Healthcare Sensing and Monitoring

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Abstract. This chapter presents an overview of many wearable devices of different types that have been proven in medical and home environments as being helpful in Quality of Life enhancement of elder adults. The recent advances in electronics and microelectronics allow the development of low-cost devices that are widely used by many people as monitoring tools for well-being or preventive purposes. Remote healthcare monitoring, which is based on non-invasive and wearable sensors, actuators and modern communication and information technologies offers efficient solutions that allows people to live in their comfortable home environment, being somehow protected. Furthermore, the expensive healthcare facilities are getting free to be used for intensive care patients as the preventive measures are getting at home. The remote systems can monitor very important physiological parameters of the patients in real time, observe health conditions, assessing them, and most important, provide feedback. Sensors are used in electronics medical and non-medical equipment and convert various forms of vital signs into electrical signals. Sensors can be used for life-supporting implants, preventive measures, long-term monitoring of disabled or ill patients. Healthcare organizations like insurance companies need real-time, reliable, and accurate diagnostic results provided by sensor systems that can be monitored remotely, whether the patient is in a hospital, clinic, or at home.

Keywords: Healthcare · Sensors · Monitoring · Sensing technologies

1 Introduction

Quality of life in most countries has been increasing a lot over the several few decades due to significant improvements in medicine and public healthcare. Consequently, there is a huge demand for the development of cost-effective remote health monitoring, which could be easy to use for elderly people. The remote health-care monitoring includes sensors, actuators, advanced communication technologies and gives the opportunity for the patient to stay at his/her comfortable home instead in expensive health-care facilities. These systems monitor the physiological signs of the patients in real time, can assess some health-conditions and gives the feedback to the doctors. Why these systems are so comfortable and necessary to use? The first reason is that they are portable, easy to use, with small sizes and light weight. A typical example is a

Health-care Monitoring System (HMS) that mostly uses a microcontroller, which tracks and processes health data and sends an SMS to a doctor's mobile phone or any family member who could provide emergency aid (Fig. 1). The main advantage of this system is that a person could carry it everywhere because the device is small, light and wireless. Another advantage of these systems is that they can monitor health conditions in real time and all the time. People use HMSs in hospitals, for home care, and to track the vitals of athletes (heart rate, blood pressure, and body temperature). All this data can be processed by various sensors integrated into the systems.
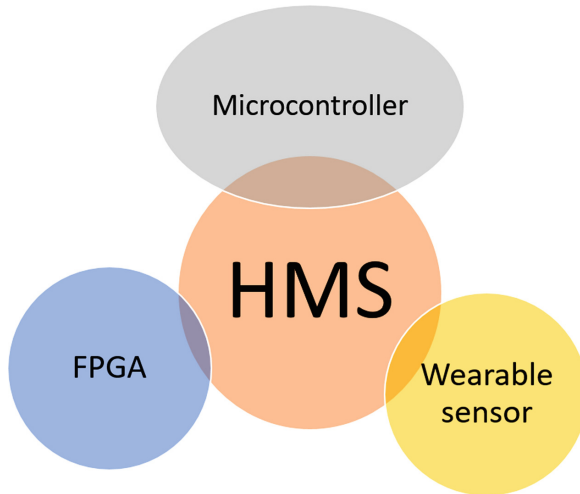

Fig. 1. Block diagram of Health-care Monitoring System (HMS).

Health monitoring systems can use microcontroller, wearable sensors or FPGA.

A transmitter receives physical signals of the heartbeat, processes the data and sends through Wi-Fi to the ZigBee. Then the data is transferred by the receiver to the computer. The transmitter uses a microcontroller which detects the patient's pulse and converts it to a voltage signal and then displayed. The idea is the same with HMS with wearable sensors, the difference comes in the fact that here the sensors which detect body temperature, blood pressure or a heartbeat rate are located on patient's body with no wires. For wireless data transmission in short distances protocols such as Bluetooth or ZigBee are used. The wireless sensor device contains respiration sensor, electro dermal activity sensor (EDA sensor) and electromyography sensor (EMG sensor). FPGA means field-programmable gate array, which could be programmed after production through HDL (hardware description language). A Health-care monitoring system using this technology contains a low-cost, analogue-to-digital converter. Digitization allows users to connect the FPGA to the entire system.

E-health Monitoring Architecture can be divided into three main layers as shown in Fig. 2.
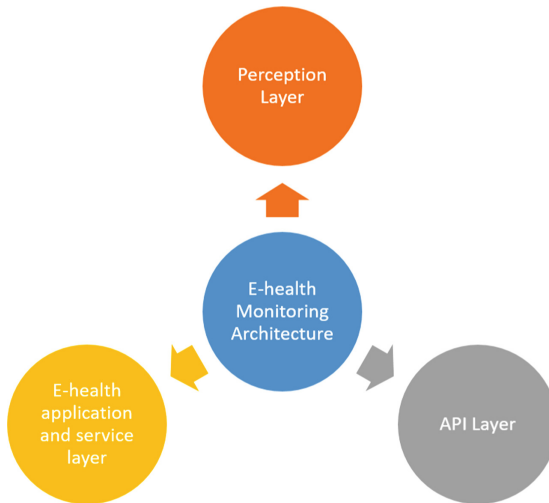
Fig. 2. E-health Monitoring Architecture.

Perception layer contains different medical and environmental sensors that are collecting data in real-time. Medical sensors measure patient's vital signs while environmental one's measure indicators, which affect a patient's condition, such as the oxygen level or room temperature.

API layer includes various application programming interfaces (APIs). The data is stored through cloud technologies providing access to patient's health data and current health records. The API layer is a layer that stores new patient health information by generating a profile using one API, and displays existing medical information for a previously registered patient data using another API.

Service layer contains an e-health application, which analyses the received data and suggests methods to improve patient's condition or give a prescription. The data is analysed by integrated algorithm and can be compared to other patient's experiences or previous health status of the same patient. This layer is responsible for alarming the medical staff in case of emergency.

HMS is an efficient instrument that can save human lives. It is compatible and can be configured depending on patient's needs, which make it cost-effective and useful not only for hospitals but also for home use.

2 Identification and Sensing Technologies

The evolution of semiconductor VSLI technologies has led to the appearance of low-power processors and sensors as well as intelligent wireless networks coupled with Big Data analytics. These are the basic building blocks of the prosperous notion of Internet of Things (IoT) in which context arises the development of identification and sensing technologies. At its core, Internet of Things is about connecting devices (things) and

letting them communicate with other devices and applications. Hence, the IoT paradigm requires for networking and sensing capabilities.

At present, the objective is to transduce (sense), acquire (collect), and analyze (process) information from various objects around us in order to ensure optimal resource consumption. The solution to this request is the Internet of Things which represents the capability of connecting every applicable device to the Internet. The huge amount of generated data could be processed by using cloud services, i.e. effective and accessible data frameworks that are able to provide computing as a service.

In the last two decades networking has been well developed and widely spread as a solution to dealing with information of any kind. In brief, the objectives of information technology are to make not just information machines, but information environments that are allowing the access to information from everywhere. The combination of semiconductor and information technologies enabled the use of huge amounts of sensors to be deployed anywhere, not just where electronics and power infrastructure exists, but anywhere valuable information is gathered regarding variety of characteristics a given object or thing.

The notion of controlling things such as rail cars, machines, pumps, pipelines with sensors and SCADA systems is well-known to the industrial world for a century. Dedicated sensors and networks are already deployed in industrial setups ranging from oil refineries to manufacturing lines. But historically these networked sensor control systems have operated as separate networks with their high-level reliability and security.

Contemporary technology advancements, including electronics, digital embedded systems, wireless communications, and signal processing, have made it possible to develop sensor nodes with sensing, control, data processing, and networking features. Connecting these sensor nodes in networks enables the backbone for the Internet of Things and Big Data era.

Smart Sensors

Sensors' importance is constantly growing as a component of overall solutions for environment monitoring and assessment, eHealth (digital healthcare) and Internet of Things (IoT). Besides, there are plenty of appearing sensor applications to spread across large areas while retaining flexibility and comfortability. The sensor market will exceed trillion sensors per year soon. Therefore, for smart sensor development, the manufacturing should be low cost, high output and with short fabrication cycles [1].

Smart sensor is a device that samples signals taken from the physical environment and processes them with its built-in computing resources before passing them to a centralized sensor hub. Smart sensors are key integral elements of the IoT notion. One implementation of smart sensors is as components of wireless sensor networks (WSNs) whose nodes can number in thousands, each of which is connected with other sensors and with the centralized hubs.

Smart sensors have numerous applications including scientific, military, civil, and home applications.

Gas Sensors

Gas sensors are a class of chemical sensors. Gas sensors determine the concentration of gas in its neighborhood. Gas sensing systems are increasingly investigated for applications in environmental monitoring (air quality control, fire detection), automotive industry (fuel combustion monitoring and polluting gases of automobiles), industrial production (process control automation, detection of gases in mines, detection of gas leakages in power stations), medical applications (e.g., electronic noses, alcohol breath tests), boiler control, home safety, etc [2].

Different types of gas sensors exist such as optical, surface acoustic wave (SAW), electrochemical, capacitive, catalytic, and semiconductor gas sensors. Gas sensing methods can be split into two categories: based on variation of electrical properties and based on variation of other properties [3].

The electrical variation methods rely on the following substances as a sensing material: metal-oxide-semiconductor (MOS) stacks, polymers, moisture absorbing materials, and carbon nanotubes. MOS-based sensors are detecting gases via redox reactions between the target gas(es) and the oxide surface; the variation of the oxide surface is transformed into a change of the sensor's electrical resistance [4]. MOS based sensors have been widely utilized as they are low cost and have high sensitivity. However, some MOS sensors need high operating temperature, which restricts their application. The problem is solved by implementing microsensor components with microheaters produced by VLSI CMOS technology [5]. Another issue is the relatively lengthy time needed for the gas sensor to recover after each gas exposure, which is impractical for applications where gas concentration changes quickly. Studies of MOS nanodimension structures (e.g. nanowires and nanotubes) have shown that they could provide a solution to overcome these disadvantages [6].

Polymer-based sensors are detecting gases using a polymer layer that is changing its physical properties (mass, dielectric properties) upon gas absorption. Polymer sensors detect volatile organic compounds such as alcohols, formaldehyde, aromatic compounds or halogenated compounds. The detection process is occurring at room temperature (as opposed to MOS sensors). Polymer gas sensors possess benefits such as high sensitivities and short response times. Their shortcomings include lack of long-term stability, reversibility and reduced selectivity [3].

Carbon nanotube sensors overcome the problem of insufficient sensitivity at room temperature observed at MOS sensors. The properties of carbon nanotubes (CNTs) allow the development of high-sensitive gas sensors. CNT sensors demonstrate ppm-levels response for a range of gases at room temperature, which makes them perfect for low power applications. Their electrical properties carry high sensitivity to very small quantities of gases such as carbon dioxide, nitrogen, ammonia, oxide, and alcohol at room temperature (unlike MOS sensors, which should be heated by a supplementary heater in order to operate normally) [7]. CNTs could be categorized in two: single-walled carbon nanotubes (SWCNTs) and multiwall carbon nanotubes (MWCNTs). Single-walled CNTs are mainly used in RFID tag antennas for toxic gas detection [8]. Multiwall CNTs have been employed for remote sensing of carbon dioxide (CO_2), ammonia (NH_3), and oxygen (O_2) [9]. To enhance selectivity and sensitivity of sensing, CNTs are often combined with other materials.

Moisture absorbing materials could be embedded with RFID tags for detection of moisture, because their dielectric constant might be altered by the water content in the environment. They can be used also as a substrate of the RFID tag antenna because the dielectric constant of moisture absorbing materials could be regulated by the moisture of the neighboring air. The tags enveloped by moisture absorbing material are appropriate for mass production and low cost [3].

The methods for gas sensing that are based on variation of non-electrical properties include optical, calorimetric, gas chromatograph, and acoustic sensing. Optical sensors rely on spectroscopy, which uses emission spectrometry and absorption. The principle of absorption spectrometry is based on absorption of the photons at specific gas wavelengths; the absorption depends on the concentration of photons. Infrared gas sensors operate on the principle of molecular absorption spectrometry; each gas has its own particular absorption properties to infrared radiation with different wavelengths. In general, optical sensors could attain better selectivity, sensitivity, and stability in comparison to non-optical methods. Still, their applications are limited due to their relatively high cost and the need for micro sizes [10].

Calorimetric sensors are solid-state devices. The sensitive elements consist of small ceramic "pellets" with varying resistance depending on the existence of target gases. They are detecting gases with a substantial variation of thermal conductivity with reference to the thermal conductivity of air (e.g. combustible gases).

Gas chromatograph is a classic analytical method with exceptional capabilities for separation as well as high selectivity and sensitivity [11]. However, gas chromatograph sensors are expensive and their miniaturization still requires technology advancement.

Ultrasonic based acoustic sensors are principally classified as (1) ultrasonic, (2) attenuation, and (3) acoustic impedance. Best studied is the ultrasonic category, i.e. the measurement of sound speed. The major method for detection of sound velocity is to determine the time-of-flight that measures the travel time of ultrasonic waves at a known distance to calculate their speed of propagation. The measured gas speed is used for (1) identification of gases by determining gas properties such as gas concentration, which is related to the difference of sound propagation time, and for (2) determining the components or the molar weight of various gases in mixtures proceeding from thermodynamic considerations [12]. Generally, ultrasonic sensors can overcome some shortcomings of gas sensors such as short lifetime and secondary pollution.

Attenuation is the energy loss due to thermal losses and scattering when an acoustic wave propagates through a medium. Each gas demonstrates particular attenuation, which is giving the means to determine target gases. Gas attenuation can be utilized together with sound velocity to find gas properties [13]. However, the attenuation method is not so reliable as the method of sound speed because it is prone to the presence of particles and droplets or the turbulence in the gas.

Acoustic impedance is typically employed for assessment of gas density. Therefore, by the quantified acoustic impedance and speed of sound, the density of a gas could be found out. In any case, the quantification of the acoustic impedance of gases is remarkably troublesome, particularly in a process environment and consequently it is rarely used in practice.

Biochemical Sensors

Biochemical sensors can convert a biological or chemical amount into an electrical signal. The biosensor includes a receptor (usually a biocomponent such as analyte molecule which performs the actual molecular detection of the targeted element), chemically sensitive layer, transducer and electronic signal processor.

We may categorize biochemical sensors in several aspects. Considering the observed parameter, sensors can be categorized as chemical or biochemical, taking into account their structure they can be disposable, reversible, irreversible, or re-usable. With respect to their external form, they can be classified as planar or flow cells. Biochemical sensors intended for detection of electrical signal either directly sense the electric charges (amperometric sensors) or they sense the electric field induced by electric charges (potentiometric sensors) [14].

System-on-chip (SoC) biosensors are integrated on-chip and connected the active circuitry. SoC biosensors have numerous improvements with respect to sensors based on principles such as mechanical, optical and other methods. A major advantage is the ease of integration in CMOS integrated circuits that provides compact size, immunity to noise, potential to multiple detection of the biomolecules, etc. For cost-efficient commercialization of SoC sensors, it is crucial that all manufacturing processes are completely compatible with CMOS technologies [15].

Planar semiconductor (CMOS technology) devices can be used as the foundation for biological and chemical sensors where sensing can occur optically or electrically. Planar Field Effect Transistors (FETs) can be converted to chemically sensitive sensors by adjusting their gate oxide with membranes or molecular receptors to sense an analyte of interest. Fundamental rule of the molecular detecting is the selective attraction between the test molecules and the target molecules. As the target molecules have electrical charges in the electrolyte solution, the nearby channel conductance is affected by these electric charges via the field effect. The electric charges have dissimilar shape depending on the biochemical reactions associated with the particular detection. Interaction of a charged probe will result in accumulation or depletion of carriers within the transistor structure, which can be electrically detected by observing a direct variation in conductance or related electrical property [16].

Most of the electrical biosensor chips are based on CMOS and MEMS technology. MEMS systems are a combination of electronics and mechanical structures at a micro- and nanometer scale. The reason for using these technologies is the ease of integration onto a CMOS chip in which the electrical signals are processed. Typical applications include poly-silicon nanowire-based DNA or protein sensors, cantilever-based DNA sensors, pH sensors based on Ion-Sensitive-FET, glucose sensors, temperature sensors, etc.

Generally, the characteristics of a sensor include sensitivity, detection limit, and noise. The limit of detection is characterized as the minimum concentration of the target molecules to be detected by the sensor. Noise can originate from non-selective tying between the noise molecules and the test molecules because in practice, the noise molecules are significantly more in number than the target molecules so that the avoidance of the non-selective tying is crucial for biosensor operation [17].

Another class of biochemical sensors transduce the chemical tying into mechanical deformation. Chemical reactions provoke mechanical deformation adherent to the

nature of nanotechnology, e.g. the ion channels in a cell membrane are proteins that control ionic permeability on lipid bilayer film and the activity of this protein is managed by the mechanical surface stress induced by chemical reaction [18].

One approach to utilize chemical-mechanical transformation is to use micro or nanometer scale cantilevers. Micro and nanocantilevers exhibit change of surface stress caused by a particular biomolecular interaction, for example, self-assembled monolayer arrangement, hybridization of DNA, cellular and antigen-antibody binding. These methods are barely accomplished into a compact gadget because of the massive optical detection equipment and poor selectivity performance [18].

Implementation of membrane technology is an alternative surface stress sensing mechanism. Polymer transducers with thin membrane are capable to exhibit of biomolecular sensing. The variation of adsorption quantity on the resonator is determined by detection of resonance frequency detection. Thin membrane transducers have a couple of valuable characteristics: (1) they are stronger and more solid than cantilever beams and they are very responsive to surface reaction, which allows easy functionalization by using mainstream printing techniques, and (2) the sensing surface is physically separated from the electrical detection surface, which is suitable for accurate low-noise measurements of capacitance [19].

In addition to the conventional field effect transistor CMOS technology, printed thin-film transistor (TFT) technology could be used for sensor development as well. In contrast to the silicon SMOS technology where MOSFETs are made on silicon substrate, TFTs could be fabricated on substrates such as plastic, glass, paper, etc. With printable TFT innovation, it is possible to incorporate an extensive variety of organic, inorganic, nanostructure functional materials for electronics, batteries, energy harvesting and sensor and display devices through coating or printing processes. This enables a new generation of low-cost, large-area flexible electronics generally unachievable with conventional silicon IC technologies. Nevertheless, there is an extensive trade-off in the device performance and integration density if using TFT technology compared to traditional Si-microelectronics [20].

Different selections of solution processable semiconductor materials are existing for TFTs: metal oxide, organic semiconductors, carbon nanotubes. The quick advances in materials widens the opportunities for manufacturing organic transistors and circuits using printing processes. Of all these, the organic semiconductors are distinguished for its mechanical flexibility, fast processing at low temperatures, and great potential for further performance improvement [21].

For practical sensor development, a hybrid integration of transducer circuits composed of printed transistors and a common read-out and signal processing chip might be employed. Various sensing materials together with an antenna can be incorporated into the transducer in the printing processes [22].

Wireless Sensor Networks

Current developments of Micro Electro Mechanical Systems (MEMS) technology and communications allowed for the advent of low-cost, low-power sensor nodes having multiple functions in a compact formfactor. They are the basis of wireless sensor networks.

Wireless Sensor Networks (WSNs) comprises huge number of sensor nodes (also called motes) that are spatially distributed autonomous devices that can accept input information from the connected sensor(s), process the information and transmit the output to other devices via a wireless network. WSNs were driven initially by military applications (e.g. battlefield surveillance), but now they are transformed in civil applications inspired by the IoT notion, such as home and building automation, traffic control, transport and logistics, industrial automation, environment monitoring, health monitoring, agricultural and animal monitoring, etc [23].

Nowadays, wireless sensor networks are allowing a level of integration between computers and the physical world that has been unthinkable before. Advances in microelectronics and communications industries have been a key enabler of the development of huge networks of sensors. Nevertheless, wireless connectivity of sensors might be considered an application facilitator rather than a feature of the sensors [24]. This is due to the fact that wired sensor networks on the scale that is required would be too expensive to set up and maintain, which means they are unusable for applications such as monitoring of the environment, health, military, etc [25].

Typically, a WSN node contains one or more sensors attached, embedded micro-processor with limited computational ability and memory, transceiver unit, and power unit [26]. These units allow each node to communicate with the network. Communi-cation between the nodes is centralized – it can be a networking platform of dedicated servers or remote (cloud) servers. This network architecture corresponds to the core of the IoT, that is to provide immediate access to information at any time and any place.

The sensor is sampling the physical measure of interest into a signal that is pro-cessed by the subsequent microcontroller giving analogue to digital conversion as well as computational capability and storage. Next, the result is passed to the wireless transceiver unit for connecting to the network [27].

The sensor transducer converts physical quantities into electrical signals. Sensor output signals may be either digital or analogue which requires for the latter case to have an Analog to Digital Converter (ADC) included (either built-in or attached to the sensor) in order to digitalize the information to let the CPU to process it. The micro-processor unit consists of an embedded CPU and memory; the latter includes program memory, RAM and optionally non-volatile data memory. A distinctive characteristic of processors in motes is that they have several modes of operation – typically active, idle, and sleep. The purpose is to preserve power without obstructing the CPU operation when it is required. The transceiver unit allows the communication between the sensor nodes and the communication with a centralized hub. The WSN communication standards include Bluetooth, ZigBee, and 6LoWPAN but the use of infrared, ultra-sound and inductive communication has also been studied. The power unit consists of an energy source for supplying power to the mote. The energy source is usually an electrochemical battery but an energy harvester can also be implemented to convert external energy (such as kinetic, wind, thermal, solar, electromagnetic energy) into electrical energy for recharging the battery; an external power generator may also be used for recharging [25].

Depending on the actual implementation, motes typically (1) realize data-logging, processing, and transmitting sensor information or (2) they are operating as a gateway in the wireless network composed of all the sensors that are sending data to a hub point.

Sensor nodes are described by several parameters ranging from physical weight, size, and battery life to electrical characteristics for the embedded CPU and transceiver unit in the respective node architecture. The parameters being monitored by the motes' sensors include temperature, sound, vibration, light, pressure, pollutants, etc., which means different sensors, should be implemented: thermal, acoustic, vibration, optical, pressure, etc [28].

One approach for handling the data generated by the networks of sensors is to use a platform of dedicated servers for collecting and processing information originating from the sensors. Another approach is to rely on cloud computing service. Typically, general purpose IoT applications rely on cloud computing which inherently provides remote access via Internet [23].

The most popular communication standard is the IEEE 802.15.4 standard (ZigBee and 6LoWPAN). The protocol stack for WSN integrates power with routing aspects. It is composed of 5 layers (physical, data link, network, transport, application) and 3 planes (power management, mobility management, task management) to ensure reliable and power efficient data transmission through the wireless medium [27, 29].

WSNs usually operate in various environments, which make them significantly different from other wireless networks such as cellular mobile networks or ad hoc networks, etc. In addition, WSNs normally have strict requirements for power, computation, and memory. All these constraints predetermine the cost of sensor devices and network topology and pose specific WSN design challenges. The most important design factors include reliability (fault tolerance), density of nodes (network size), network topology and scalability, power consumption, hardware specifications, quality of service, security of communications [30].

Foremost among all is the factor of security. Many WSNs are intended to collect sensitive data (e.g. personal health, confidential manufacturing data of a company, etc.). The wireless character of the sensor networks greatly complicates detecting and avoiding of snooping on the data. Best choice for ensuring WSN security is to implement hardware-based encryption rather than software encryption, which is advantageous in terms of speed and memory handling for network nodes [25].

RFID

Radio Frequency IDentification (RFID) is a notably evolving technology for automated identification based on near-field electromagnetic tagging. It is a wireless method for sending and receiving data for various identification applications. Compared to other identification systems (e.g. smart cards, biometrics, optical character recognition systems, barcode systems, etc.) RFID has many advantages since it is cost and power efficient, withstands severe physical environments, permits concurrent identification, and does not require line-of-sight (LoS) for communication. A RFID can turn common daily objects into mobile network nodes that might be followed and monitored, and can respond to action requests. All these perfectly fit the notion of Internet of Things.

A RFID system typically consists of 3 major components: (1) an application host, which provides the interface to encode and decode the ID data from data reader into a personal computer or a mainframe, (2) an RFID tag, which stores the identification information or code, and (3) a tag reader or tag integrator, which sends polling signals to an RFID transponder (transmitter-responder) or to a tag that should be identified [31].

A tag (analogous to a barcode) is a unique entity that can be attached to an object or a person and thereby enables information environments to remotely distinguish objects and individuals, track their position, detect their status, etc. The RFID tag is a microchip with programmed identification plus an antenna. The distance between the tag and the tag reader (in fact the reader is the base station) should be short enough so that the signal could be coupled. In reality, there is no true antenna because no far-field transmission is employed. The tag communicates with the tag reader by electromagnetic coupling via radio frequencies. Parts of the tag and parts of the reader are coupled together in a way that is analogous to the transformer windings (inductive coupling) or as opposing plates in a capacitor (capacitive coupling). Generally, the information acquired by the tag is further processed by a more complex computer equipment. In fact, the tag is a kind of low-level network, which enables the transmission of sensor data.

The principle of operation is so that the tag behaves as an electrical load on the tag reader. Hence, the tag can transfer information to the reader by altering its own impedance. The RFID tag changes the value of the impedance via an electronic chip that is effectively an active switch. In result, the tag is not required to create a transmitted signal, and the impedance switching sample is utilized to encode the data in the tag. At any random moment, a tag reader can just read one tag in its locality and a tag must be read by one tag reader [32].

Tags might be either active or passive. Active tags have a dedicated power supply (a battery). They possess extended processing functionalities and have some capabilities for pressure or temperature sensing. Active tags are characterized with an operating perimeter of hundred meters and a relatively lower error rate.

On the contrary, passive tags have a limited operating perimeter of up to several meters and they are characterized with a pretty high error rate. Passive tags are cheaper and that is why they are most common in the RFID marketplace. They have no physical power source as they are powered by the near-field coupling between the reader (the radio waves caused by the reader) and the RFID tag. Passive tags have limited processing and communication capabilities but have no sensing capabilities for the information-carrying medium [33].

RFID technology has numerous applications such as tracking of assets and people, healthcare, agriculture, environment monitoring, etc. Many tracking RFID applications are based on the universal communication and computing technologies available [34–37].

A prospective area for development of applications is the integration of RFID systems and wireless sensor networks (WSNs). So far these are relatively separate areas of research and development. The combination of RFID and WSNs would open new scientific and industrial fields by utilizing the benefits of these technologies.

RFID systems are primarily used for identification of objects or tracking their location without delivering information about the object and its physical condition. In numerous applications the location or the identity of an object is not enough and extra information is needed – it can be extracted from other parameters characterizing the environmental conditions. Sensor networks could help in such cases. WSNs are systems consisting of small sensor nodes that can collect and deliver information by detecting environmental conditions, for example, temperature, humidity, light, sound, pressure, vibration, etc [38]. Nevertheless, the identity and location of an object is still vital information and it can be extracted by RFID techniques. In these situations, the

ideal arrangement is to combine both technologies in order to ensure extended capabilities, portability, and scalability [39].

Sensors with integrated RFID tags can be classified in two categories: (1) tags communicating with RFID readers only and (2) tags communicating with each other and creating an ad hoc network [38]. RFID systems can be combined with wireless sensor networks by integrating the sensor nodes with RFID readers [40]. Another option for integration is the so-called mixed architecture where the sensor nodes and the RFID tags remain physically separate but they exist together and they operate separately in an integrated network. Accordingly, it is not necessary to design a separate hardware device in order to integrate the benefits of both technologies.

3   Monitoring and Assisted Living Systems for Elderly and Disabled People

Trend of the European Population

The proportion of the adult-population in the European Union is in a phase of rapid increase. The aging of the population is accompanied by increased occurrence and spread of chronic diseases, and hence a significant increase in healthcare costs. Staying at their own homes, or at places freely chosen by the elderly people, is one of the approaches already taken improve the quality of life and to reduce healthcare costs of the aging population.

The idea is to support elderly people to improve their quality of life and to create better conditions for their stay in the environment of their choice. To do this, it is necessary to develop modern equipment and systems for health status monitoring and to introduce comprehensive eHealth technologies. The use of such technologies at home or at home-like setting is still in its infancy, but this method is one of the most promising approaches to facilitate the independent living of the elderly people.

Combining health monitoring systems with smart home technologies (Fig. 3) makes it much easier for elderly people to access medical care without the need to leave their homes.

Contactless sensor systems provide 24-h surveillance of the elderly in their homes by collecting data from different sensors and fusing them from the so- "Data aggregators". Data aggregators can be devices that provide only simple offline storage and analysis features. However, in modern monitoring systems, they typically perform pre-processing and retransmission of online analysis data to systems of higher hierarchical level.

In addition to monitoring some medical-specific indicators, the main groups of indicators that can be monitored (Fig. 4) are related to:

- Activities of everyday life
- Safety
- Location - Position system
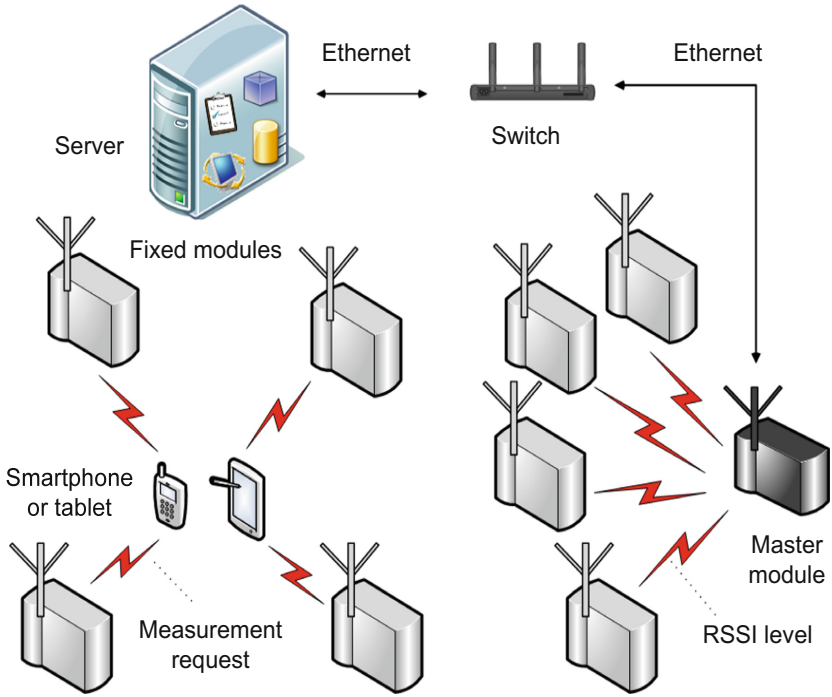- Characteristics and speed of gait.

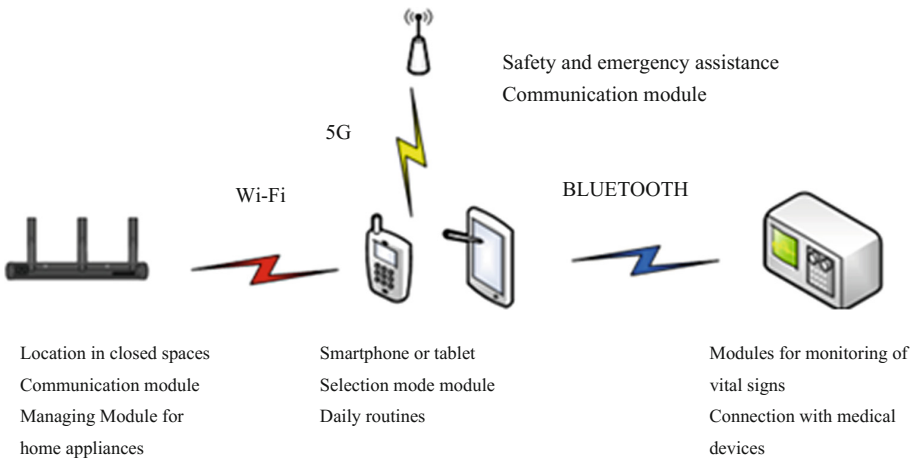**Fig. 3.** Combining health monitoring systems

Fig. 4. Main groups of indicators.

Since the end of the last century, global trends have seen a rapid increase in the share of elderly people. In 2035, one-third of the Europeans will be over the age of 65 [41]; for the USA this figure is expected to rise to 70 million in year 2030. This

estimated figure is double than the one counted in 2000. In 2009 the average age, which allows daily activities can be carried out without difficulty, was about 67 for women and 63 for men.

The most developed countries are concerned about the aging of their population [42]. Quality of life is deteriorating with aging, which leads to worsening the skills and abilities of the people [43]. Statistics show that 30% of adults fall at least once per year and 75% of these events can even cause death. Much of the elderly people suffer from chronic illnesses that require medical treatment or periodic reviews.

Various initiatives have been taken to handle these issues. One approach is the called Assisted Living Systems (ALS). It acquires immense importance in helping elderly people who live alone in their own homes and need care [44]. The proposed assistance aims at increasing the autonomy and quality of life of the consumer and contributing to its social consolidation. The results in this area have a direct public impact. Many authors have discussed the requirements and engineering aspects of ALS.

Development of technology and research are directed towards systems for fall detection, detection of pressure to a chair or bed, video monitoring, motion and tilt sensors and devices, accelerometers, smart clock with gyroscopes or worn on the belt [45].

A European Union initiative [46] is being undertaken to increase the care of the aging through the penetration and use an information and technologies of communication. It aims to help elderly people to carry out their daily activities, thereby increasing their autonomy [47].

Assistive Systems: State-of-the-Art [47]

Ambient Assisted Living (AAL) includes concepts, devices, systems, methods, and services that ensure constant support without intruding user's system. Assisting everyday life depends specifically on the situation of the user. The technologies that are used in AAL are user-centric, that is, oriented to the potential needs of the particular consumer and integrated into the user's immediate personal environment. As a result, the technology adapts to the user, not vice versa. Internal and external monitoring is necessary especially for elderly people or people with disabilities (heavy hearing, deafness, limited mobility, etc.) The use of intelligent sensors is a desirable service that can potentially increase consumer autonomy and independence, while reducing the risk of life alone.

The services and systems developed aim being tailored to elderly people and their cognitive problems. By default, it is expected that the systems are able to integrate several subsystems that have been developed by different manufacturers [48]. Also, it is expected that every user could to adapt quickly and easily so that no constraints and difficulties arise. However, the real implementations are still fragmented and isolated.

One of the major projects in the field is Intel's fashionable smart home [43]. The aim is to help elderly people by making use of four technologies: sensors, networks, monitoring daily activities and environment visualizing. Sensors determine the location of people and objects. The networks integrate motion sensors, cameras and switches that define the activity and visualize the environment.

The idea of automating and introducing technology into people's homes is to build a positive home atmosphere. Numerous authors make analyses of experimental data from

sensor systems used to monitor and demonstrate the functional capabilities of elderly people and analyze and produce statistics on how they change over time. The built-in system includes sensors in all rooms: kitchen, living room, vestibule, bedroom, bathroom, etc. There are high requirements for data visualization displays as it reflects to the end-user perception of the service [47].

The Intelligent Home Monitoring System at the University of Virginia [49] focuses on collecting data using a set of cheap, unobtrusive sensors. The information was recorded and analyzed in an integrated data system. It is managed through the Internet and collects the information in a passive way respecting the privacy of the older adults.

The Rochester University [50] developed a prototype smart medical home, consisting of computers, infrared sensors, video cameras and biosensors. The main service is used for a medical consultation through a conversation between the medical person and the patient. The activities and movements of the users are also monitored. The process supports decision making for the patient and caring personnel.

Hong Sun and others [51] show arguments that most of AAL's ongoing efforts to tackle older people's problems do not fully reflect the importance of social activities. Intelligent sensors and devices use has preference in comparison to the more important than human interaction. The AAL's assume that the older adults are passive and weak by default and it is not true in all cases as some people desire to support monitoring.

The SOPRANO Integrated Project [52] aims to extend the time that people can spend living alone in their own homes being independent in their activities and feeling safer. Required technologies include products and services that allow people to perform their everyday tasks.

Aviles-Lopez et al. [53] tested a lab platform for deployment at home for the older adults. This research aimed at helping people with physical and psychological abnormalities such as arthritis, Alzheimer's disease, diabetes, senile dementia, and cardiovascular diseases coming from the aging process. It is achieved by maintaining a certain degree of independence using new types of mobile embedded computing devices, wireless intelligent sensors and so on. The platform is contextual, mobile, invisible, and adaptable supposing that the users are traced and identified in space thanks for the wearable device as watch, bag, cups or other embedded accessory in clothing. If the older user has suffered a fall or an unpleasant event, the system should alert caring personnel without any interference. The communication way to the end-user and data on blood pressure, sugar levels, etc. have to be acquired, extracted and transmitted in a reliable and way.

Drug management applications have a special place in the daily schedule. customized approach towards this problem is presented in [47].

In this way, the supervising medical consultant could do a medical examination remotely and change the dose of any drug. Other components of the supervision include cameras and sensors with a built-in accelerometer. This provides an opportunity to track the motion of users and instantly record an event such as a fall. Patients who use electrically powered wheelchairs can move freely. However, very often they need help in opening or closing doors.

Various studies have found that large TVs and monitors are not the most appropriate means of monitoring. The whole system should be easy to use by the elderly. They find it difficult to adopt new technologies that they cannot understand. Homes are

equipped with sensors that measure the state of the users and maintain communication with their friends and relatives.

Holtzinger and others [44] assessed the wrist unit that is well received by users. It is designed to monitor the vital signs and detect different situations such as loss of consciousness, detection of falling, etc. Healey and others [54] presented a monitoring prototype system that can record, transmit and analyze permanent echocardiogram data. The system is also designed to have the ability to record events, activities, and various medical symptoms.

Different researchers do experiments using systems to monitor daily activities, activity, exercises and medical tests. Madeira et al. [55] looked at the possible enhancement of the quality of life of the elderly people through telemedicine. The proposed system combines intelligent items such as wheelchairs and walkers with corresponding built-in sensors for remote measurement of mechanical and physiological parameters. In this way, the elderly will be monitored in different situations.

Some studies [56–58] focus on the development of a smart home where the elderly and disabled people can enjoy quality of life and greater independence. Smart monitors can constantly monitor patients and their vital parameters. Technologies that can track changes in activities and alert the care provider are: a smoke detector; flood detector; temperature sensor; gas detector; occupancy sensor for bed; occupancy sensor for the chair; a fall detector; hanging around the neck, on the wrist, or clinging to clothing; an epilepsy sensor located under the bed and more.

The publication of Wang et al. [59] describes the prototype of the so-called I-Living Assisted Living architecture, which includes various built-in devices such as sensors, actuators, displays, and Bluetooth-enabled medical device. This device may be a dedicated computer or black box equipped with one or more wireless interface cards. Independent devices can communicate with the appropriate server over the Internet that provides web-based interfaces to allow cares, healthcare providers and healthcare professionals to monitor the environment and analyze measured data.

De Florio and Blondia [60] do not believe that the expansion of the traditional approaches to social organization might be enough to provide effective support for the elderly [47].

All listed and described projects are only part of the AAL activities collected. Analyzing the results and new opportunities and trends shows that the topics discussed are up-to-date and will continue to develop significantly in the coming years. Various projects are aimed at solving many problems of some groups (adults, adults with special needs and people with diseases). Applied approaches and applications are specific, which limits the dissemination of results.

Flexibility of systems is a prerequisite for universality, as far as possible, of hardware that would lead to rapid production of the product at a reduced price. Similar to telemetric monitoring systems for high-risk patients, relatively simple AAL systems can perform two main tasks:

- Warning about life-threatening situations
- Minimize false signals, which are the common cause of system compromises.

In addition to the constantly available communication interface between the observer and the user, it is also possible to automatically detect falls as well as momentary observation of many vital parameters.

4   Risks and Accidents Detection for Elderly Care

In order to improve people's lives, it is very important to reduce threats when people get older, such as detect and prevent falls. The research areas as fall detection (FD) and fall prevention (FP) have been developed for over a decade trying to improve people's lives through the use of pervasive sensing and computing. The most common reasons that can cause falling are obstacles at home and the aging. Getting older, people's bodies pass through some physical changes making them more fragile, and more prone to falls.

Why is so important to detect falls? Falls can result in critical injuries, especially for the elderly. The longer someone stays unassisted, the less chance he/she has to make a full recovery. Unfortunately, a fall detection system does not detect all fall cases. The most common injuries are to the head and lips which results in long-term complications. So, the faster help is very important in these cases [61].

Fall sensors use advanced technology to detect your movements and the position of human's body. They are able to give the difference between an emergency case and everyday movements, for example, can detect if the person is just laying down or there is a sudden change in the position, which means a fall.

Most falls happen at home because there are a lot of hazards there, such as slippery floors, clutter, poor lighting, unstable furniture, obstructed ways and pets, etc [61].

The first measure to be taken into account is to conduct a detailed analysis of the house and to identify the possible reasons which may lead to injuries. Then a preventive checklist can be developed to minimize the risk of fall.

Figure 5 demonstrates an example of a wearable elderly care system. The technologies are used for detection of accurate positioning, tracking the physical activity and monitoring the body signs data.

In order to track precisely the position of elderly people, a precise positioning sensor network should be developed in real time. Also, a software system should be designed with modules for data processing, data extraction, vital signs detection to support human activity recognition (Fig. 6). Biomechanical sensors are needed to monitor the physical state of elderly care which in essence are multiple sensors incorporated into the clothing, for example.

Overall, a wearable system consists of interconnected modules that can be placed at different body areas. Each module consists of sensors, Analog to Digital Converter (ADC), Radio Frequency, computing elements, circuitry and hybrid power supplies. When designing such systems, it should be taken into account the so called "wearability", which means weight, form, heat generation, flexibility and other properties. In technical point of view, the main considerations include the power consumption and overall system size in order to achieve good "wearability" [62].
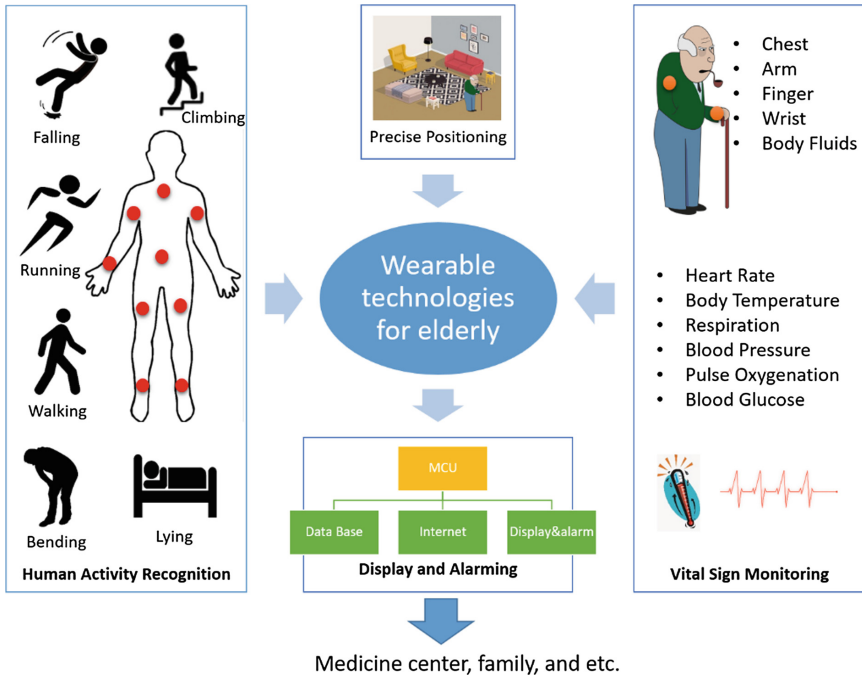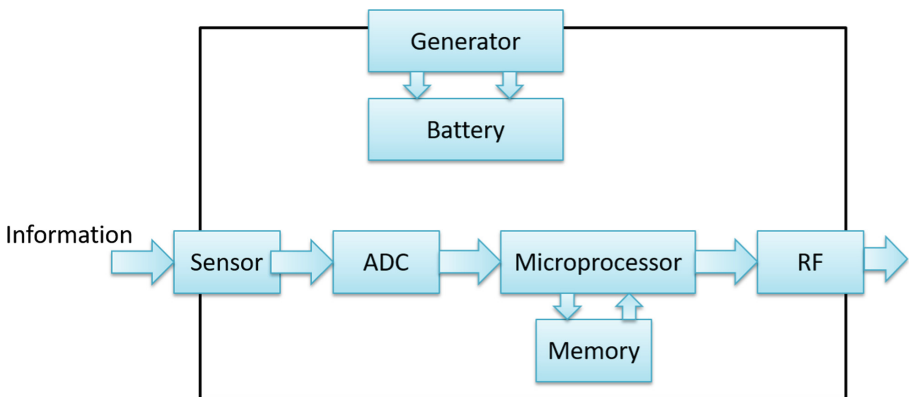
Fig. 5. Wearable elderly system

Fig. 6. Monitoring system for data processing

One fall detection (Fig. 7) and prevention systems consist of either external sensors or wearable sensors. External sensors depend on subject of interest (SOI), and wearable sensors are attached to the SOI.

The most common types of external sensors are the camera sensors. They are placed in fixed locations where the person daily activities will be performed. The main
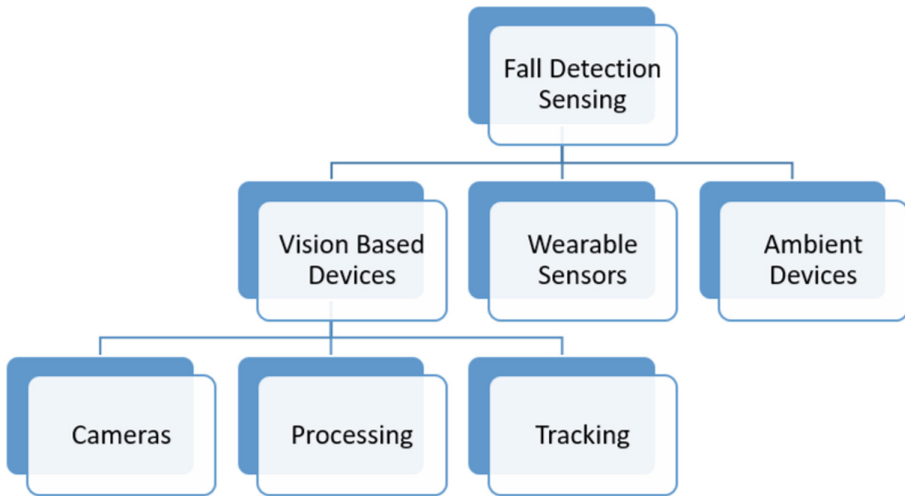
Fig. 7. Fall detecting sensing components

disadvantage of these sensors is that the person can fall out of the visibility area and the system can be unable to track the user.

Another type of external sensors is the proximity sensors, which are used in fall detection systems. They are commonly attached to walking-aid devices (cane, walker, etc.). When the user suddenly falls, the sensor detects the change of the position of the SOI. The disadvantages involve the price of such sensors and the short proximity range.

An alternative to the external sensors is the wearable sensor, which is employed into fall detection and prevention systems. They are attached to user's body and are cheaper than the external sensors.

Widely used in fall detection systems are the accelerometers because of their price and the fact that can be placed on different parts of the body. They can also be embedded in other devices as shoes, belts, watches, etc. The advantage of accelerometers is that with a single sensor a lot of movement characteristics can be successfully detected, especially falls.

Wearable Sensors for Fall Detection

Due to the rapid development of Micro-electro-mechanical systems technologies, such as accelerators, gyroscopes, magnetic sensors, particularly wearable sensor-based human activity recognition technologies, such devices become more and more attractive for use in ambient assisted living systems, especially in monitoring elderly people. Because of the advances in these technologies, MEMS sensors become cheaper, lighter and small enough to carry. These systems do not require the use of base station, as cameras which have to be installed on particular area. These systems collect the data in passive mode and do not create electromagnetic pollution. Accelerometers and gyroscopes are easy to wear but also have less power consumption and also less sensitivity to body movements, which may cause false alarms. But from a commercial point of

view, this technology is the most utilized one for commercial devices and can take the form of a belt or watch, for example. In order to minimize false alarms using such kind of sensors, researchers propose different methods, such as placing the sensor into human's head or ear [63–65].

The advanced wearable sensors incorporated multiple sensor technologies, for example in [66] proposed a system of gyroscopes and accelerometers, another approach has barometric sensors in additions for high variations sensors.

Interesting solutions for fall detections and prevention away from home became attractive after phone technology developments. In [67] a very promising solution is proposed that reports 100% fall detection prevention. The system is based on accelerometers which are used in mobile phones.

There are also systems that can not only detect a fall but also can specify the fall type. Such systems are proposed from [68, 69] and incorporate a tri-axis accelerometer, gyroscope and magnetometer, as well as the data processing, fall detection and messaging.

Ambient Devices for Fall Detection

Ambient devices detect the environment of a person under protection. The technologies are used in commercial fall detection devices and the most common one is the infra-red technology, but there is also vibration sensing, noise sensing, etc. In order to cover the whole area, the system has to be installed in all needed rooms which is one of the drawbacks of such systems.

One example of infrared ceiling sensor network (Fig. 8) is proposed by [70]. They are using the "values of pixels" as features, 8 activities recognition, which are performed by 5 subjects at an average recognition rate of 80.65%. They have obtained a performance of 95.14%, the false alarm recognition of 7.5% and the FRR of 2.0%. This accuracy is not sufficient in general but high according to with such low-level information.

It is explained that such system has the potential to be used at home providing personalized services and detecting abnormalities of elders who live alone.

Another way for fall detection is through vibration sensors, which are incorporated into the flooring. In source [71] a system with 100% success is reported, which detects movement through vibrations. Electromagnetic sensors are present [72] which are again incorporated into the flooring, which can generate images of objects touched to the floor.

There are systems for fall detection based on lasers. A laser is used which interacts with light-sensitive device, which generate together a network of theoretical cross-sections, which detect stable objects [73].

Vision Based Devices for Fall Detection

Systems based on object monitoring have the same disadvantage as ambient devices and must be installed in all necessary rooms in order to cover the required range. Another issue is privacy, working with photo material from everyday life. There are cases in which pictures are sent only when a fall is detected. It is also easy to process these photos; the person's face can be faded.

Camera-based monitor the posture and shape of the subject during and after a fall, which happens in fractions of seconds.
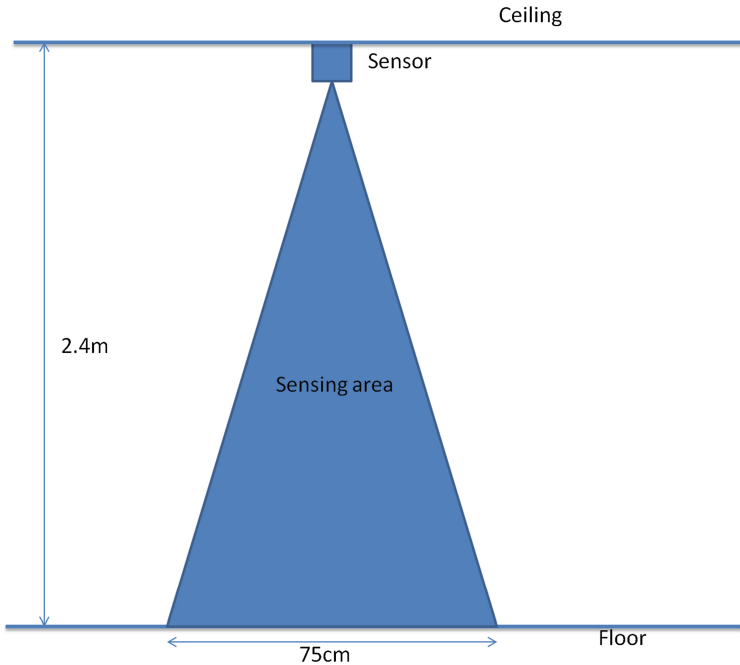
Ceiling

Sensor

2.4m

Sensing area

75cm

Floor

Fig. 8. Example of infrared ceiling sensor network

A considerable amount of processing power is consumed by the image dealing. To compensate the computational cost, images are usually compacted and with smaller pixels in a pre-processing stage.

In camera-based sensing systems there are different ways in detecting falls. Some systems are based on human skeleton, but their computational cost is not valuable for real time situations. Other types calculate and transform some parameters, as falling angle, vertical projection histogram etc., but their disadvantage is the false alarm rates.

Nevertheless, regardless of the number of cameras installed, continuous monitoring is still restricted to the camera locations. Another disadvantage is that such systems are influenced by light variability, which leads to lower recognition from laboratory environment to outdoor environment. Due to such limitations, vision-based human activity recognition systems are not so well suited to most elderly care applications.

A system architecture (Fig. 9), for example, includes a wearable device which is placed on human's waist [74]. The system uses acceleration analysis for fall detection. Then it gets the geographic position of the SOI and send short message for fall alarm.

The system has low power consumed hardware design and highly efficient algorithm which could extend the service time of the wearable device.

Overall, a wearable system is comprised of interconnected modules, which can be installed at different parts of the body. Each module consists of sensors, Analog to Digital Converter, computing elements, RF circuitry and hybrid power supplies (batteries and energy scavenging generator).
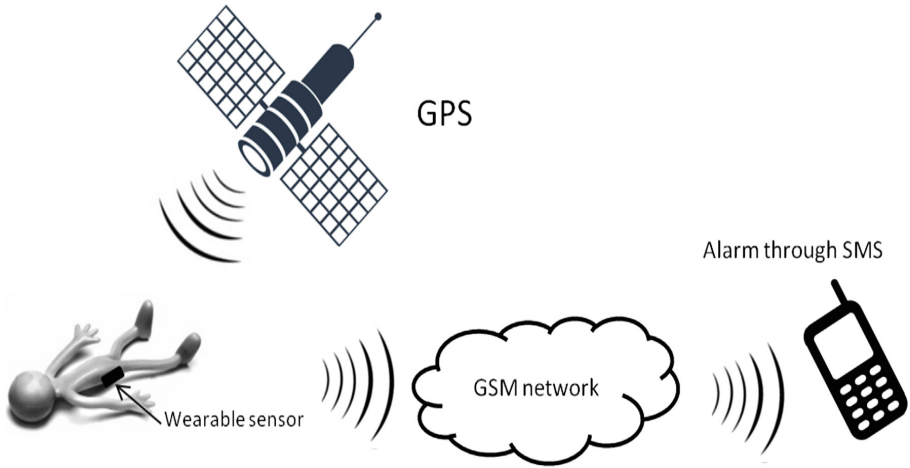
Fig. 9. Example of system architecture for fall detection with wearable sensors

Vital Signs Monitoring

Most elderly people suffer from age-related diseases, as diabetes, hypertension, hypertension, etc. So, it is of great importance to design reliable real-time health monitoring system for elderly care. Most common used are wearable and non-invasive biosensors, which can be put on the body or near the body which can successfully measure a variety of vital signs. In Table 1 a summary of several vital signs is presented.

Table 1. Summarize of most common vital signs.

Parameter	Range	Technology
Rate of the heart	0.5 ÷ 4.0 mV	Skin electrode Optical MI sensor
Body temperature	32.0 ÷ 45.0 °C	Thermistors Optical means Thermoelectric effects
Blood pressure	10.0 ÷ 400.0 mm Hg	Capacitive strain sensors Piezoelectric capacitors
Respiration rate	2.0 ÷ 50.0 breaths/min	Strain gauge/Impedance
Glucose in blood	0.5 ÷ 1.0 mM (millimoles per liter)	Electrochemical
Pulse oxygenation	80% ÷ 100%	Optical means

Body Temperature

One of the most important vital signs to be monitored is the body temperature. Another important issue that should be taken into account is the location at which the temperature will be measured because it is different at the different locations. There are

several means that can be used for measurements, such as thermistors, thermoelectric effect, optical means, etc. The most common technique for non-invasive measurement using wearable sensors is the thermistor. There are methods proposed in [75], where negative temperature coefficient resistors a temperature sensing element is used and the textile wires incorporated into the sensor element are integrated into wearable system for monitoring, in this case baby jacket. Other methods propose textile-based temperature sensor which is incorporated into knitted structure [76]. There are a lot of wearable temperature sensors available at the market that can be directly attached to the skin, as LM35 [77].

Heart Rate

The heart rate is one of the most important signs, especially when we talk for elderly care, which should be precisely monitored. The heart should be in perfect working condition in order to consider that the patient is healthy. The heart rate of a healthy adult in resting position ranges from 60 to 100 beats per minute. Nevertheless, depending on person's activity and physiological state, these values can vary. During the night, a healthy person's heartbeat may vary from 40 to 50 beats per minute, which also should be considered. This parameter can be used in order to diagnose a lot of cardiovascular diseases. Heart rate can be measured through various technologies, as electrical, optical or strain sensors. The electrical measurements include electrocardiography through electrodes. There are some methods for such measurements proposed, for example in [78] chest electrodes are investigated which are silver coated, without the need to use gel or paste during the measurements. Other approaches use soft micro fluidics and adhesive surfaces to achieve highly stretchable state-of-the art systems [79]. Other researches describe magnetic sensitive sensors which are able to measure quasi noncontact pulse rate. These sensors can measure magneto-cardiogram in non-shielded conditions [80, 81].

Respiration Rate

Respiration rate is very indicative parameter for distinguishing diseases as asthma, sleeping apnea, anemia, etc. A healthy resting person respiration rate is typically one breath in every 6.4 s, the amount of inhaled air is approximately 500 mL [77]. Elderly people often have difficulties in breathing normal because the lungs expansion and contraction rates decreases. The methods for respiration rate measurement can be divided into two types, the first one detects directly the airflow during the breathing, the second one measure indirectly responding to chest and its expansion and contraction. For directly measurements sensors can be placed near the nose or mouth and respond to changes in the temperature of the air, the pressure, humidity, the concentration of carbon dioxide, etc [82]. The indirect measures involve physical parameters that need to be monitored, as changes in the lung volume and movement. With the advanced developed textile-based technologies nowadays, there are a lot of sensors available, which can be directly incorporated into the clothing which accurately detect the breath levels without interfering person's comfort. In [83] a garment-based sensing system with piezoresistive sensor is represented, which is able to determine a 10 s pause in breathing.

Blood Pressure

The blood pressure gives the force inside an artery and is typically 120/80 mm of mercury for healthy persons, the systole is 120 mm Hg (maxima) and the diastole is 80 mm Hg (minima) [77]. Blood pressure is typically detected using sphygmomanometers, but they need stationary setup, not cost effective and do not have the possibility of monitoring. Nowadays the state-of-the-art sensors are capacitive sensitive strain sensors [84], which are compressible and piezoelectric. The difference between both of them is that compressible capacitive strain sensors are composed of elastic dielectric, while the piezoresistive sensors are composed of robust dielectric placed between 2 flexible electrodes. When an external pressure is applied to the dielectric, it will lead to change in the capacitance of the device. In the same way, if the piezoelectric material is strained, this will generate an induced voltage in the device. For example, in [85] a conformable lead zirconate titanate sensors are presented, which have piezoelectric response. It is reported that these sensors have 0.005 Pa sensitivity and 0.1 ms response time. Such kind of performance ensures that the sensor can be used for blood pressure measurements. Another approach that can be used for blood pressure measurements is the RFID (radio-frequency identification) technique, but such device require implantation under skin, such as presented in [86].

Pulse Oxygenation

Oxygenation is the oxygen saturated hemoglobin compared to total hemoglobin in the blood, which is saturated and unsaturated. The normal state for the human organism is considered as 95% to 100% blood oxygen level. When this level is below 90% it can cause hypoxemia (more particularly tissue hypoxemia). The oxygenation may be separated into three groups: tissue, venous and peripheral oxygenation. The measurement technique is non-invasive in fresh pulsatile arterial blood. The most common method for measurements is using optic-based device, such as a pulse oximeter. The working principle is based on generated light by light emitting diodes through parts of the body as earlobe, forehead, wrist, fingertips, etc. Nowadays with the advances in organic electronics, the production of OLED (organic light emitting diode) and organic photo-detectors became prime devices for use in pulse oxygenation measurement due to their comfort in use [77]. Such sensors are described in details in [87].

Blood Glucose

The measurements for blood glucose involve the glucose amount in human blood which concentration is usually lower in the morning and increases after every meal. If the blood glucose is out of its normal range, this may indicate health problems as hyperglycemia (low levels) or diabetes (high levels). In recent years, the number of people with diabetes has increased. The World Health Organization reports that 9% of adults worldwide suffer from diabetes [77]. It has been found that frequent (possibly continuous) measurement of blood glucose levels is essential for conducting insulin therapy and minimizing the harmful effects on the body. Modern methods of testing include periodic tests in specialized laboratories or analysis of daily profiles (periodically over several hours), using a portable blood analyzer at home. For this purpose, after a pinch, usually on the fingertip, a certain amount (drop) of blood is delivered to a special test strip which is placed in the analyzer and within a few seconds the current blood glucose level is indicated. These persistent pricks cause discomfort, especially in

young children, and rarely can lead to infections. New developments in the art are directed to alternative methods for measuring glucose concentration, e.g. bloodless, by measuring glucose levels in body fluids (sweat, tears, urine) as indicated in [88]. Saliva nano-bio-sensor is presented there for noninvasive glucose monitoring which provide low-cost, accurate and disposable bio-sensor. Another method for non-invasive method is proposed in [89]. The described methods are still not applicable in mass practice. Another part of the research is directed to the development of invasive methods for the delivery and analysis of blood micro-bleeds. At this stage, there are no data on the implementation and applications in the mass practice of nanobiobs for determining blood glucose levels by analyzing blood micro beats in the absence of pain sensations for the patient.

5   Activity Recognition for Sports

Research of human activity is becoming a most popular and relevant topic for multiple scientific areas. Human activity recognition includes mobile computing [90], surveillance-based security [91], context-aware computing [92] and ambient assistive living [93]. The sensor technologies and data processing techniques have achieved much progress. Work on these supporting technologies has led to developments in the area of data collection and transfer and information integration. Many of the solutions to real problems related to human life are increasingly dependent on the human activity recognition. Recognizing human activity as a topic of work can contribute to many important activities related to security and monitoring, preservation of the environment, help in maintaining independent living and aging, etc. To develop such a system, it is crucial to work on four main tasks. The tasks include selection and deployment of sensors designed to collect information about and capture a specific user's behaviour while simultaneously monitoring respective changes within the environment. Another task is related to the application data analysis techniques which are used for/while processing and storing the accumulated information, to create computational activity models which, when incorporated within complicated software (packages/products), are designed to select algorithms to provoke responsive activities from sensor data through reasoning and manipulation. There is a variety of tools, methods and technologies available to implement each task.

Sensor-based activity is used for activity monitoring. The approaches involve computer surveillance, structural modelling, characteristic elements extraction, action extraction and movement tracking with the main purpose being to make analysis aiming to recognize certain pattern based on collected visual information. Another category is based on the application of recently developed sensor network technologies for activity monitoring [94].

Sensors are attached to the monitored person. This approach is applicable in order to follow physical movements such as workouts. There are multiple types of sensors available for activity monitoring (contact sensors, accelerometers, audio and motion detectors etc.). The sensors are divided according to their purpose – there are different types based on particular output signals, involving theoretical principles and defined by technical infrastructure. They are represented within two basic categories according to

the way they are positioned during the activity monitoring process. Activity monitoring based on Wearable sensor. This type of sensor is attached directly or indirectly to the observed person. While the monitored object performs any type of action, the sensors generate signals. In this way we are able to monitor features which describe the human state of mind and respective motion patterns. The sensors can be put into clothing, in shoe soles or heels, inside cell phones, watches and other mobile devices etc. They can be located directly on the body as well. From them we get the necessary indicators about the position and movement of the test object at a given moment, the pulse, temperature, and so on. There are different types of relevant sensor information applicable for various types of activities. Accelerometer sensors are sensors for activity monitoring. They are used to monitor actions such as body movements such as walking, running, jumping and more. In a paper [95] a network of three-axis accelerometers has been reported. These accelerometers are fixed on different parts of the object's body and provide movement and orientation data for the part of the body that is selected. In [96] are used body worn microphones and accelerometers to measure acceleration and angular velocity through accelerometers and gyroscopes. In the paper [97] provides a method for determining the user's location. With this method, the behavior of sitting, standing and walking can be recognized. Another used wearable sensor are GPS sensors. These types of sensors are mostly applied when monitoring activities involving location changes or open air and mobile environments [98].

The state of the art can be divided into two sub-topics, the recognition of human activity and Human Activity Prediction. Activity recognition is a complex process. The basic tasks include:

- selecting and using appropriate sensors to objects and environments. The main purpose is to observe and capture the user's behavior.
- collection, storage and processing of the information received. This task is performed through data analysis techniques.
- Creating computing models so that software systems generate reasoning and manipulation.
- selecting or developing reasoning algorithms, to derive activities from sensor data.
- Depending on the type of sensor, there are two categories of activity recognition sensors.

The first one is based on surveillance tools, such as video cameras to monitor the object's behaviour and environmental fluctuations. The provided data can be a series of video or digitally presented visual image. Common are computer vision techniques for action extraction, feature extraction, structural modelling, motion detection, and motion tracking to specify pattern recognition.

The second one is based on sensor-based activity recognition using the newly developed sensor network systems for motion monitoring. The acquired sensor data is presented as time series of state changes. They can be used as parameters for data integration, probabilistic or statistical analysis. Beside the already described attachment techniques, the sensors can be also placed within the object's environment as long as the position allows the tracking activity. These types of sensors use inertial measurement units to capture the object's behavior. This method is used for registering motion. The use of multiple multi-modal miniature sensors enables a robust capture of activities

to be accomplished by monitoring interactions between a person and an object. The activity information can be acquired through motion monitoring models. The motion monitoring models can be built to recognize activity models from previous experiments including rich database about monitored persons' behaviors. For this purpose, they can be used data mining and machine learning techniques through creation of statistical activity models. This method is based on data. The actions that follow are based on probabilistic or statistical classification. This approach has its advantages as handling uncertainty and timing information. On the other hand, requires large datasets for training and learning, and also suffers from the problems of scalability and re-usability. Another method involves the use of predefined models with a large database and research results directly using knowledge engineering and management technologies. The models in this method are used for activity recognition or prediction through logical reasoning. Knowledge-driven approaches are semantically clear and easy to get started. The drawback of this method comes from handling uncertainty and temporal information.

The field of vision-based activity recognition is focused on surveillance, improvement of robots and counter-terrorism, and this field includes a wide variety of options.

Human body structure extraction data from images, action recognition and tracking across frames [99], survey on the approaches based on the movement recognition as opposed to structured approaches [100], research focused on monitoring human movement using 2D or 3D models and the other recognition techniques [101] etc.

In the 2000s, a new approach based on sensors utilizing other sensors fixed to objects was development. This approach has been named "dense sensing" approach with the main purpose of performing activity recognition through user-object interactions. Over the past few years, there have been numerous impressive developments in sensor-based activity recognition [95].

There are two approaches:

- Wearable sensors focus mainly on mobile computing.
- Dense sensing-based activity recognition is predominantly driven by smart environment applications such as ambient assisted living. The application smart sensors and sensor fusion directed to biomedical applications and the different types of sport are an interesting topic. There is an ever-growing demand in the field of systems for monitoring with local processing or a network of sensors. We will classify the following activities and will explore how these technologies are implemented in several fields, such as:
- Biomedicine: monitoring biological functions of human;
- Bio signal interfaces: using bio signals for performing activities;
- Physical therapy and sports – this science studies sports and human achievements in this field;

Smart sensors are devices able to acquire, process and display data to users. The interconnection between two or more sensors present in the same system is called sensor fusion. This provides a more complex analysis which is not achievable using a single or multiple separate sensor. Sensor fusion combines this data with strategies to provide consistent and effective responses.

In the sensor fusion, two cases are possible. In the first case, sensors with different signals are merged, while in the second case, data is merged from sensors operating in different situations. The sensor fusion has three levels: acquisition and data merger, fusion of characteristics, and merger of decisions.

Figure 10 shows the three levels of a sensor fusion system. Signal types can be physical, chemical or biological quantities or images. Below is description of processing obtained signals. Smart sensors are used when the accuracy of signal processing complexity is not as significant, but different points should be interconnected. The smart sensors must contain a discrete communication system. In this way the sensors are integrated into a sensor network [102].
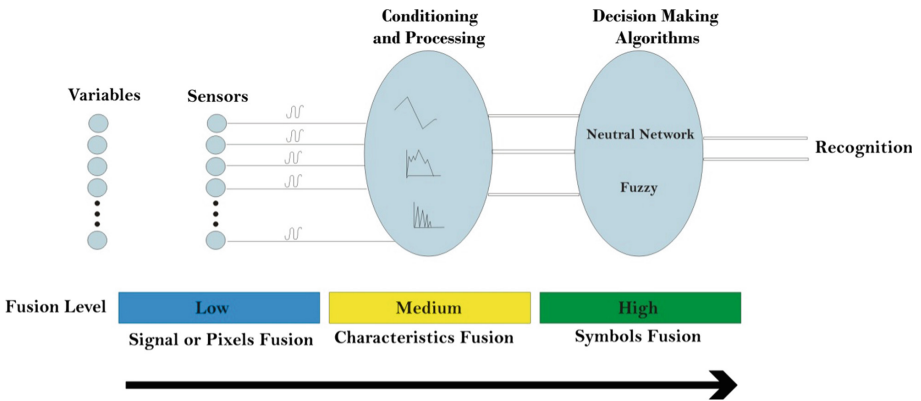

Fig. 10. Sensor fusion system [102].

In Fig. 11 a single module which includes the acquisition of all physical quantities by the sensor(s) is presented. Generated signals are electronically conditioned by filters, A/D converters, etc., and then they are processed by microcontrollers and/or microprocessors. The stage of communication, using different means in a system with other sensors for post processing elements and analysis of data is followed. The full system can be configured remotely or on the device itself.
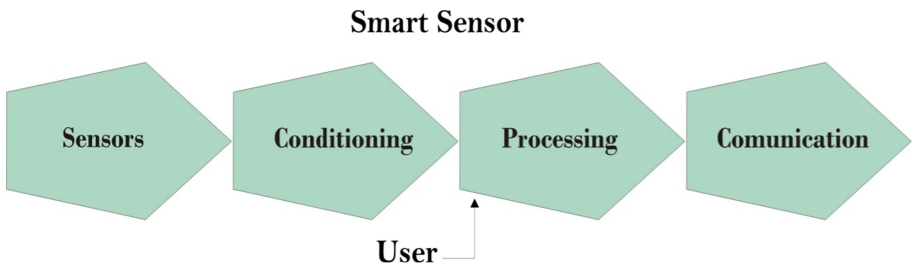

Fig. 11. Flowchart of a smart sensor [102]

There is a great interaction between biomedical and sports applications. The physiological, physical and technical types of data can be analyzed in the development of athletes in sport. The physiological variables can be described as power, oxygen consumption, and others, to the physical variables: detach speed, acceleration, and fatigue index, and technical variables: starting time, correct execution of movements, correct gait, posture, etc.

Sensor fusion contains the following sensors: Accelerometer, Gyroscope and Magnetometer. The concepts of sensor fusion and smart sensor can be used in combination.

Athletics is the basis of many sports. For many types of sports, the main thing is running, jumping and throwing. The main thing is to perform an analysis during training and to have an interaction between the trainer and the sportsperson thus giving more help in a competitive environment and in sport. Inertial sensors are widely used in athletics. This category includes an accelerometer, a gyroscope and a magnetometer. They provide data for quantities such as acceleration, angular velocity and magnetic field and provide orientation analysis. When we fusion the data with video signals, we can compare and analyze the performance of two athletes. In order for the coach to provide corrections and instructions to the competitor, it is important to investigate the inertial behavior of the sensors, depending on the time of displacement of two athletes. In this way can be corrected positioning at starting time, starting time and others. It is also important to analyze the gait and the correct execution of movements in training and racing in real time.

In almost all kinds of sport (athletics, figure skating, short track speed skating, hockey, soccer, basketball, etc.), gait analysis is important. The gait depends on the correct position and movement. This analysis can be done by means of sensors for force and inertia in the athlete's footwear. In order to achieve the necessary analysis of the athlete's pace, three sensors measure force, acceleration and angular velocity.
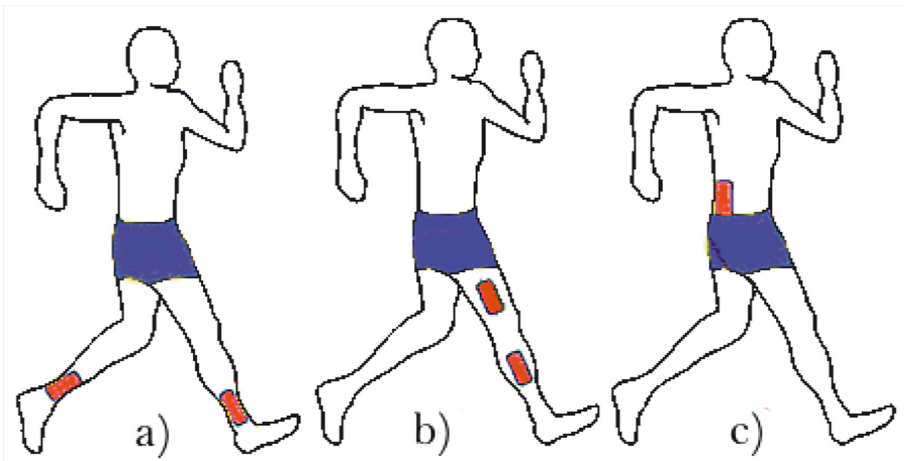

Fig. 12. Smart sensors body placement: (a) ankle; (b) thigh and tibia; and (c) lumbar [102].

In Fig. 12 some examples of area to attached smart sensors are shown: (a) sensor on each ankle, (b) two sensors that are positioned on the thigh and tibia and (c) a sensor placed in the lumbar. Below we will describe the application of the types of sensors in different sports [102].

In the different swimming styles, the turn type and speed and resistance are measured. Two variables in the development of the sport person are important, the resistance and propulsion of the body in water, and also the efficiency of the arms during the movement. Based on these results, an analysis of the style of swimming and assessment of the necessary adjustments is made. In team sports (hockey and football), protection of the athlete is required [103]. Using the same type of sensor application, an analysis of the impacts experienced by the athlete can be made. In [103, 104] concussions and other injuries in the head area caused by impacts, especially in hockey and football are described. The impact monitoring system is built of smart inertial sensors. The sensors transmit impact acceleration, impact time, impact locale, impact direction, and the amount of impacts in sequence. A research impact on the head is important, such as the protective equipment is the helmet. The vest can also be instrumented. There are smart sensors in the hockey stick as well. These sensors analyze athlete movements, force and position of the hands. To analyze the stick movement in the hands during movement, the fusion of three sensors installed on the stick can be used. Inertial sensors at the top of the stick analyze the movements of the stick in the hands and linear potentiometers can be used to analyze the position of the hands on the stick and deflection of the stick at the time of the strike [102].

Figure skating (Fig. 13) is an individual's, duos, or groups sport. The skaters perform on figure skates on ice. This sport includes the disciplines men's singles, ladies' singles, pair skating, and ice dancing. UD biomechanics analysis is used to improve the potential in figure skaters. A behavioral analysis of 60 figure skaters was made. Richards and his research team used an array of 10 cameras that capture data from reflective markers. The markers are placed on the skaters. The cameras capture their precise positions, the speed of their rotation, and their time in the air. The movement in the air are monitored. The figure skaters have to get into their tightest position within a specific time period [105].

Figure skating is an extremely precise sport. Improving each jump requires a lot of work and hours on ice. Minimal displacement of a part of the body is sufficient for an inaccuracy in the performance of the jump and can cause the competitor to fall. Working in this area saves the contestants a lot of falls and makes it possible to see the error and adjust it in time, also to improve and reach a level of triple and quadruple jumps in combinations.

Additional comparison parameters for different environments could be found in [106]. The sensor use in the AAL/ELE platform is shown also in [107] and the position in the use-case scenarios is demonstrated in [108].

Fig. 13. Position: preparation of the competitor for the Lutz

6 Conclusion

The integration of RFID and WSNs will bring a higher level of synergy and more technological advances. These integrated networks will extend traditional RFID and sensor systems giving an advantage to control the environment.

An important step toward the wider adoption of identification and sensing technologies would be the implementation of techniques, methodologies, and approaches that are mature enough to be used in a wide range of applications. Nevertheless, it is important to take into account the restrictions posed by the available resources when deploying these tools methods and standards. In addition, it is desirable that the developed solutions would allow their evolvement into technical standards and future integrated platforms.

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