown in Figure 3. BASN users are likely to tolerate and accept some degree of burden of using all if they perceive enough value in doing so.



**Figure 3:** Body Area Sensor Network

#### B. Placement of Bio-sensors

Sensors in typical WSNs are numerous, homogeneous, and insensitive to placement error. BASN sensors, in contrast, are few, heterogeneous, and require specific placement. Indeed, ineffective placement or unintended displacement from movement can significantly degrade the captured data quality. Such requirements call for strategies that will minimize and detect placement error, such as better packaging combined with on-node signal classification. Commercial sensors exhibit a wide range of power supply requirements, calibration parameters, output interfaces, and data rates. Engineering BASN nodes to accommodate this breadth of sensing requirements could necessitate an application-specific approach that minimizes the design space, improves efficiency, and amortizes cost over a single application. Likewise, BASN nodes designed with a high degree of configurability could amortize cost over a much larger range of applications, including those unforeseen.

#### C. Working Principle

BASNs must effectively transmit and transform sensed phenomena into valuable information and do so while meeting other system requirements, such as energy



efficiency. A BASN's value therefore rests in large part on its ability to selectively process and deliver information at fidelity levels and rates appropriate to the data's destination, whether that is to a runner curious about his heart rate or a physician needing a patient's ECG. The desperate application requirements call for the ability to aggregate hierarchical information and integrate BASN systems into the existing information technology infrastructure. Current work to address these challenges and realize these opportunities points to a critical need for collaboration between technologists and domain experts who can help define the specifications and requirements for BASN systems and applications. In applications targeting the aging population, for example, such collaboration could involve physicians, nurses, psychologists, and sociologists to ensure that a BASN provides valuable information while being usable by the elderly in a safe and socially acceptable manner. The need for such collaboration is only one of many requirements that research must satisfy to pave the way for practical, accessible BASN use.

#### 4. Implementation Details

All patients have to be completely monitored under certified monitoring technicians. This could not be practically possible all the time. Therefore a health monitoring system has been designed in such a way to overcome such situations. It automatically monitors and if there is any problem relating to abnormality in heartbeat or so, it certainly buzzes an alarm which indicates that there is an urgency to monitor and treat that patient according to the situation. In this design, a micro controller is used to control the patient's conditions automatically, depending upon the various biomedical parameters such as body temperature, heart rate, respiration rate etc. Some patients in hospital require constant attention when the patient's health is in critical condition. Such patients have to be monitored all through the day so that even a small movement made by the patient is noticed by the doctors and nurses such that they can rush to that particular patient whenever required and take immediate care.

Using this hardware, the doctors can monitor a patient even if they are far away from the patient. At certain emergencies, they can go to that patient or direct a nurse to attend that patient immediately. The patient bed has certain measuring instruments to send signals through the RF transmitter. The RF receiver and announcement section at the doctor's room produces the announcement according to the sensor and at the same time it displays a message on the LCD display. Some features of E-life saver shown in figure 4 are as given below.

- Automatic checking of heart pulses
- Automatic check-up of human body temperature
- Automatic checking of patient urine
- Automatic checking of glucose level
- RF transmitter and RF receiver is used for communication
- Separate code for every sensor attached to the patient

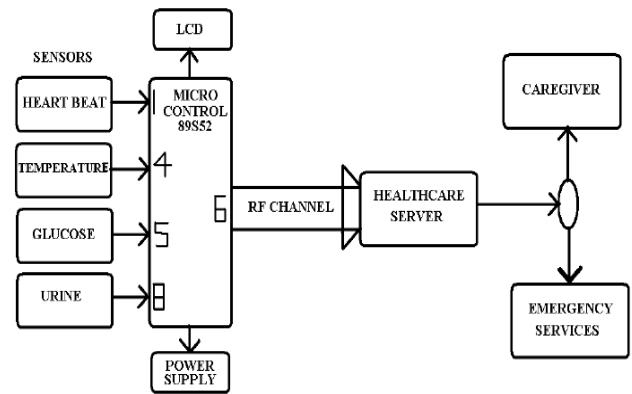
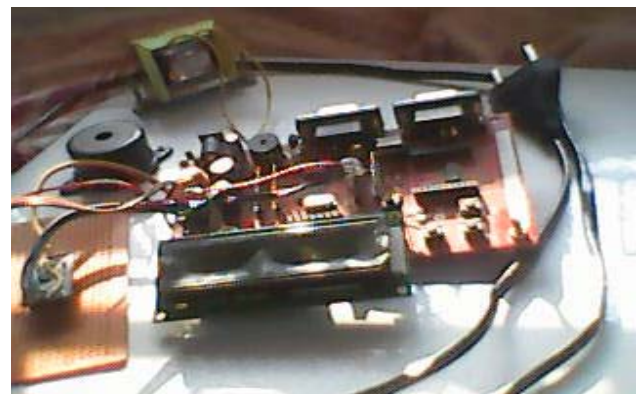


Figure 4: E-Life Saver

#### 5. Output and Result



#### 6. Conclusion

The potential of using wearable sensor systems for a wide range of clinical applications has moved beyond the theoretical scope and has even reached the commercial stage for falls detection and physical activity monitoring. Further research is nonetheless required in order to resolve an array of outstanding issues and enable mainstream utilization of such systems, particularly in an unsupervised long-term context, which is viewed by most as the leading objective due to anticipated global demographic trends.

#### 7. Future Scope

In the near future, we will further investigate the fall detect and alarm issue in the sensors-based wireless wearable systems to further improve accuracy. We may extend current health data delivery from fixed range to anywhere to improve the practicality of the system.

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