INFORMATION TECHNOLOGY FOR EUROPEAN ADVANCEMENT

DELIVERABLE 3.1.1

State of the Art

LIFEWEAR, MOBILIZED LIFESTYLE WITH WEARABLES

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Czech Republic	GiTy	1.0	26/06/2012
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CONTENTS

1 DELIVERABLE DESCRIPTION

1.1 Executive summary

In this document we describe the three different possible use cases or profiles needed to be treated on the project on the WP3 as they appear in the Story Board. For each profile, we identify the type of data to be treated and the type of communication and network required.

This document also provides the state of the art of the different aspects relevant for the achievement of the work package three of this. First of all an overview of smart textiles and personal protective equipment is done. After, an overview of the possible communication protocols and sensors is given and an analysis of commercial of the shelf hardware platforms is done.

1.2 General objectives

The objectives of this document are multiple.

The first objective is to show the wearable devices targeted by this project according to the working profiles detected and explained in the history board. For that purpose, a classification on the different requirements on communication according to the possible use cases derived from the story board is presented.

The second objective of this document is to give an appropriate :

- Textiles
- Personal protective equipment
- Communication protocols
- Sensors
- Commercial hardware platforms

2 WEARABLE DEVICES AND USE CASES

2.1 Wearable devices

Wearable devices are electronic devices either integrated into clothing which the user wears or attached to human body like wristwatch, and that enable interaction with its environment, in an intuitive way. These electronic devices integrated in the garment or in fabrics that make up the garment, are mainly sensors, RFID, communication modules, batteries, etc. The devices are integrated into the garment and should offer a very high level of comfort and ergonomics for the user and must never hinder the activities of the users that will put on. It is therefore necessary to analyze which are the profiles of the people and their needs. It is also necessary to examine whether the environments or these activities are limited by international regulations which may restrict its use, or the use of certain specific materials or components.

2.2 Use cases

From the needs identified by Estambril in the field of labor protection of persons in conditions of risk, Estambril has conducted a study of cases, environments and sectors of application. In this study has worked together with partners and subcontracted in order to determine the profiles to develop taking into account the following aspects:

- User typology:
  - Individual
  - Group
- Data collected by the devices:
  - Data of the individual
  - Data from the environment of the individual
- Type of network:
  - Personnel (BAN)
  - Distributed (WSN)
- Type of communication:
  - Local
  - Global

Based on this study there have been identified three profiles with incremental complexity which are as follows:

- Profile 1: person monitoring his own vital signs or personal data
- Profile 2: person monitoring his environment or external data and sharing it with the Group
- Profile 3: group mapping an area together and sharing the resulting map with the exterior

Taking into account the Story Board and Estambril knowledge in the field of protection of persons in different risk sectors, the scenario that has been raised is the protection for firefighters, where there is a high risk due to multiple causes, with great variability and complexity (fire, explosive environments, corrosive materials, releases, ...) In this scenario it is very important take into account the firefighter data individually, the group of firefighters as a whole and obviously the environment. Therefore, we can make an interpretation of selected profiles by applying them to the sector of firefighters:

- Profile 1: firefighter monitoring his vital signs for the prevention of the risk of thermal stress. The device, through the sensors network, located in the garment that wears the firefighter, is able to warn him that his body runs the risk of loss of guidance, dizziness, dehydration… due to high body temperature, humidity,...
- Profile 2: firefighter monitoring via sensors integrated in the garments, PPE's (Personal protection Equipment) or accessories, external data such as for example the presence of fire, environmental temperature, solar radiation, contaminants in the environment, etc. and sharing it with the rest of firefighters during the intervention.
- Profile 3: Group of firefighters during an intervention needs to map the space where the intervention is performed and sending the data to the exterior, to analyze the risks and the position of persons. These situations occur very often depending on time of day, weather conditions or the smoke produced by fire or pollutants, it is not possible to make a correct visual recognition, or is not possible to access to an updated cartography. It is also vitally important mapping, as in a situation of emergency everybody should evacuate the emergency area quickly and safely.

Finally we can summarize the three profiles making a tabular clustering:

USE CASES	**PROFILE 1**	**PROFILE 2**	**PROFILE 3**
USER	PERSON (FIREFIGHTER)	PERSON (FIREFIGHTER)	GROUP (FIREFIGHTER BRIGADE)
DATA	OWN DATA	OWN & EXTERNAL DATA	OWN & EXTERNAL DATA
NETWORK	PERSONAL(BAN)	PERSONAL(BAN) & DISTRIBUTED (WSN)	DISTRIBUTED (WSN)
COMMUNICATION	LOCAL	GLOBAL	GLOBAL

Table 2.1: Profiles and parameters

3 TEXTILE TECHNOLOGIES

3.1 Introduction

In Lifewear project, fabrics are an important part of it. The aim is to integrate new technologies into a garment or develop a wearable device. This objective could be reach thanks to the fabrics. For this reason, in this section Smart textiles will be introduced including its state of art.

3.2 Smart Textiles

Smart textiles also known by the acronym SFTIT (Smart Fabric and Interactive Textile), can be defined as fabrics that can detect and react to external stimulus or different environmental conditions, including mechanical, thermal, chemical, and magnetic or electrical sources.

They are therefore, one of the most interesting technological activities within the textile industry, which includes a wide range of disciplines such electromagnetic protection, conductive fabrics, generation of chemical and biological responses and new mechanical, acoustic, thermal, electrical and optical materials required to meet these potential needs of the population.

Smart fabrics show a clear evidence of the enormous potential and opportunities that have still to be explored and exploited from the textile industry, fashion or design, and are very important in the sector of technical fabrics.

In a close future, our daily life could be regulated for smart devices, where many of them will be integrated on garments and textile substrates.

There are different levels of integration, from simple solutions to adapt Microelectronics in the clothing, the textile integration thought connected modules, to the most desirable in which the sensors and microsystems function are direct integrated among the fibers of the fabric.

Smart fabrics are divided into three families or generations depend on the integration level of the device with the textile substrate.

The classification is summarized below according to the union of the device with textile component:

<u>Addition of the device in the textile processes</u>

• **1st Generation – Thread Manufacturing**: devices are present in the yarn or during the polymer extrusion to obtain the filament or synthetic multifilament and also during the spinning to have the thread.

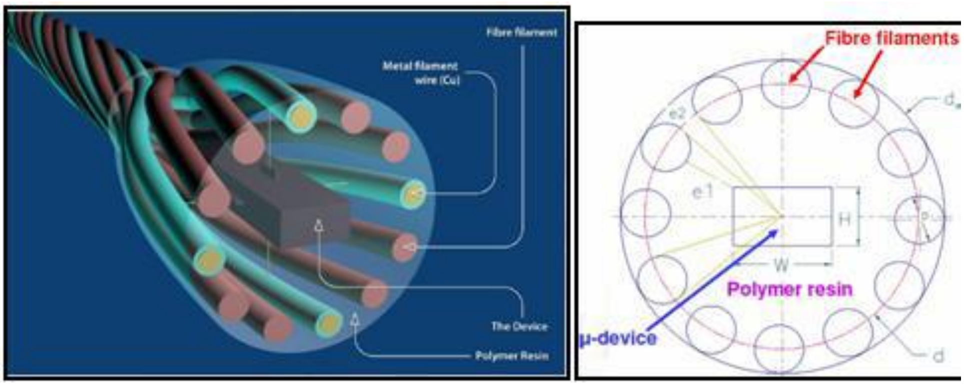

Figure 3.1. Metal Filament tube inserted in a multifilament.

• **2nd Generation - Textile Manufacturing:** Addition of the device or sensor in some stages of the textile process like weaving or stamping.

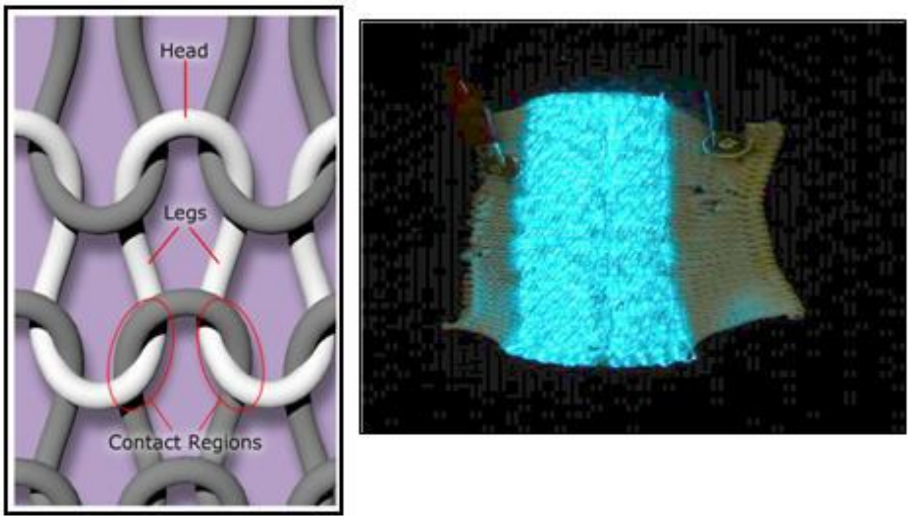

Figure 3.2. Introducing an electroluminescent thread during dying.

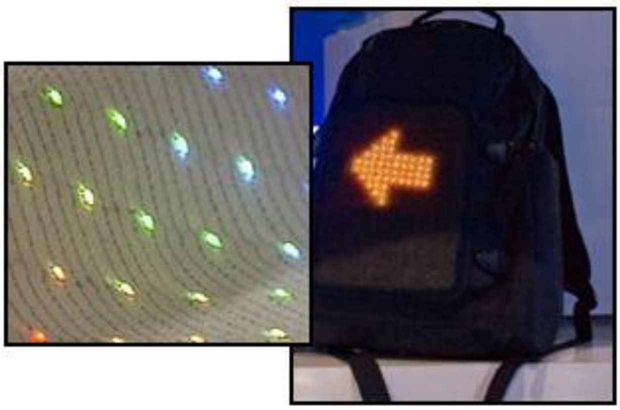

Figure 3.3. LEDs integrated in the embroidery of an article.

• **3rd Generation:** Fabrics that detect stimulus analyze the situation and act correctly for the user benefit. The intelligent process takes place through a combination of sensors, electronic processing and acting system using physical, chemical and telecommunications phenomena's. Generally, are integrated as part of the garment or textile article providing high added value.

3.3 Smart Textiles and PPEs.

The risk for workers' health and safety, originate by working exposed to extreme heat conditions, are caused by an extreme heat accumulation in the body. This phenomenon is called thermal stress, which can be defined as the heat load received, resulting from the interaction between environmental conditions of the workplace, the physical activity and the clothes that workers wear.
When a person works under conditions of thermal stress, the body is altered and the person suffers physiological overload as a result of an increase of the body temperature.
Certain physiological mechanisms (such as sweating and peripheral vasodilatation) make the body leave the heat excess and if even thought, the body temperature exceeds 38 º C, serious health problems and even death may occur. This phenomenon is a major cause of death among firefighters and it can also happen to professionals working with high heat sources such as foundries and metal or glass industry.
Personal Protective Equipment (PPE) is defined as any equip made for being worn or held by a worker in order to protect him from many health and safety risks of the workplace.

At present there are no garments that can assure and certify the workers are not going to suffer from any risk as they develop their job tasks, it only must complies an specific requirements depending on the standards and/or regulations.

The most important requirements evaluated in protective clothing are the following:

- Penetration resistance
- Steam resistance
- Ergonomic requirements

The current garments used for fighting flames action are made of one or more pieces made of fire resistant or thermal resistant fibers that could be classified as high performance fibers or high tech. These are characterized because they have a good behaviour to the long flame action and/or heat, in addition to offer high mechanical and abrasive properties.
Some of these fibers, para and meta aramides, clorofibers, fluorocarbonates (PTFE) etc… are commercially known with names like Nomex, Twaron, Kermel, FR polyester, etc…
One of the most used in the manufacturing of fire protective clothes, army garments and F1 clothes is Nomex® Fiber , that has an easier manufacturing process.
It is a material that can hold temperatures from -196ºC to over 300ºC, self-extinguishing, and it doesn't tolerate the combustion and doesn't melt or drip when is heated or burned.

Other products that can help enhancing the action of these textiles in contact with flames is the addition of flame retardants chemicals like pirovatex ®.
Therefore, one of the current concerns is to develop smart textiles systems that minimize the risks and react to danger when the health of workers is in danger.
There is a need in improvements in personal protective clothing thought the development of intelligent products that give a thermal regulation, a weight optimization of the clothes and an increase of the thermal isolation of these protection articles.

Current studies show that solutions exit for its aim. We are going to show 3 examples of innovative projects we can find in the market. All of them present improvements focused in the thermal regulation of the end-user.
Among the latest developments in the field of smart textiles to palliate problems of these professions has been manufacturing a vest called LifeShirt ® and manufactured by Vivometrics that incorporates sensors distributed throughout the garment which are in contact with the subject's body.
These sensors are able to transmit information about heart and breathe rate, pulse, physical activity and temperature and act accordingly. The wireless technology that is incorporated makes this product transfer the analyzed data to the computer severs giving information about the health status of the user, and if the person is in danger, could be replaced and/or makes the subject act to its warning.

Figure 3.4. LifeShirt ®Vest that monitors vital constants.

AIS Intercooler ® is a system developed together with the following companies: Grado Zero Espace, Spider Safety Lab and the European Space Agency.
This product is used mainly in high competition motor sport. It provides a thermoregulation through a cooling microsystem designed by ESA (European Space Agency).

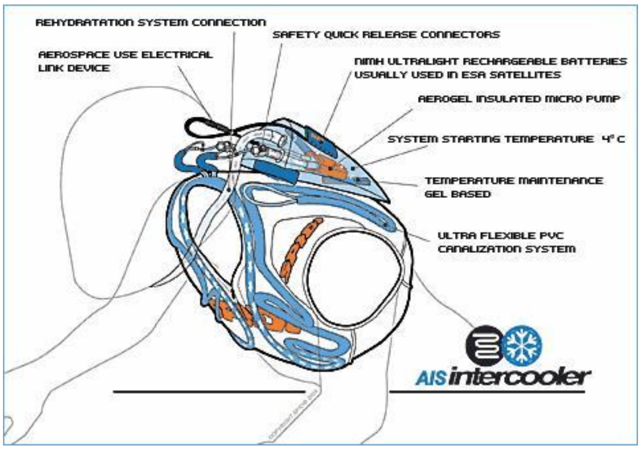

Figure 3.5. Outline of operation of the AIS Intercooler.

The operating system is based on a gel that keeps the temperature and cools down the water that is pumped up and it goes thought a closed circuit. This mechanism is integrated in the textile which helps in the user's thermoregulation in contact with the skin.
Note that the cooling that there will be on the back (in this case), it is not achieved by a thermoelectric or compression system, but the cause is the gel. For this reason the energy consumption it is reduced, although its cooling capacity is also more limited.

This system was designed and subsequently used in the championship World Moto GP and F 1 achieving the comfort and pilots performance.

Eliminator ® Vest: It is based on a vest that incorporates an inner polymeric coil connected to a charging station that introduces cold or hot water depending on the necessary thermoregulation in the coil. The inner coil is developed with evaporative and polymeric materials that once is wet it keeps the temperature 1 or 2 hours.
In this way, the user connects the coil to the charge station that regulates water temperature (hot or cold) through thermoelectric devices and during 2 seconds, the coil absorbs the temperature of the water flowing along the route, improving the temperature of the person.
The company who sells the item is Jenkins Comfort.

Figure 3.6. Thermal regulation system: Eliminator Vest

4 COMMUNICATION PROTOCOLS

4.1 Introduction

The present section presents a general vision of the most relevant communication protocols that can be used in the different scenarios of the LifeWear project. Although there is large number of wired communication technologies, we focus on wireless technologies because they are under the scope of this document.

In the set of technologies studied we could find short-range technologies such as Bluetooth or Zigbee that introduce interesting properties such as very low consumption providing a long battery life, but with a low data rate.

Among the technologies that provide a longer rate, technologies such as Wi–Fi and WiMAX will be studied in order to cover all the needs of the project. These technologies offer very high data rates but without any restriction on consumption.

Finally, it is made a comparison between these wireless standards attending to its most important features in order to make a complete study of each of them providing an overview of the technical properties needed into the LifeWear project.

4.2 Wireless Communications Standards

Wireless Sensor Networks (WSNs) are the key to gathering the information needed by smart environments, whether in buildings, utilities, industrial, home, shipboard, transportation systems automation, or elsewhere. In the majority of these environments, running wires or cabling is usually impractical. A sensor network is required that is fast and easy to install and maintain. The interconnection of WSNs with Internet or other communication networks also relaxes the control and management tasks of WSNs under dynamic changes of the application environments.

In this section Wireless Communications Standards are presented with a short description of their most significant technical features.

- Bluetooth: short-range communication system with the aim of removing the wired connections between electronic devices (portables and fixed) but providing high levels of security [8]. The main features of this technology are its reliability, low power and low cost. It can manage voice and data transmissions simutaneusly.
- Bluetooth Low Energy: is a digital radio technology designed for ultra low power consumption (button cell batteries) with a very short range (10 meters) based around low-cost transceiver microchips in each device. The devices that support this technology could be smaller and more enenergy-efficients than Bluetooth devices.
- IEEE 802.15.4: is a standard that defines the physical layer and medium access control for wireless personal area networks with low rates of data transmission (low-rate wireless personal area network, LR-WPAN). Its main features can be seen in the following table:

- Zigbee: is the name of the specification of a set of high level wireless communication protocols for reliable, cost-effective and low-power wireless networking. This specification is defined by an association of companies called the Zigbee Alliance [2]. It is based on the IEEE 802.15.4 standard for Low Rate Wireless Personal Area Networks (LR-WPANs). The stack specification over IEEE 802.15.4 defines the network and the security layer, handling star and peer-to-peer network topologies. It also provides a framework for application programming in the application layer.

- 6LowPan: is the name of a workgroup of the Internet Engineering Task Force (IETF) that has defined mechanisms in order to work with IPv6 networks over IEEE 802.15.4 networks [5]. The methods defined are used for the encapsulation and header compression methods that allow IPV6 packets to be sent and received over these networks. It provides an important capability for future sensor networks because of its high compatibility with the present Internet infrastructure, allowing the connection of these networks with other IP networks. Connectivity to other IP networks must be provided by any arbitrary link, including Ethernet, Wi-Fi, GPRS or satellite.

- Wireless-Hart: is an open standard wireless networking technology developed by the HART Communication Foundation (Highway Addressable Remote Transducer) [4]. It is based on the IEEE 802.15.4 standard but defines new Data Link, Network, Transport and Application layers. It operates in the 2.4 GHz band using a time synchronized, self-organizing and self-healing mesh architecture.

- Mi-Wi and MiWi P2P are designed by Microchip Technology. They are proprietary wireless protocols based on the IEEE 802.15.4 standard using small, low-power radio. The main goal of this technology is to achieve low data-rate and short range distances reducing the complexity of other WSN technologies (e.g Zigbee) and the reduction of footprint for constrained memory devices. The application of this technology could be seen in areas such as industrial monitoring, home and building automation, lighting control and automated meter reading.

- Z-Wave: is a standard developed by ZenySys and standardized by the Z-Wave Alliance [7] (including Intel and Cisco). It is designed for mesh network topologies being important for home automation and commercial environments applications. The technology uses a low-power RF radio that operates in the sub Gigahertz frequency range (900 MHz).

- DASH7 is a wireless sensor networking technology using the ISO/IEC 18000-7 standard for ultra low-power wireless technology promoted by the non-profit consortium called the DASH7 Alliance [3]. It operates in the 433 MHz band for active RFID, with a range of more than 1 kilometre. It main strength is the providing of a multi-year battery life, its range of up to 2 km (potentially farther), low latency for tracking moving objects, small protocol stack, sensor and security support, and data transfer of up to 200 kbit/s. Range of up to 10 km was demonstrated by Savi Technologies (USA). Range in the EU zone may be even longer, because the regulations are less limiting. DASH7 devices use just one frequency worldwide, so the global functionality is guaranteed. A neutral testing authority is designated that conducts device testing under the DASH7 Certified program. It can be used with a variety of devices, from stand-alone DASH7 tags than monitor goods to phones that allow consumers to monitor the energy usage in their own home.

- Wi-Fi – IEEE 802.15.11: The term Wi-Fi is used as a generic term for products that incorporate any variant of 802.15.11 wireless technology, which allows the creation of WLAN wireless networking. At first, the term Wi-Fi was used only for devices with 802.11b technology, the dominant standard in the development of wireless networks. To avoid confusion in the compatibility of the devices and interoperability of networks, the term Wi-Fi was extended to all appliances equipped with 802.11 technology: 802.11a, 802.11b, 802.11g.
- WiMax – IEEE 802.15.16: The WiMAX expression integrates the IEEE 802.16 family of standards and the standard HyperMan of the European standardization organism ETSI [6]. WiMAX is a wireless data transmission standard (802.MAN) that provides concurrent access in areas of up to 50 mile radius at speeds up to 70 Mbps, using portable technology LMDS.
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4.2.1 Comparison of communications standards

It is mandatory to do a comparison between technologies that it is possible to use to implement wireless communications in the scenarios of the project. Based on communication requirements (coverage, topology, consumption, latency)[9] and other characteristics like interoperability, scalability and weaknesses, we can do the following analysis:

	Zigbee IEEE 802.15.4	6LowPAN IEEE 802.15.4	Bluetooth	WiFi IEEE 802.11	DASH7
Supporter	Zigbee Alliance	IEEE	Bluetooth Special Interest Group	WiFi Alliance	ISO IEC 18000-7
Access	Proprietary License	Open	Proprietary License	Proprietary License	Open
Application	Home automation, smart buildings, personal care	Home automation, smart buildings, personal care, industrial environments	PAN networks, short range data transmission	LAN networks	Home automation, smart buildings, personal care, industrial environments
Topologies	Star Cluster-Tree Mesh	Star Cluster-Tree Mesh	Peer-to-peer Star	Peer-to-peer Star Mesh	Peer-to-peer Star
Range	20-75 m	20-75 m	10 – 100 m	30 – 90 m	1 km
Data Rate	250 kbps	250 kbps	2.1 Mbps (2.0)	11 Mbps (b) 54 Mbps (g)	200 kbps

				300 Mbps (n)	
Frequency Band	868/915 Mhz 2,4 Ghz	868/915 Mhz 2,4 Ghz	2,4 Ghz	2,4 Ghz 5 Ghz (a)	433.92 MHz
Output power	30 mw	30 mw	100 mw	200 mw (b) 65 mw (g)	

Table 3.1 Communication Standards Comparison

Although there are no wide differences between topologies, everyone implements at least star, cluster-tree and mesh topology. If we compare out power features we will see that Zigbee and 6LowPAN have lower values than the other ones. Bluetooth are in medium values if we compare with WiFi-b, but it reaches top values since WiFI-g was released.

Everyone works on the 2,4 GHz band, with the inconveniencies that this circumstance has, because 2,4 GHz is open frequency band, so it is too much crowded. Noise reduction functions will be developed in every technology.

Wi-fi offers better data rate than other technologies, where Zigbee and 6LowPAN have the lower rates with 250 kbps. Range capabilities are in similar situation, technologies based on 802.15.4 standard have the lower rates. Nevertheless, we shouldn't forget output power features.

Table 6.3: Difference between technologies DASH7 and ZigBee:

Technology	Standard	Frequencies used	Globaly available frequencies	Water penetration	Concrete penetration	Rage [m]	Average power input
DASH7	ISO/IEC 18000-7	433.92 MHz	Yes	Yes	Yes	1 000	30–60 µW
ZigBee	IEEE 802.15.4	2.4 GHz, 915 MHz, 868 MHz	2.4 GHz – yes; 915 MHz – no; 868 MHz – no	No	No	30 -500	125–400 µW

Technology	Average latency	Device cost	Multi-hop capabilities	Sensor and security support	Interference from IEEE 802.11n	Rage [m]	Max bit rate
DASH7	max 2 seconds	$10+	Yes	Yes	No	1 000	200 kbit/s
ZigBee	Varies from seconds to minutes	$10+	Yes	Yes	Yes	30 -500	250 kbit/s

5 SENSORS

A wireless network of sensor nodes (that may interact which each other) aim at monitoring real world physical parameters (in many cases, covering a certain geographical area) and offering the sensed data to one or more data collection elements. In some cases, the same elements can be used to activate actuators in order to perform certain tasks in response to an event or to exceed a predefined threshold for a certain parameter.

Sensor nodes are devices that account with at least one sensor and may include actuators as well as having processing and networking capabilities to process data and use the wireless access.

Sensors are devices included into de sensor nodes and convert the physical parameter (for example: temperature, blood pressure, humidity, speed, heart rate, etc.) into a signal which can be measured electrically.

Typically, sensors are small, low-cost, and low-power consumption devices requiring a limited amount of information transfer. However, a wider concept may include microphones, GPS-receivers or cameras as sensors. There are also innumerable applications for sensors of which most people are never aware. Applications include cars, machines, aerospace, medicine, manufacturing, robotics, health-care, security, etc.

5.1 Sensor parameters

5.1.1 Sensor Sensitivity

The sensitivity of the sensor is defined as the slope of the output characteristic curve (DY/DX in Figure 5.1) or, more generally, the *minimum input of physical parameter that will create a detectable output change.* In some sensors, the sensitivity is defined as the input parameter change required producing a standardized output change. In others, it is defined as an output voltage change for a given change in input parameter. For example, a typical blood pressure transducer may have a sensitivity rating of 10 mV/V/mm Hg; that is, there will be a 10-mV output voltage for each volt of excitation potential and each mm Hg of applied pressure.

Sensors need to be designed to have a small effect on what is measured; making the sensor smaller often improves this and may introduce other advantages. Technological progress allows more and more sensors to be manufactured on a microscopic scale as microsensors using MEMS technology. In most cases, a microsensor reaches a significantly higher speed and sensitivity compared with macroscopic approaches.

Sensitivity Error

The sensitivity error (shown as a dotted curve in Figure 5.1) is a departure from the ideal slope of the characteristic curve. For example, the pressure transducer discussed above may have an actual sensitivity of 7.8 mV/V/mm Hg instead of 10 mV/V/mm Hg.

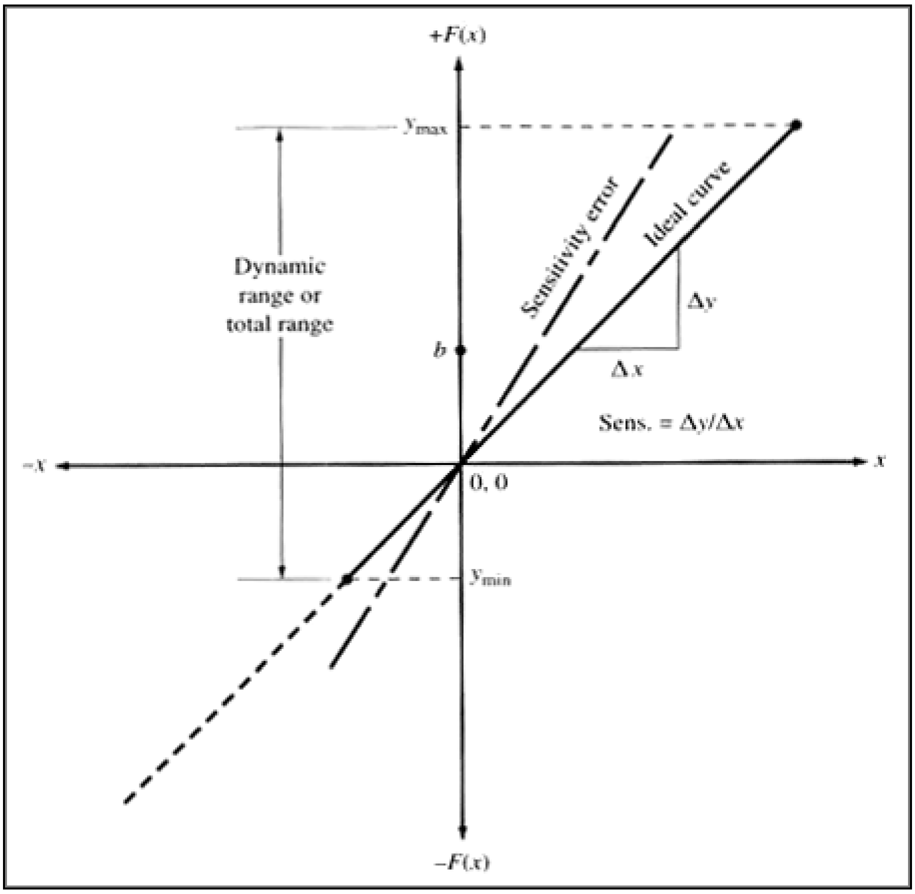


Figure 5.1: Ideal curve and sensitivity error. Source: J.J. Carr, *Sensors and Circuits* Prentice Hall.

5.1.2 Sensor range

The range of the sensor is the maximum and minimum values of applied parameter that can be measured. For example, a given pressure sensor may have a range of -400 to +400 mm Hg. Alternatively, the positive and negative ranges often are unequal. For example, a certain medical blood pressure transducer is specified to have a minimum (vacuum) limit of -50 mm Hg (Y_{min} in Figure 5.1) and a maximum (pressure) limit of +450 mm Hg (Y_{max} in Figure 5.1). This specification is common, incidentally, and is one reason doctors and nurses sometimes destroy blood pressure sensors when attempting to draw blood through an arterial line without being mindful of the position of the fluid stopcocks in the system. A small syringe can exert a tremendous vacuum on a closed system.

Dynamic Range

The dynamic range is the total range of the sensor from minimum to maximum. That is, in terms of Figure 5.1, $R_{dyn} = Y_{max} - | -Y_{min}|$.

5.1.3 Sensor Resolution

The resolution of a sensor is the smallest change it can detect in the quantity that it is measuring. Often in a digital display, the least significant digit will fluctuate, indicating that changes of that magnitude are only just resolved. The resolution is related to the precision with which the measurement is made. For example, a scanning tunnelling probe (a fine tip near a surface collects an electron tunnelling current) can resolve atoms and molecules.

5.1.4 Accuracy

The accuracy of the sensor is the maximum difference that will exist between the actual value (which must be measured by a primary or good secondary standard) and the indicated value at the output of the sensor. Again, the accuracy can be expressed either as a percentage of full scale or in absolute terms.

5.1.5 Offset

The offset error of a transducer is defined as the output that will exist when it should be zero or, alternatively, the difference between the actual output value and the specified output value under some particular set of conditions. An example of the first situation in terms of Figure 5.1 would exist if the characteristic curve had the same sensitivity slope as the ideal but crossed the Y-axis (output) at *b* instead of zero. An example of the other form of offset is seen in the characteristic curve of a pH electrode shown in Figure 5.2. The ideal curve will exist only at one temperature (usually 25°C), while the actual curve will be between the minimum temperature and maximum temperature limits depending on the temperature of the sample and electrode.

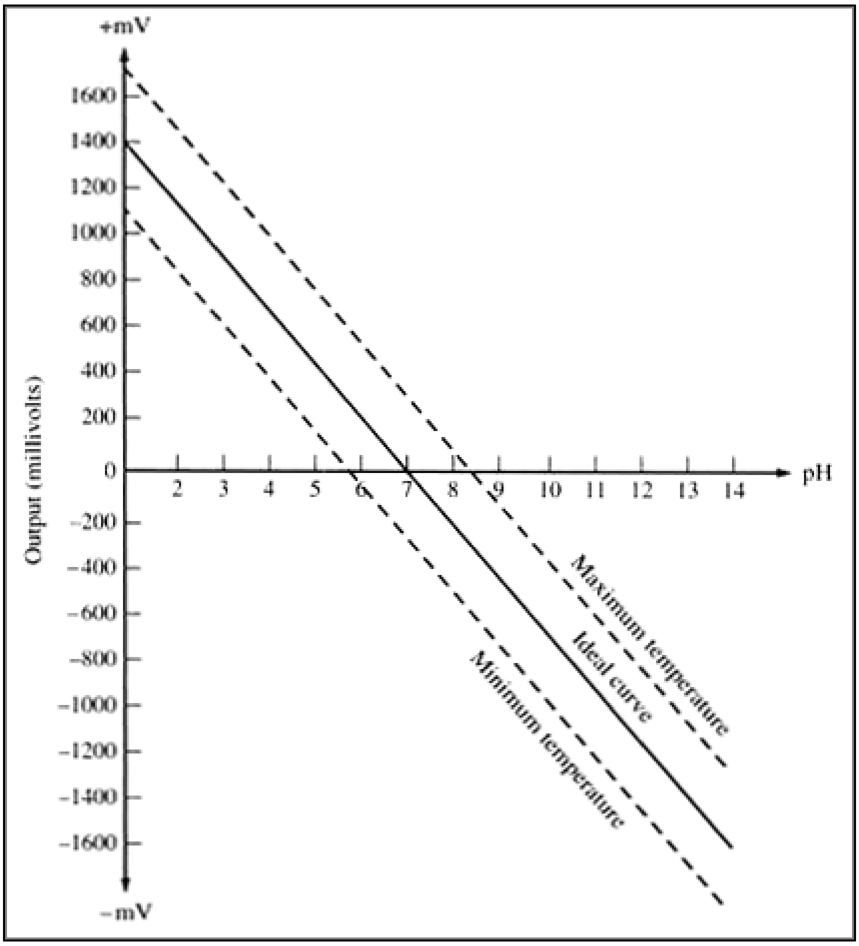


Figure 5.2. Typical pH electrode characteristic curve showing temperature sensitivity. Source: J.J. Carr, *Sensors and Circuits* Prentice Hall.

5.1.6 Linearity

The linearity of the transducer is an expression of the extent to which the actual measured curve of a sensor departs from the ideal curve. Figure 5.3 shows a somewhat exaggerated relationship between the ideal, or least squares fit, line and the actual measured or *calibration* line *(Note* in most cases, the static curve is used to determine linearity, and this may deviate somewhat from a dynamic linearity) Linearity is often specified in terms of *percentage of nonlinearity,* which is defined as:

$$Nonlinearity\ (\%) = \frac{D_{in(max)}}{IN_{f.s.}} \times 100$$

Where:

Nonlinearity (%) is the percentage of nonlinearity

$D_{in(max)}$ is the maximum input deviation

$IN_{f.s.}$ is the maximum, full-scale input

The static nonlinearity defined by Equation 6-1 is often subject to environmental factors, including temperature, vibration, acoustic noise level, and humidity. It is important to know under what conditions the specification is valid and departures from those conditions may not yield linear changes of linearity.

5.1.7 Sensor deviation

If the sensor is not ideal, several types of deviations can be observed:

The sensitivity may in practice differ from the value specified. This is called a sensitivity error, but the sensor is still linear.

Since the range of the output signal is always limited, the output signal will eventually reach a minimum or maximum when the measured property exceeds the limits. The full scale range defines the maximum and minimum values of the measured property.

If the output signal is not zero when the measured property is zero, the sensor has an offset or bias. This is defined as the output of the sensor at zero input.

If the sensitivity is not constant over the range of the sensor, this is called nonlinearity. Usually this is defined by the amount the output differs from ideal behaviour over the full range of the sensor, often noted as a percentage of the full range.

If the deviation is caused by a rapid change of the measured property over time, there is a dynamic error. Often, this behaviour is described with a bode plot showing sensitivity error and phase shift as function of the frequency of a periodic input signal.

If the output signal slowly changes independent of the measured property, this is defined as drift (telecommunication).

Long term drift usually indicates a slow degradation of sensor properties over a long period of time.

Noise is a random deviation of the signal that varies in time.

Hysteresis is an error caused by when the measured property reverses direction, but there is some finite lag in time for the sensor to respond, creating a different offset error in one direction than in the other.

If the sensor has a digital output, the output is essentially an approximation of the measured property. The approximation error is also called digitization error.

If the signal is monitored digitally, limitation of the sampling frequency also can cause a dynamic error, or if the variable or added noise noise changes periodically at a frequency near a multiple of the sampling rate may induce aliasing errors.

The sensor may to some extent be sensitive to properties other than the property being measured. For example, most sensors are influenced by the temperature of their environment.

All these deviations can be classified as systematic errors or random errors. Systematic errors can sometimes be compensated for by means of some kind of calibration strategy. Noise is a random error that can be reduced by signal processing, such as filtering, usually at the expense of the dynamic behaviour of the sensor.

5.1.7.1 Response time

Sensors do not change output state immediately when an input parameter change occurs. Rather, it will change to the new state over a period of time, called the response time (T_r in Figure 5.3). The response time can be defined as the *time required for a sensor output to change from its previous state to a final settled value within a tolerance band of the correct* *new value.* This concept is somewhat different from the notion of the *time constant* (T) of the system. This term can be defined in a manner similar to that for a capacitor charging through a resistance and is usually less than the response time.

The curves in Figure 5.3 show two types of response time. In Figure 5.3a the curve represents the response time following an abrupt positive going step-function change of the input parameter. The form shown in Figure 5.3b is a decay time (T_d to distinguish from T_r, for they are not always the same) in response to a negative going step-function change of the input parameter.

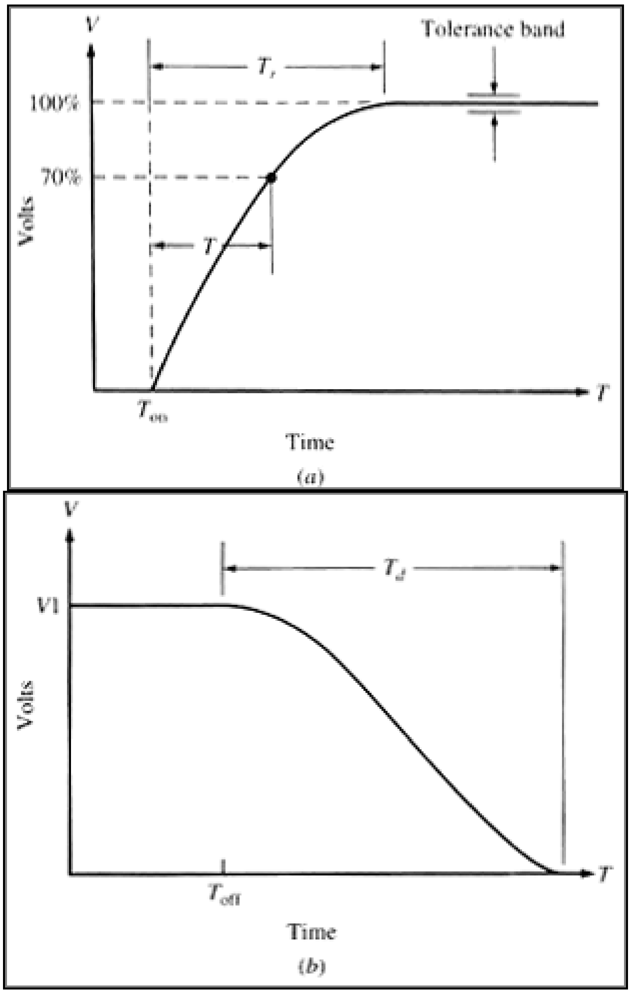


Figure 5.3: (a) Rise-time definition; (b) fall-time definition. Source: J.J. Carr, *Sensors and Circuits*Prentice Hall.

5.2 Types of sensors

There is a large variety of sensors, and the following is a non-exhaustive list that aims at introducing the most common sensors.

- **Temperature:** This type of sensor can be based in a thermistor (a device able to change the resistance according to the temperature) or a thermocouple that is a junction of metals that produces a voltage when they have different temperature.

- **Air humidity:** Also known as hydrometer, it measures the relative humidity of the air. At present, it can be implemented using a resistive material that changes according to the humidity of the air.
- **Light:** It measures the amount of visible light. It can be based on a photodiode or a photo resistor.
- **Pressure:** An instrument component which detects a pressure and produces an electrical, mechanical, or pneumatic signal related to the pressure. In general, the complete sensor system comprises a pressure-sensing element such as a bourdon tube, bellows, or diaphragm element; a device which converts motion or force produced by the sensing element to a change of an electrical, mechanical, or pneumatic parameter; and an indicating or recording instrument. Frequently the sensor is used in an autocontrol loop to maintain a desired pressure.
- **Acceleration:** It measures the acceleration produced by a movement. It is based on piezoelectric, magnetic induction or capacity effect to mention the most common ones. It can provide information from one dimension, two or three. It can be used to measure vibration or as mobility detector. Also, as the gravity force appears as a type of acceleration it is possible to use this type of sensor to measure the inclination of the sensor.
- **Presence:** It is implemented mainly using passive infrared (PIR). It consists in an integrated circuit able to receive infrared light and to measure differences between them. If a person enters in the range of the sensor, the heat differences (that result in an infrared emission) will be detected indicating the presence of a person.
- **Force:** It measures the force applied to the sensor. It can be based on the variation of resistance when pressure is applied.
- **Sound:** This consists in a microphone able to transform an audible pressure signal into an electrical magnitude.
- **Soil moisture:** Used in gardening and agriculture, this type of device should provide the content of water in soil. One of the most common solutions for this type of sensor is based on the capacitance variation at different frequencies.
- **Proximity:** This is a sensor able to detect the presence of a close object without getting in touch with it. It is based on an electrostatic or magnetic field that is modified by the nearby object. It is clear that the last one is only affected by metallic objects.
- **Magnetic field:** Also called magnetometer, it measures the magnetic field strength. It can be used as a compass based on the magnetic field of the earth or to detect the proximity of a metallic object that modifies the magnetic field. This type of sensor can be scalar (measuring the total magnetic field) or vectorial (measuring values of each component of the field).
- **Ultrasound receiver:** Similar to a microphone, this device is able to convert an ultrasound (higher than 20 kHz) pressure wave into an electrical signal. Usually, this type of sensor uses the 40 kHz frequency, but it is also possible to find devices working at the frequency of 235 kHz. They are used to receive reflections from pulses generated by an ultrasound transmitter and detecting the presence of obstacles.
- **Infrared receiver:** It produces a signal proportional to the amount of infrared radiation received. It is based on a photodiode.
- **Gas and chemical sensors:** They can be implemented in several ways, but the most attractive ones are the chemical ones, which require low power consumption and

present small size. A drawback is that they require replacement after several years of usage. Examples of common gas sensors are able to detect a variety of gases such as CO, CO_2, NO_2, CH_4, NH_3, O_2 or smoke.

5.3 Brief Overview of Available Sensors Considered for Usage in the LifeWear

There are thousands of sensors commercially available and it will be impossible to list them all or even a small part of them. A brief overview of sensors considered for usage in the LifeWear project is presented in this chapter.

5.3.1 Accelerometers

Accelerometers are sensors for measuring static and dynamic acceleration. It is used to measure the centrifugal and inertia forces. They can determine the position, tilt or vibration of the body. The principle of accelerometers is in acceleration transformation (change in motion) to a measurable electrical signal. It uses mainly the following four types: piezoelectric accelerometers, piezo-resistive accelerometers, thermal accelerometers and accelerometers with variable internal capacity.

Piezoelectric accelerometers: They use piezoelectric material that generates a charge proportional to the mechanical stress that makes acceleration. Measurement of charge on the piezos crystal is done either directly by external electronics with high input impedance or the internal electronics converts charge to voltage output with low impedance. The disadvantage of these sensors is that they cannot be used to measure frequencies below 0.1 Hz, therefore, they cannot be used for constant acceleration measuring.

Piezoelectric sensor is composed of three parts: a piezoelectric material, the seismic substance and sensor frame. One side of the piezoelectric material is attached to the sensor frame and the other side to seismic substance. See Figure 5.4. If acceleration impact accelerometer, force F cause generation of voltage output on the piezoelectric element.

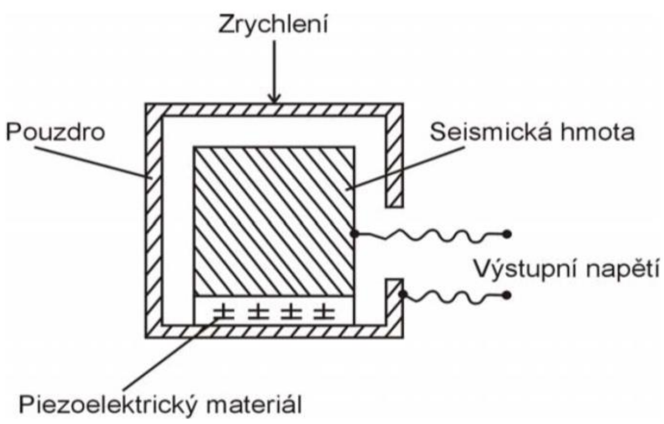
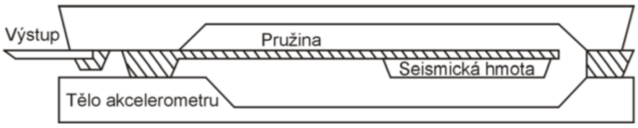


Figure 5.4: Block diagram of a piezoelectric accelerometer

Piezo-resistive accelerometers: They use the resistance change of piezo-ceramic during mechanical stress caused by acceleration. Resistance measurements are performed by basic or half Wheaston piezo-ceramic bridge. Simple sensor design allows connection to a simple evaluation circuit. As piezoelectric accelerometers can't be piezo-resistive accelerometers used for measuring constant acceleration.

Piezo-resistive accelerometer is composed of three parts: the seismic substance, deformation springs and sensor frame see Figure 5.5. If acceleration starts to affect the accelerometer, the frame moves, but the substance will tend to remain at rest until tight spring transfer enough power to the substance movement. The force affecting the spring is proportional to the deformation and this is directly proportional to the measured acceleration.



Obr.5.5: Block diagram of piezoresistiv accelerometer

Accelerometers with variable capacity: The function of this accelerometer is based on a variable capacity of three-electrode air capacitor. It is used here known nonlinear dependence of capacity C on electrode distance d. So if one electrode is movable and it's movement depend on the direction of acceleration, we get an accelerometer with variable capacity.

Mechanical construction of the accelerometer have to provide linear and enough sensitive transfer of acceleration to mechanical sliding motion. Force F is then transferred through the flexible girder onto the body of accelerometer. It is designed so that some parts are movable capacitor electrode. Position of these electrodes to the left and right fixed electrodes determines electronically measurable capacity value (Figure 5.6).

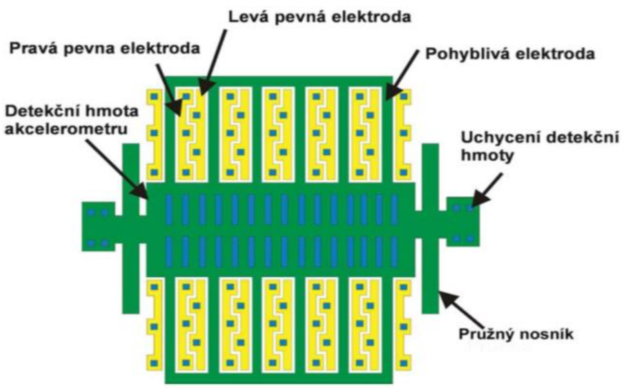


Figure 5.6: Schematic structure of the MEMS accelerometer

This method of accelerometers production is called Girders and is easily realized by MEMS technology. Technological process of etching the polycrystalline silicon are used in the manufacture of MEMS accelerometers. This process enabled to stretch the length of the movable and fixed electrodes and thus get a better signal/noise ratio, more accurate responses to acceleration scale and smaller cross-sensitivity. Cross sensitivity determines the effect of acceleration in the X axis at Y axis.

MEM structure described above allows acceleration measuring only in one direction - perpendicular to the moving electrode. Thus, measurement of acceleration is performed in one axis only. Nowadays is not technology problem to add another sensor to the same structure rotated by 90° compared to the previous one. We get 2D accelerometer who measure in two axes X, Y. Similarly, we can add a floating structure to the axis Z. This will provide the 3D accelerometer measurement in three axes X, Y, Z.

Thermal accelerometers: They use the physical principle of heat transmission in gas. Next temperature distribution around the source of thermal radiation is measured. Heat element heats the surrounding gas in the air cavity to constant temperature. Temperature distribution, depending on the distance from the heating element, is measured by temperature sensors. They are implemented by a set of aluminum / polycrystalline silicon thermocouples and are located at regular intervals. This entire mechanism including detection system is located in one CMOS chip.

If the accelerometer is in the steady state, heated air is distributed spherically around the heating element. If the accelerometer starts to move, air will stir in the cavity due to its inertia. There is a movement of air against the direction of motion of the sensor, that changes the short-term temperature distribution, measured by temperature sensor. By this is caused a temperature difference contrary the still state. The spatial increase or decrease of temperature can determined the direction of motion and temperature difference between the size of acceleration. Block diagram of the thermal accelerometer is shown in Figure 5.7.

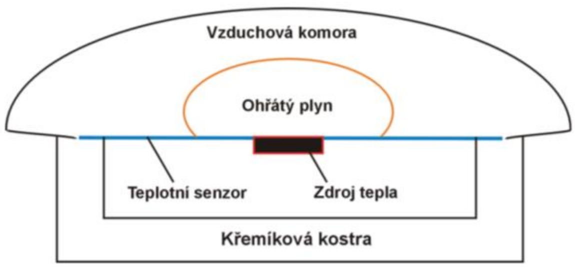


Figure 5.7: Block diagram of the thermal accelerometer

Types of suitable accelerometers

For our application are the most suitable accelerometers with variable internal capacity. They have small dimensions, are integrated in one component with circuits for signal processing, are affordable and can be assumed that due to electronics never ending development will be their specific properties continue to improve.

Accelerometer ADXL345

ADXL345 is a small, thin, low-power, 3-axis accelerometer with high resolution (13-bit) measurement up to ± 16 g. The digital data output is formatted as 16-bit and can be accessed either through the SPI (3 - or 4-wire) or a digital I2C interface.

ADXL345 is well suited to detect static gravity acceleration in tilt, as well as dynamic acceleration resulting from motion or shock. Its high resolution (4 mg / LSB) allows measuring the change in slope of less than 1.0 °.

There are several special detector features. Findings of activity or inactivity and of the presence or lack of movement, if the acceleration on any axis exceeded (user preset level). The findings out one or double click.

ADXL345 is well suited to detect static gravity acceleration in tilt, as well as dynamic acceleration resulting from motion or shock. Its high resolution (4 mg / LSB) allows measuring the change in slope of less than 1.0 °

There are several special features. Findings of activity or inactivity caused by presence or lack of movement, if the acceleration on any axis exceeds the user preset level. The find out single-click or double-click. Free-fall finds out when the device falls. These functions can be mapped to one of the two interrupt output pins. Integrated memory with 32 level first-in, first-out (FIFO) buffer that can be used to store data in order to minimize host CPU load. Low power modes enable intelligent motion-based power management with threshold and active acceleration measurement at extremely low power demands.

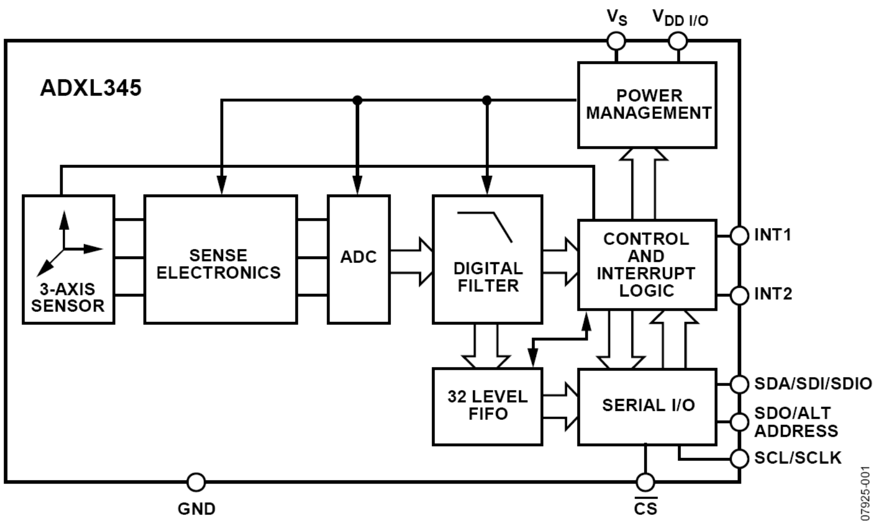


Figure 5.8: Functional block diagram

Accelerometer ADXL 202

ADXL202E is a biaxial digital accelerometer manufactured iMEMS by technology and improved version of older type ADXL202AQC/JQC. Among its basic parameters belong the range of ± 2g (± 20m/s2), low power consumption and cost. ADXL202E is designed for measurement of both dynamic acceleration (e.g. vibration) and static acceleration (e.g. gravity).

The accelerometer has both analog and digital output. Digital accelerometer output for each of the mutually perpendicular axes is a signal whose duty cycle (ratio between pulse width and signal period) is linearly proportional to acceleration (PWM - Pulse Width Modulated) in a given axis. These output signals can be measured directly by a microprocessor counter, so there is no need for additional circuits (A/D converter). The period of the PWM signal is adjustable from 0.5 to 10 ms (i.e. 0.1 to 2 kHz) using the value of the external resistor (RSET). Analog output can be directly used due to analog outputs XFILT and YFILT or we can connect filters to digital outputs and reconstruct analog signal.

ADXL202E bandwidth can be set from 0.01 Hz to 6 kHz via capacitors CX and CY. Typical noise level 200µg / √ Hz, allows signal detection with the minimum level 2 mg in the bandwidth 0 to 60Hz.

BMA180

Bosch BMA180 a three-axis, high-performance digital accelerometer, which provides 14-bit digital output via a 4-wire SPI or 2-wire I2C interface. The measuring range can be set to ± 1g, 1.5g, 2g, 3g, 4g, 8g or 16g. Other features include a programmable alarm, detection of minimal or high g, the possibility of tap detection, fall detection, and self-testing capability. The sensor also has two modes of operation: low noise and low power operation mode.

BMA180 comes in small packages 3x3mm 12-pin LGA. The sensor can be powered between 1.62 V to 3.6 V for VDD and 1.2 V to 3.6V to VDDIO. Typical power consumption is in standard mode only 650uA.

MMA7260QT

MMA7260QT low-cost capacitive micromechanical accelerometer with single-pole low-pass filter, temperature compensation and g setting, which allows to choose among 4 sensitivities. Setting the zero-g offset in full scale and a border filter, which are set from factory and don't require any external devices. It also includes idle mode, which makes it ideal for handheld electronics.

Table 5.1: List of available accelerometers and parameters comparison

Accelerometer	Operating voltage [V]	Nominal voltage [V]	Signal	Analog	I2C	USB	SPI	Linear acceleration. [g]	Axis no.
LIS244ALH	3 - 5	5	-	2	-	-	-	up to 6	2
ADXL330	3 - 15	5	-	3	-	-	-	up to 3	3
MMA7455	2,5 - 5,5	5	-	3	1	-	1	2 to 8	3
MMA7260	2,2 -– 3,6	3,3	-	3	-	-	-	1,5 to 6	3
LIS3L02	2,16 - 3,6	2,5	-	3	1	-	1	2 to 6	3
ADXL327	1,8 - 3,6	3	-	3	-	-	-	up to 2,5	3

5.3.2 Gyroscopes

Using gyroscopes is in addition to accelerometers other way to measure the movement. They measure rotation speed in degrees per second. One of the producers of integrated MEMS gyroscopes, where everything is in one component, is a company STMicroelectronics.

The general principle of MEMS gyroscopes

The gyroscopes are generally designed to measure angular velocity, ie. indication of how fast the object rotates measured in units of degrees / second (deg / s). Rotation is typically possible to measure in one of three axes z, y, x, which is sometimes referred as vertical (perpendicular) axis (yaw axis), transverse axis (pitch axis) and the longitudinal axis (roll axis). Integrated gyroscopes, produced by various manufacturers such as MEMS integrated circuits, works on the Coriolis force principle.

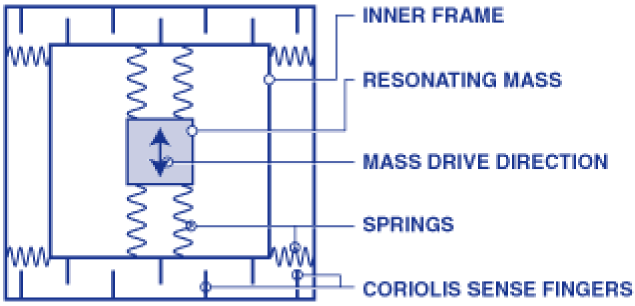


Figure 5.9: Simplified structure of the MEMS gyro sensor

The principle of integrated MEMS gyroscopes

In practical use of the Coriolis force in integrated gyroscopes is used MEMS technology. Chip creates both electrical circuits and mechanical micro-components that make up the sensor itself. Although different manufacturers use slightly different structure, basic principle is always similar. The base is periodically moving (mechanical resonance) structure of a specified weight, mounted in the frame by springs. The direction of movement (Mass drive direction) must always be perpendicular to the direction of rotation. Under these conditions occurs and the physical moving of the sensor operates Coriolis force whose size is proportional to the angular velocity of rotation. This causes compression of the outer frame springs and cause mutual displacement of measuring pads (Coriolis sense fingers) functioning as an air capacitor electrodes. So, change of output capacity is proportional to the angular rotation speed°/s.

The difference between the MEMS gyroscope and accelerometer

In terms of basic principle is only one difference, but so significant. Both use a similar frame with movable sensing flats, working as capacitor electrodes, which changes capacity while frame moves. But while moving the accelerometer structure is loose and moves only when a force impacts (acceleration), the gyroscope is with this structure deliberately periodically moved (mechanical resonance), what can show the effect of the Coriolis force. Thus, while the accelerometer measures the rate of internal displacement MEMS structure as a result of acting acceleration (forces generated during acceleration or deceleration of a moving object directly), gyroscope detects rotary motion (steady rotation).

Suitable gyroscopes types

A well-known manufacturer of integrated circuits and MEMS sensors, the company STMictroelectronics, has in its wide range totally 15 different types of integrated MEMS gyroscopes with different ranges and directions of measurement. Gyroscopes are a combination of one actuator and one accelerometer built in a micromechanical structure. That includes a sensing element which consists of one propel element material kept in mechanical oscillation motion. This whole structure is held in its ability to respond to the rotation and use of Coriolis force.

At the same chip integrated CMOS circuits evaluate electrical capacity changes of the MEMS structure and regulate the output signal of the integrated sensor. Although the output is analog, digital processing takes place inside. Therefore, signal from the MEMS structure is converted to digital, then numerically evaluated and its proportional value change of capacity is recalculated to change of rotation speed in degrees per second. The sequence of consecutive numbers generated is then again converted by D/A converter to final linear analog voltage signal. It is adapted and connected to component ports. Most of the gyroscopes is encapsulated in a plastic LGA case.

Basic parameters:

- Separate analog outputs for each sensed axis
- For each axis separated amplified output 1x or 4x
- Extended Supply: 2.7 to 3.6 V
- Measuring range: from 30 °/s (Lxx503AL circuit) up to 6000 °/s (circuit Lxx5150AL)
- The ability to measure changes in frequency to 140 Hz (band -3 dB)
- Consumption: <10 µA in low-power mode
- Large Temperature stability: -40 ° C to 85 ° C
- Built-in self-test
- High resistance to shock and vibration
- LGA case

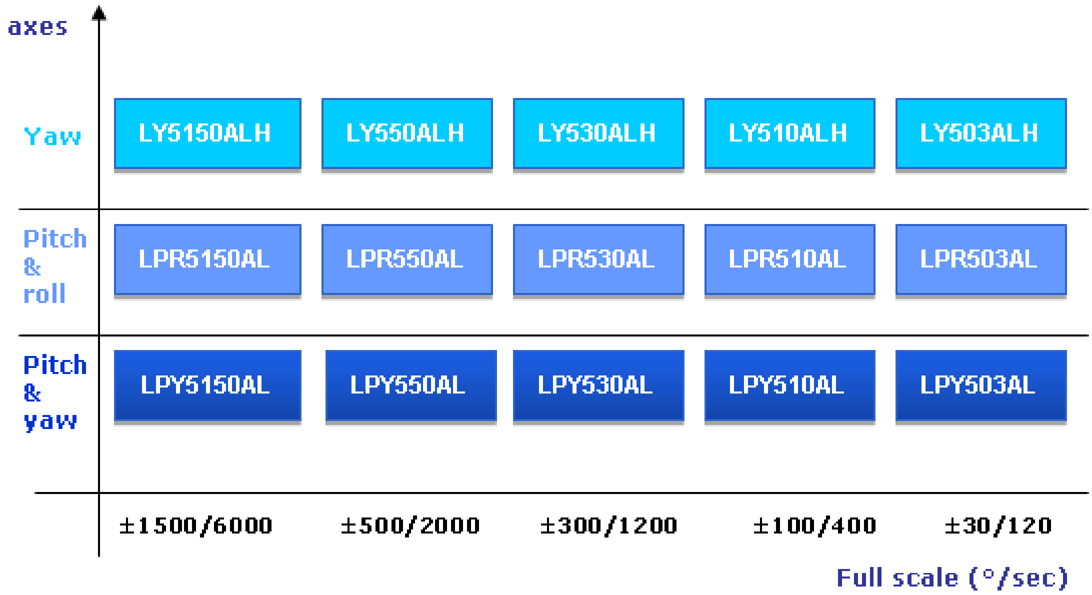


Figure 5.10: A complete MEMS gyroscope overview of STMicroelectronics

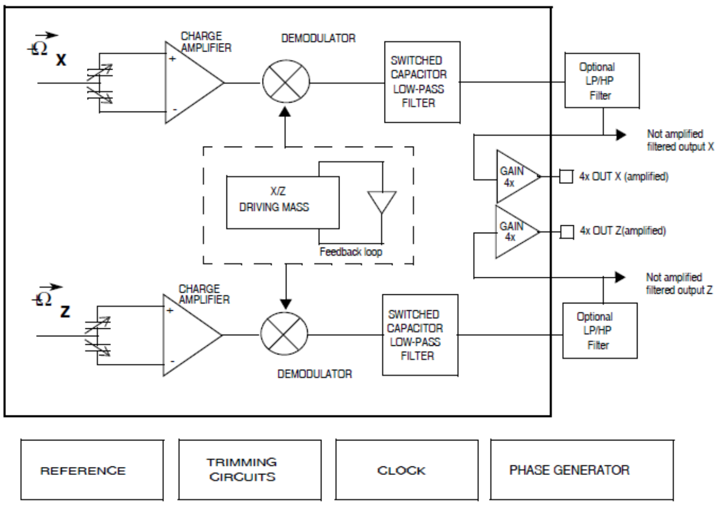


Figure 5.11: The internal structure of 2D MEMS gyroscope LPY510AL

Selecting a suitable gyroscope

As a suitable candidate was selected biaxial gyro (pitch and roll ± 300 °/s) LPR530AL due to its cost, a suitable power 3.3 V supply, high stability at high temperatures, two separated outputs, which can be amplified up to four times. Another big advantage of this gyro is that it has little power, built-in self-test and a low pass filter.

As a convenient alternative for the third axis was chosen gyroscope (yaw ± 300 °/s) LY530ALH, where are same benefits as above LPR530AL with the only difference - this chip is uniaxial (Yaw). As in the previous case was set to analog output low pass filter with ~48 Hz and high pass filter ~0.5 Hz.

5.3.3 Magnetometers

The main principle of the most used vector magnetic field sensors is based on *Hall effect, AMR, and induction* (especially fluxgate); of the scalar than *proton process* and *Overhauser magnetometers*.

Hall sensors

They use the Hall effect - the origin of cross electro motoric voltage U_H (in tens of mV) in a semiconductor (Si, InSb, GaAs) exposed to a magnetic field *B*, which is perpendicular to the current I. This is due to Lorentz force acting on charge carrier *q*.

Application of Hall sensors is as non-contact measurement of currents and especially "smart" sensors with dual-state output, where the evaluation electronics is integrated on chip. Hall sensors are most manufactured magnetic sensors. Measurable range is about 100nT - 200MT with a typical nonlinearity of 1-2%. The disadvantage is a considerable temperature coefficient and the Hall voltage instability offset (up to 0.1%/K and 10 T).

Anisotropic magneto resistors AMR

Anisotropic Magneto resistive phenomenon occurs in ferromagnetic materials, thin films of transition elements (Py = 81% Fe, 19% Ni). They operate on the principle of increase, respectively decrease of the electrical resistance of the material according to influence of external magnetic field applied due to influence of rotation magnetization vector (2-3%), determining the direction of current in the layer. The resistance of structure is then determined by - anisotropic - resistivity in a given direction (see Figure 5.12). Characteristic (Fig. 5.13) is unipolar, and non-linear especially near zero. Linearization can be achieved by using offset (disadvantage in terms of temperature drift) or involving a bridge. For gaining bipolar structure of the response is used Barber-poles. When exposed to strong external fields is a danger in flipping of the direction of internal magnetization and therefore the characteristics of the sensor. This phenomenon prevents periodic material magnetization in both directions (= "flipping"), except that the reduction of the sensor hysteresis.

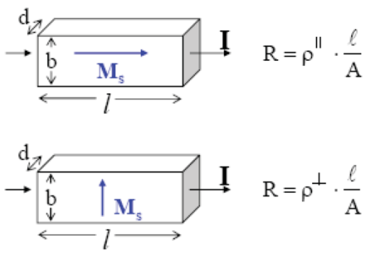


Figure 5.12: Structure Resistance during change of the internal magnetization vector

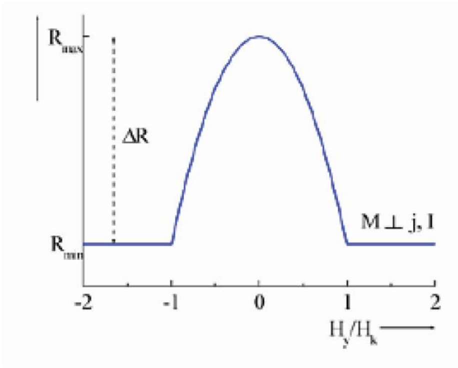


Figure 5.13: Characteristics of the AMR sensor. Hk is a critical intensity

Magneto resistor temperature coefficient is lower than that of Hall sensors, has fast response and thanks pulse flicking has good offset stability. AMR sensors can be operated in compensated mode, than it is possible to achieve linearity to 0.04% when is measured range 1mT. AMR sensors resolution can be better than 10nT. For these reasons are AMR sensors currently a direct competitor to fluxgate sensors in applications such as less accurate electronic compasses, at proximity detection, contactless currents measurement etc. Their major disadvantage in more accurate applications is the temperature dependence of offset (typically 10 nT/K) and the influence of perpendicular fields - the cross-filed effect.

Inductive sensors

Inductive sensors operate on the basis of Faraday's law of induction. The output of inductive sensors is the electromotorical voltage, proportional to the time change of magnetic flow.

Fluxgate sensors

Fluxgate sensors are currently the most sensitive sensors operating at room temperature, typically operate in the range 0.1 nT - 100 µT with distinctiveness to 100pT and long-term stability up to 1 nT.

Their basic principle is periodical oversaturation core material with the excitation current I_{exc} (Figure 24) - permeability is variable in time and direct flow generated by the measured field with induction B_0 is modulated. At zero external field and the sinusoidal excitation is also current flow sinusoidal and contains only odd harmonics. When non-zero external field is violated odd symmetry is also violate even components that are for fluxgate sensors measure carrier in terms of induced voltage.

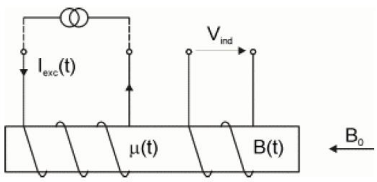


Figure 5.14: The basic configuration of fluxgate sensor

Selecting a suitable gyroscope

To compensate of the magnetic field and determine the direction of testing device, we chose a chip from Honeywell HMC5843. It belongs to a type of three-axis magnetometers with 12-bit ADC and I2C serial line. The advantage of this chip is low cost, small size and low power consumption at 3.3V supply. Resolution of magnetic field is ~6 Oe. In our case, the magnetometer is connected as shown in the Figure 5.15.

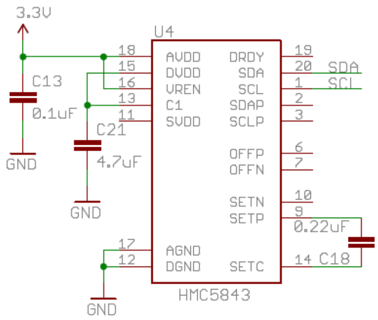


Figure 5.15: HMC5843 connection

5.3.4 Sensors based on optical elements

We plan to use the system developed for the management of industrial sensors based on optical elements. Development in this area is still in its beginnings and there is therefore a good opportunity to market application. Sensors based on optical elements need verify the possibility of using optical fibers for non-electrical measurement of physical quantities. Searching and verification of principles and application possibilities of sensing non-electric physical quantities that use optical methods is still in progress. For measuring is used optical fiber and the specific optical fiber elements feasibility. Includes design and verification of the diffractive optical fiber components, electro-optical processing circuits of primary signals design and verification and converts these signals for further processing into the digital blocks.

6 HARDWARE PLATFORMS

During the last few years there has been a risen interest in the development of several wireless sensor nodes. Many times, those designs started at universities as research platforms, but eventually those designs reached the industry after several years of maturation between hardware and software, that is, the operating system the node can run.

This is so, because the design of the operating system has been proved as one of the most difficult aspects to verify for robustness in the long-run. That has leaded to many of the available nodes in the market to be supported by at least one low-footprint operating system, and in this way many of the difficult parts, e.g. networking, are relieved from the final user or practitioner.

With exceptions noted, most of the nodes in the following list are supported by the two most prominent operating systems in the WSN field, namely TinyOS [TinyOS] and Contiki [Contiki].

Some of the most widely spread nodes are those nodes manufactured in the past by Moteiv and Crossbow. This generated a lot of agreed know-how in the WSN field, mostly because many people shared the same hardware platform, and also because of the success of the two operating systems mentioned before.

Hardware platforms in the market can be classified in several groups, depending on several aspects like size, employed RF band, MCU employed, supported OS, power consumption, targeted audience (general, medical, body-area-networks, etc.), and a few more. In the following subsections we give a brief overview of several of the most successful nodes in the market or the research field.

6.1 MicaZ

Figure 6.1 MicaZ

Manufactured by Memsic, the MicaZ is based on an Atmel AVR microcontroller and a Chipcon CC2420 transceiver.

Features

- 2.4 GHz, IEEE 802.15.4 compliant radio
- Many sensors available: Light, temperature, RH, barometric pressure, acceleration/seismic, acoustic, magnetic, GPS, and other
- 58x32x7 mm

Table 6.1 MicaZ Power Consumption - Typical Operation

Battery Supply	2xAA cells
Minimum Vin	2.7 V
Battery Capacity	2000 mAh
Regulated Supply	no
uC sleep with timer on	0.048 mW
uC active, radio off	36 mW
uC active, radio idle listening	95.1 mW
uC active, radio TX/RX	88.2 mW
Max. Power (uC active, radio TX/RX + flash write)	140.91 mW

6.2 Mica2

Figure 6.2: Mica2

Manufacturerby Memsic too, it is based also on an Atmel AVR MCU and a Chipcon CC1000.

Features

- 433, 868/916, or 310 MHz multi-channel radio transceiver
- Many sensors available: Light, temperature, RH, barometric pressure, acceleration/seismic, acoustic, magnetic, GPS, and other

Table 6.2 Mica2 Power Consumption - Typical Operation

Battery Supply	2xAA cells
Minimum Vin	2.7 V b
Battery Capacity	2000 mAh
Regulated Supply	no
uC sleep with timer on	0.054 mW
uC active, radio off	36 mW
uC active, radio idle listening	66 mW
uC active, radio TX/RX	117 mW
Max. Power (uC active, radio TX/RX + flash write)	165 mW

6.3 Mica2DOT

Figure 6.3: Mica2DOT

Manufactured by Memsic, this mote is based on an Atmel AVR MCU and a Chipcon CC1000 transceiver.

Features

- 433, 868/916, or 310 MHz multi-channel radio transceiver
- Many sensors available: Light, temperature, RH, barometric pressure, acceleration/seismic, acoustic, magnetic, GPS, and other

Table 6.3 Mica2Dot Power Consumption - Typical Operation

Battery Supply	1 coin cell
Minimum Vin	2.7 V
Battery Capacity	560 mAh
Regulated Supply	No
uC sleep with timer on	0.054 mW

uC active, radio off	36 mW
uC active, radio idle listening	66 mW
uC active, radio TX/RX	117 mW
Max. Power (uC active, radio TX/RX + flash write)	165 mW

6.4 Tmote Sky

Figure 6.4: Tmote Sky

Manufactured by Moteiv, the Tmote Sky is one of the most successful motes on the market. Its great market penetration has to do with the fact that it was easily programmable, offered some of the most impressive low-power figures at that time, and it was receiving support from most of the embedded operating systems that were appearing at the time.

Unavailable to buy it any more, it was an ultralow power IEEE 802.15.4 compliant wireless sensor module based on a ultra-low power TI MSP430 and Chipcon CC2420 radio. It was very similar to a TelosB, although it offered some advantages to it.

Features

- TI MSP430F1611 microcontroller at up to 8 MHz
- 10k SRAM, 48k Flash + 1024k serial storage
- 250kbps 2.4 GHz Chipcon CC2420 IEEE 802.15.4 Wireless Transceiver
- On-board humidity, temperature and light sensors
- Ultra-low current consumption
- Fast wakeup from sleep (<6usec)
- Programming and interface via USB
- Serial ID chip
- 16-pin expansion port
- 32x80 mm

Table 6.4 Tmote Sky Power Consumption - Typical Operation

Battery Supply	2xAA cells or USB
Minimum Vin	2.1 V (min. 2.7V during flash programming)
Battery Capacity	2900 mAh
Regulated Supply	internal linear regulator for CC2420 radio at 1.8V
uC sleep with timer on	0.0153 mW b
uC active, radio off	5.4 mW
uC active, radio idle listening	65.4 mW
uC active, radio TX/RX	58.5 mW
Max. Power (uC active, radio TX/RX + flash write)	69 mW

6.5 TinyNode

Figure 6.5: TinyNode

Manufactured by ShockFish SA, it is a compact sensor node platform based on an MSP430 microcontroller and a XemicsXE1205 radio transceiver.

Features

- TI MSP430F1611 microcontroller at 8 MHz
- 10k SRAM, 48k Flash + 512k serial storage
- 868 MHz Xemics XE1205 multi channel radio transceiver
- On-board temperature sensor
- 30-pin Molex connector
- 30x40 mm

Power Consumption - Typical Operation

- 3V design
- Regulated core voltage at 2.8V with limited operation (no flash programming) down to 2.4V (input range 2.4-3.6V)
- Supply voltage: 2.4 - 3.6V

Table 6.5 TinyNode 584

Battery Supply	1 lithium, 2 alkaline batteries or 3 rechargeable cells	
Minimum Vin	2.4 V (min. 2.7V during flash programming)	
Battery Capacity	n.a.	
Regulated Supply	only for Vin > 2.7 V	
	Current Draw a	Power Consumption
uC sleep with timer on	6.5 uA	0.0195 mW
uC active, radio off	2.1 mA	6.3 mW
uC active, radio idle listening	16 mA	48 mW
uC active, radio TX/RX at +12dBm	62 mA	186 mW
Max. Power (uC active, radio TX/RX at +12dBm + flash write)	76.9 mA	230.7mW

6.6 Shimmer

Figure 6.6: Shimmer

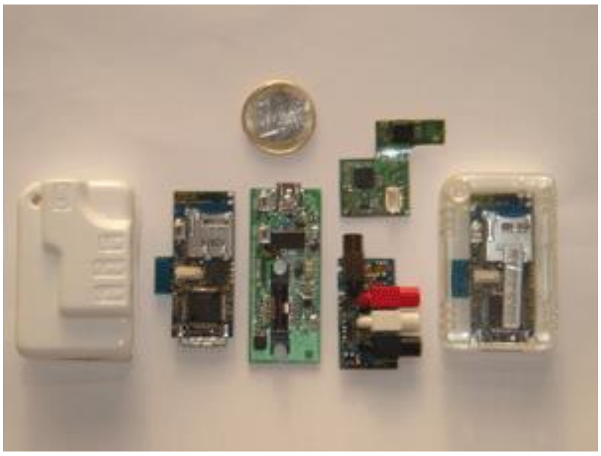


Figure 6.7 Shimmer

SHIMMER stands for Sensing Health with Intelligence, Modularity, Mobility, and Experimental Reusability, and it is a small wireless sensor platform designed to support wearable applications. It was created at Intel's Digital Health Group and provides an extremely extensible platform for real-time kinematic motion and physiological sensing. It features a large storage capacity and low-power standards based wireless communication technologies which facilitate wearable or wireless sensing in both connected and disconnected modes.

Features

- Compact Form Factor, Light & Wearable (Weight: 15 Grams, Volume: 50mm x 25mm x 12.5mm)
- Support for Bluetooth and 802.15.4 wireless communications (WML-C46A, CC2420)
- Offline Data Capture - Micro SD Card Storage - 2 Gigabytes
- Open Platform, driven by TinyOS - http://sourceforge.net/projects/tinyos/
- Internal and external connectors for expansion
- Integrated TCP/IP stack for 802.15.4
- Integrated 3-axis MEMs accelerometer with selectable range
- Integrated Li-ion battery mgmt.

Available as add-on extension boards and accessories:

- Kinematics sensing (3 axis Gyroscope)
- Advanced Kinematics sensing (3 axis Gyroscope + 3 axis magnetic sensing)
- 3 Lead Micro-power ECG

  - Breakout board to thru-holes for rapid prototyping
  - USB programming/charging dock
  - 6-SHIMMER Charger

The SHIMMER platform is being utilised for a variety of applications. These include:

- Gait Analysis
- Sleep Studies
- Cognitive Awareness
- Activities of Daily Living Studies
- Vital Signs Monitoring
- Chronic Disease Management

Since its architecture is based on the original design of the TelosB/Tmote Sky, the power consumption values are basically the same as its predecessor.

6.7 EPIC

Figure 6.8: EPIC

Epic is an open mote platform for application-driven design. Inspired by the hierarchical nature of software and integrated circuit design, the University of Berkeley proposed sensornet platforms be composed hierarchically from a family of modular components to make platform development accessible to a much wider community; developers do not need to be analog, sensor, or radio frequency experts, and can instead reuse components that encapsulate the needed functionality. The Epic design is open source, and all design files are available.

Again, since its architecture is based on the original design of the TelosB/Tmote Sky, the power consumption values are basically the same as its predecessor.

6.8 Zolertia Z1

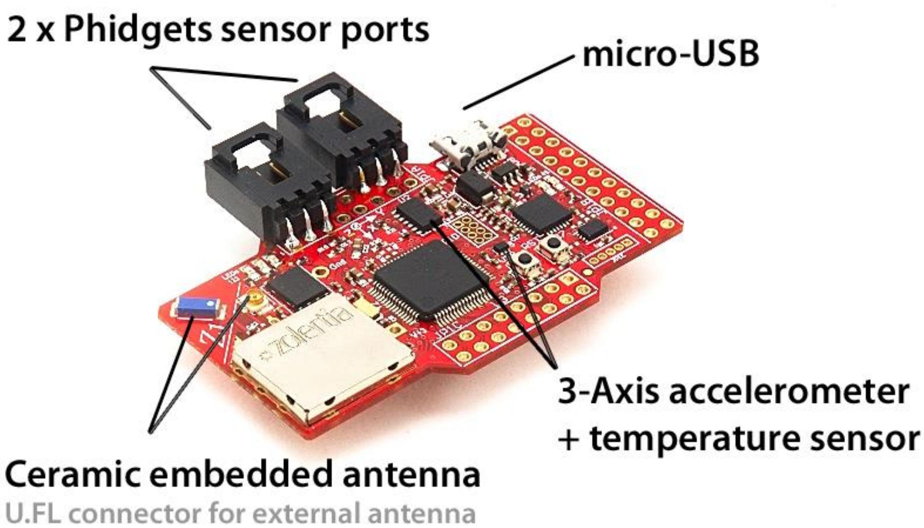


Figure 6.9: Zolertia Z1

Z1 by Zolertia is a low-power wireless sensor network (WSN) module that serves as a general purpose development platform for WSN developers, re-searchers, enthusiasts and hobbyists. This module has been devised from the beginning with two clear goals in mind:

1. maximum backwards compatibility with the successful Tmote-like fam-ily motes while improving the performance in several aspects, and
2. maximum fexibility and expandability with regards to any combination of power-supplies, sensors and connectors.

It comes with support for some the currently most employed open source operating systems by the WSN community, like TinyOS 2.x (currently available) and Contiki (coming soon). The network stacks supported include 6LowPAN (by means of BLIP in TinyOS), Texas Instruments' SimpliciTI and Z-Stack (up to Zigbee 2006), Contiki's 6LowPAN

The Z1 is compliant with IEEE 802.15.4 and Zigbee protocols intended to help WSN de-velopers to test and deploy their own applications and prototypes with the best trade-off between time of development and hardware fexibility.

Its core architecture is based upon the MSP430+CC2420 family of microcontrollers and radio transceivers by Texas Instru-ments, which makes it compatible with motes based on this same architecture. However, the MCU present in Z1 is the MSP430F2xxx instead of the MSP430F1xxx, as is customary among other motes, like Crossbow's TelosB, Moteiv's Tmote, and alike. This fact entails subtle differences due to inner changes between F1xxx and F2xxx devices, but these differences are not expected to arise at the frmware application level if a supported operating system is employed when developing, but in a lower power consumption and faster operation speed.

Product Features

- Ideal development platform for rapid prototyping/deployment of WSNs
- Industrial-grade temperature range (-40ºC-85ºC)
- 52-pin expansion connector
- 2nd generation MSP430™ ultra-low power 16-bit MCU 16MHz
- 2.4GHz IEEE 802.15.4, 6LowPAN compliant and ZigBee™ ready
- 3-Axis, programmable ±2/4/8/16 g digital accelerometer
- Low-power digital temperature sensor with ±0.5ºC accuracy (in –25°C ~ 85°C range)
- Optional external antenna via U.FL connector
- Micro-USB connector for power and debugging

Zolertia offers several customizations to its mote, as well as enclosures, plug&play digital sensors (called Ziglets), accessories, gateways, etc. See as an example the figures below.

Figure 6.10: Different images of the Zolertia WSN motes

The improvements that this change entails are roughly a two-fold performance increase.

A list of the improvements related to the MCU and some of its architectural changes can be seen in the following list:

- 16 MHz clock speed (vs 8MHz)
- Built-in clock factory calibration
- 92KB flash (vs 48KB)
- Half as much power consumption in low-power mode
- 2MB external flash memory (vs 1MB)
- Digital 3 axis accelerometer
- Accepts 2 phidgets for seamless sensor integration
- Most of the MCU ports are visible (all the ADC and DAC)
- USB pins are visible to be able to use custom USB connector
- 32 user space bytes to store the node id or whatever information needed by the user
- Calibration tables are not deleted during programming

6.9 WaspMote

Figure 6.11 WaspMote

Manufactured by Libelium, the WaspMote is another sensor network module that has gained some popularity in the last few years. It is based on a successful hardware architecture named Arduino, which happens to be an extremely popular platform between hobbyists and students that would rather not cope with the insights of electronics and several other details but plug some sensors or modules and play.

It is based on the combination of an 8MHz MCU and a radio transceiver as a module manufactured by Digi. Unlike all of the previously WSN nodes, it is not supported by any standard open source embedded OS in the WSN field. One of the main drawbacks is that by doing so, it is impossible to run open-source standards like IPv6 communication stacks on it and thus all of the research efforts that are being poured in e.g. routing algorithms are difficult to be seen employed in such platforms. The developer is tied to a single provider, a single choice in routing algorithms and

These facts entail interoperability problems, power-optimization limitations of the firmware and several others out of the scope of this document.

6.10 General Embedded Systems Based Sensor Units

For many applications we can utilize general small and smart computer module commonly denoted as Embedded system.

The term Embedded system refers to an electronic device, programmed to control specific appliance. Due to single-purpose design, it is possible to optimize it for specific applications and thus reduce the final product price. This category also covers devices, that are in terms of software (mobile phones, PDAs) and hardware (modular "stacking" boards e.g., for a developer - BeagleBoard, Gumstix), expandable and can be widely used as personal computers, which is of course advantage to using. Embedded systems we can use for both a standalone unit maintaining all the required sensors and/or a communication gateway which connect sensors communicating on industrial-grade serial interface like SPI, I^2C, etc., to more common interfaces like USB, Bluetooth or WiFi.

As an example of an embedded system is shown in Figure 1 embedded Intel platform iMote2 based on Intel processor PXA271 Xscale. It is obvious that the system consists of identical (similar) components, as a personal computer - processor, RAM and flash, IO interfaces, power, real-time signal processor and radio module standard 802.15.4 (ZigBee). Most of these components is advantageously combined in one integrated circuit - a system on a chip (see separate chapter) and the PCB (printed circuit board) is only a base for mounting other components and accessing chip interfaces.

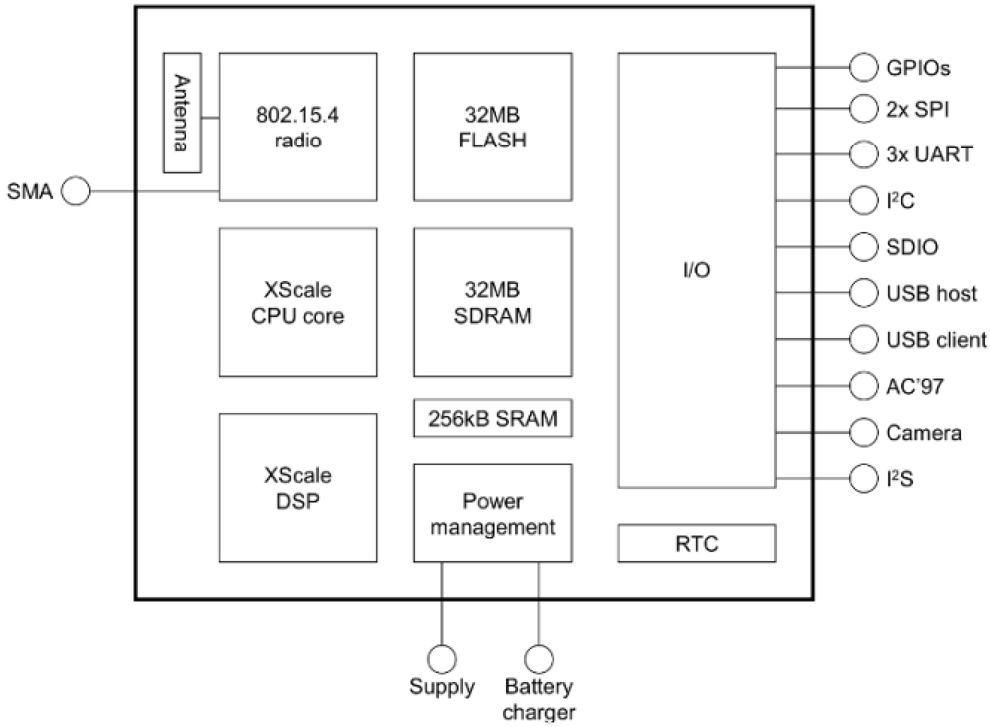


Figure 6.12: Block diagram of embedded computer Imote2

System on a chip - SOC

The SOC integrates all computer components into a single cover of integrated circuit. These components are: microprocessor (or microcontroller, or a combination of several processors - then it is a multiprocessor system, often is accompanied by one or more signal processors for digital signal processing), a combination of memory (RAM, ROM, EEPROM or flash), sources of timing signals, interfaces (including standards such as USB, FireWire, Ethernet and others), voltage regulators and power management circuits. These individual blocks are connected by an internal bus (as an example it is can be mentioned bus AMBA1 - Advanced Microcontroller Bus Architecture - developed by ARM). Block diagram of the circuit shows Figure 6.13.

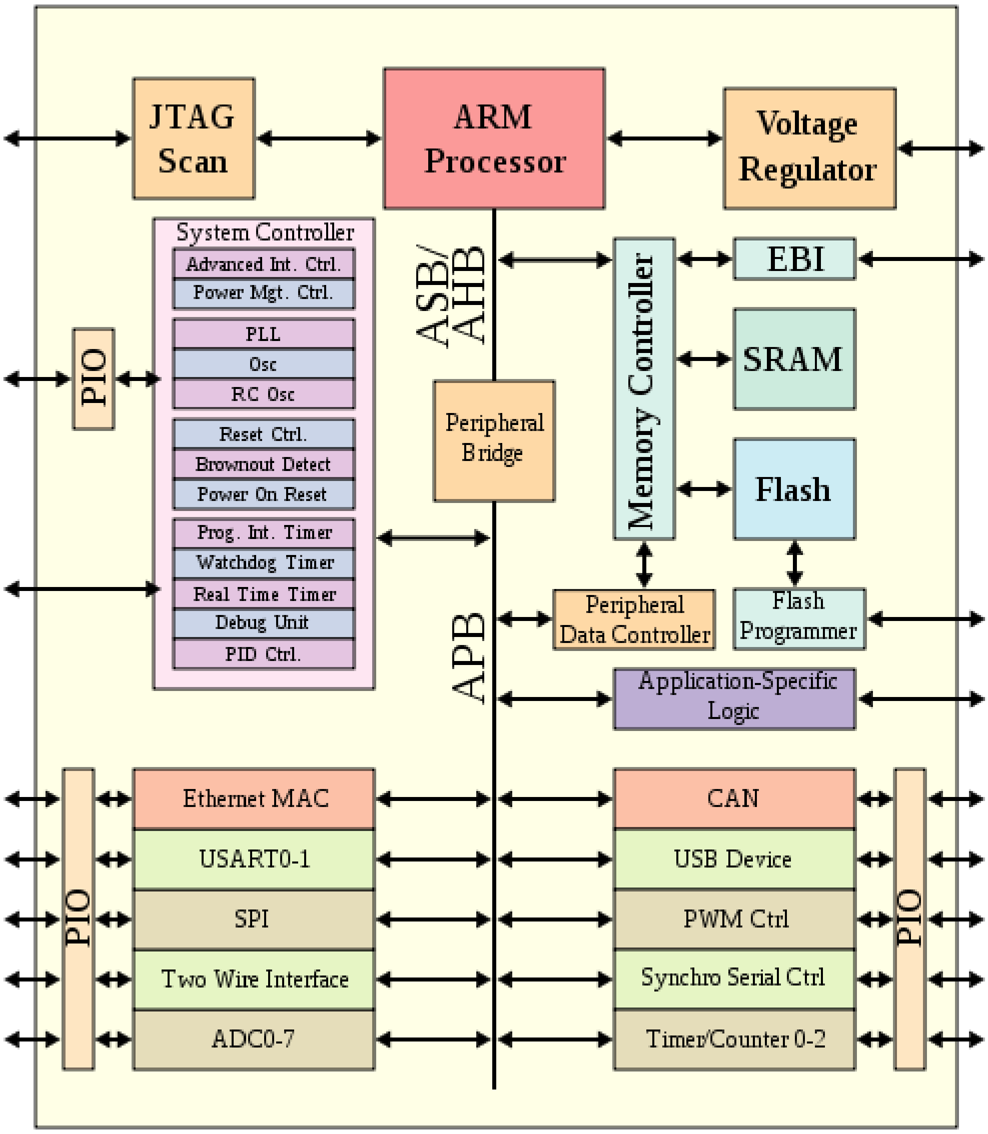


Figure 6.13: Block diagram SoC

Today's SoCs contain integrated graphics engine, often with support for 3D graphics based on OpenGL ES. As an example, it is possible to mention systems from Texas Instruments OMAP series 35xx1, whose core consists of a processor ARM Cortex-A8 with frequency up to 720MHz. These chips are produced 65nm technology. For illustration is block diagram of the series shown at Figure 6.14.[1].

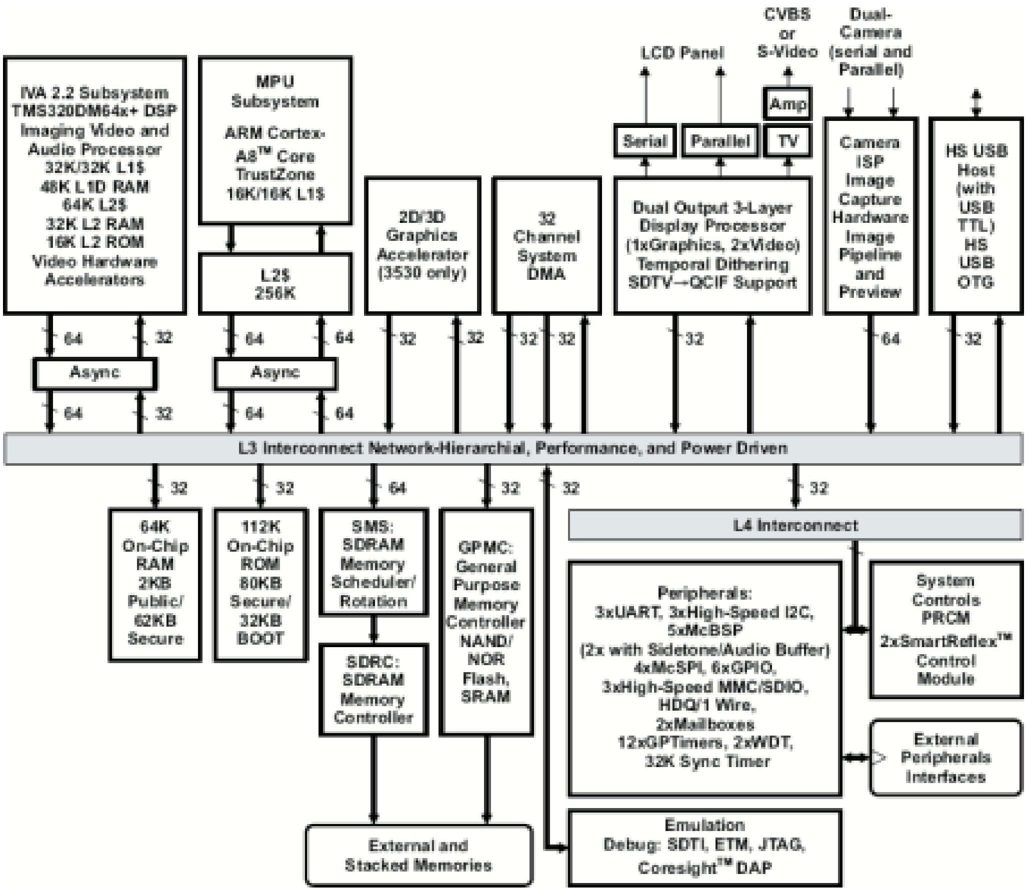


Figure 6.14: Block diagram of the system OMAP 3530

Operating system

The operating system is computer software that is loaded into the computer memory during its boot and remains in operation until its shutdown. It consists of core and auxiliary system tools. Its main task is to enable user control computer (run programs, transfer their inputs and outputs ...), create stable APIs abstracting hardware control with easy-to-use features (Application Program Interface - API) to enable management resources - processes to allocate system resources. As an example, it is can be mentioned the operating systems Microsoft Windows, Unix operating systems (BSD branch, branch of AT & T UNIX System V, the GNU branch, which includes the Linux operating system), OS / 2, Minix, and more. For use in embedded devices it is possible to think realistically about the GNU operating system Linux,

[1] http://pandatron.cz/?1005&720_mhz_procesor_omap3530

which supports many processor architectures (eg PowerPC, ARM, x86, SPARC, MIPS ...), or Windows CE - real-time operating system (see below). It is also convenient to mention TinyOS system, which is used in the sensor network as a system running on each node.

TinyOS[2] – open, component-based operating system designed specifically for sensor networks. This is an event-driven system, where when event occurs, it is called the corresponding code (user application that was compiled together with the operating system). TinyOS is standard platform for academic research in the field of sensor networks

Real-time operating system

Real-time operating system (RTOS) is a multitasking operating system oriented to run processes in real time. By real-time process is meant the process by which the accuracy of the output depends not only on the correctness of the result of calculation, but also the time in which the result was calculated[3].

RTOS system can be specially developed as a real time system, or a classical system with modified kernel. The following is a list of the best known / most popular RTOS:

PikeOS[4] - operating system for safety-critical applications specially developed for easy separation and verification of the individual parts of an electronic system using the Partitions. In these Partitions can run applications or whole operating systems, without affecting each other. Guest operating systems must be adapted to PikeOS interface. It runs on processor architectures like PowerPC, x86, ARM, MIPS, SuperH and SPARC.

RTX[5] - extension of the Windows operating system using a collection of libraries providing access to the subsystem via the RTX API. Adds an independent thread planner and shortens the time unit distinguishable from 5ms to 20 microseconds. Supported processor architecture is the same as for Windows NT/2000/XP.

RTLinux[6] – Commercial real-time Linux modification, which in addition to core adjustment also brings its own set of tools and modules that extend the capabilities of the core enough. It tries to approach as much as possible to standard POSIX 1003.1. It was designed to run on cheaper and less powerful computers based on x86[7]. RTLinux can be considered as a complete operating system with predictable operations in real time, without the interface for standard none real-time Linux.

VxWorks[8] – most widespread commercial real-time operating system. But it is not POSIX compliant. Supported platforms are x86, MIPS, PowerPC and ARM.

WinCE[9] - Windows optimized for devices with limited storage space for operating system. The system is designed as a "proprietary", which does not allow further expansion - the core is stored in ROM. It supports 256 priority levels and uses priority inheritance to work with processes. Supported processor architectures are x86, MIPS, ARM and SuperH.

SymbianOS[10] - operating system designed for use in mobile phones, a follower of EPOC system used in the Psion handheld computers. It runs on the ARM and x86[11] processor architecture.

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2 http://www.tinyos.net/
3 http://cs.wikipedia.org/wiki/Operační_systém_reálného_času
4 http://www.sysgo.com/products/pikeos-rtos-and-virtualization-concept/
5 http://www.odbornecasopisy.cz/index.php?id_document=33664
6 http://www.rtlinuxfree.com/
7 http://www.abclinuxu.cz/clanky/system/real-time-modifikace-linuxu-1-rtlinux-a-rtai
8 http://www.windriver.com/products/vxworks/
9 http://www.microsoft.com/cze/windows/embedded/WindowsCE.mspx
10 http://www.symbian.org/

Hardware

Selection of specific circuits, from which the system should consist, begin by selecting a processor architecture, the choice of specific processor and other related circuit, but these tend to be encapsulated as a system on a chip. Selected circuits would have very similar characteristics and properties, and differ only in details, according to which it is possible to select specific circuits for the implementation.

Processor classification according architecture

From the principle it is possible to classify devices according microprocessor architecture into two groups - with a reduced instruction set (RISC) and a large set of machine instructions (CISC). The difference between implementations is shown in Figure 4. Characteristics of architectures are discussed below.

Architecture with a complex instruction set – CISC

The reason for construction of architecture with a complex instruction set was primarily price and capacity of memory. So there were the need to minimize the amount of memory that the program needs for its activities and the amount of memory that the program needs for its storage. This led to the creation of processors that perform complex operations. However, since complex operations require more complex hardware (which is also more expensive), interlayer was created - micro program, an interpreter, which re-translate complex instructions to simple instructions.

As an example, it is possible to specify the i386 processor series, which uses one part of the processor (micro program) to interpret complex instruction to simple ones, and the second part of the processor treats them, using instruction parallelism, speculative evaluation, and other advanced methods. One CISC instruction is performed as several RISC microinstructions. The main advantage of this approach is that the micro program can be changed without intervention in hardware.

A main disadvantage results from the different lengths of instruction: different length and decoding complicates planning, it is not possible (or very difficult) to implement advanced methods mentioned above.

Architecture with a reduced instruction set – RISC

Unlike architecture with a comprehensive instruction set, where designers try to eliminate 'semantic gap' between the higher programming languages and native language of processor consists of complex instructions, the architecture with a reduced instruction set focuses on simplifying their own instruction set. The reason is that nowadays compilers of higher programming languages rarely implement the same functionality in the same way. Sometimes they even bypass complex instructions - so compilers use simpler instructions to implement the code.

Architecture with a reduced instruction set also uses fewer data types and tryes to work effectively with simple data types. With them can be created more complex structures (which are not used so often). Thanks to it, number of addressing modes is reduced, although this leads to a reduction of flexibility. But there are no problems with different access times to

[11] http://blog.symbian.org/2009/04/16/symbian-on-intels-atom/

operands located in different places and especially the memory problems with decoding and instruction execution planning, which have different lengths.

Access to memory is also reduced by using a large number of registers (IA-32 architecture has for general use only 8 registers, unlike the Itanium, which can use 128 registers)

Fundamental properties of architecture with a reduced instruction set can be summarized as follows:[12]

- All instructions have the same (fixed) length
- Each instruction must take place in a single cycle (cycle means the time needed to load operands from registers, the execution of appropriate operation and store the result into the register)
- Uses execution pipeline
- All operations are performed in registers; memory access is realized only through Load and Store
- It does not use microcode (all instructions are fixed)
- The large number of registers for different uses

In the following text will be considered only RISC architecture. It is unnecessary to use emulated architecture, which has higher demands for power consumption, or which is applied at various transient effects, increases power dissipation and other effects that can be neglected at lower frequencies. So, we will not consider container microprocessors, specially processors designed for running Java. This is mainly because of the fact, that Java was not designed to run on real hardware. These "Java processors", perform at the hardware level only 30-60% of byte codes, the rest is necessary to perform by software. Even Sun Microsystems (now Oracle) don't develop "Java processors"[13], anymore.

The most popular 32-bit RISC processors used today are ARC, ARM, Atmel AVR, ColdFire, MIPS, PowerPC, SPARC, and SuperH. Of those listed, it makes sense to further consideration only ARM, MIPS and PowerPC. Only they offer "PC-like" options, small packaging (hence the possibility of implementation in embedded devices) and low cost.[14]

MIPS

MIPS (Microprocessor without Interlocked Pipeline Stages) is not real processor, but fully synthesized core, that manufacturers can incorporate into their products. Probably the best known is the use in SGI computers (eg R10000 processor), famous for its performance and work with three-dimensional scenes and rendering. MIPS processors found huge application in widespread consoles like Nintendo 64, PlayStation 2, PlayStation Portable, and other devices such as set-top boxes, mobile phones, printers and so on.

Pipeline idea is based on the fact that one instruction does not necessarily use all CPU resources. The processor can then process multiple instructions simultaneously, but only on condition that these instructions do not use the same CPU resources.

[12] http://www.feld.cvut.cz/education/bk/predmety/12/06/p12066704.html
[13] http://www.misantrop.info/684142-lzi-o-mikroprocesorech.php
[14] http://help.lockergnome.com/linux/ARM--ftopict463029.html

PowerPC

PowerPC is microprocessor architecture created by alliance Apple-IBM-Motorola in 1991. Originally designed for use in home computers, but also became popular in embedded devices as well as the high-performance processors. The greatest architecture success was in Apple's personal computers in years 1994-2006 (after this Apple company turn to Intel platform). Today, the PowerPC core is used in the Cell processor, which uses Sony game console Playstation 3.

ARM

ARM (Advanced RISC Machine) is a microprocessor architecture developed by ARM Limited, which is used in many embedded systems. With its energy saving properties, ARM processors are mainly used in mobile industry of consumer electronics, where is very important low power consumption. Today, the ARM family of processors include 75% of all 32-bit RISC processors in embedded devices. It makes ARM the most widely used architecture in the world. ARM processors can be found in all sectors of consumer electronics from PDAs, mobile phones, multimedia players, portable game consoles, calculators to computer peripherals.

ARM technology offers many advantages from the perspective of developers. Because it is only a processor core, which is already used by a variety of manufacturers, is very easy to migrate between entirely different types of circuits. Another significant advantage is the availability of good development environment and development kits with any equipment. 32-bit microprocessors based on ARM core are often well equipped with a variety of peripherals, that offer much more than the basic version of the common microprocessors.[15]

Gumstix Verdex Pro XL6P

Gumstix Verdex Computers are on the market for some time. Model Verdex For XL6P is currently the most powerful of them. Technical parameters of this model are summarized in Table 6.6. For the model Verdex exists expansion modules, especially module with Ethernet 10/100 Mb / s. The board Verdex XL6P and Ethernet module Netpro-H can be seen in Figure 6.15. Figure 6.16 shows a firewall based on computer Verdex For XL6P developed at Masaryk University.

Table 6.6: Computer Gumstix Verdex Pro 6LP specification

Processor	MarvellTM PXA270 with XScaleTM 600MHz
Memory RAM	128MB
Memory FLASH	32MB
Interfaces	60-pin Hirose, 80-pin Hirose, 24-pin flex ribbon
Size	80mm x 20mm
Price	169.00 USD

[15] http://pandatron.cz/?606&at91sam7s_-_1.dil:_seznameni_s_obvody

Figure 6.15:Mainboard Gumstix Verdex Pro 6LP and Ethernet interface board Hetéro-vx.

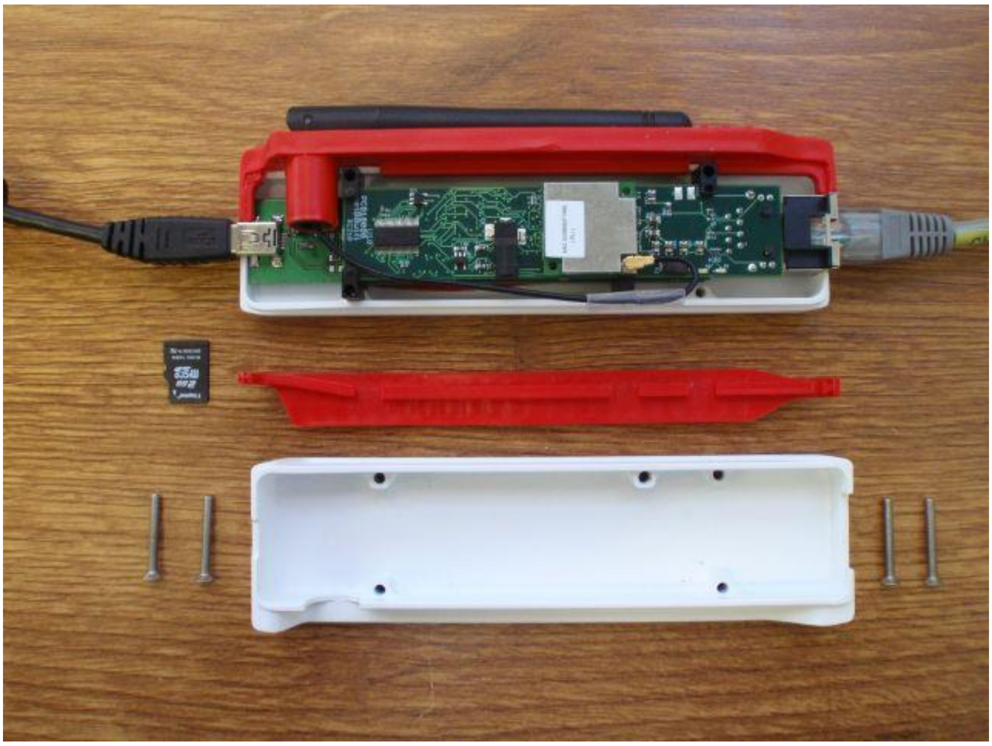

Figure 6.16 : Uncovered firewall prototype microcomputer-based on Gumstix Verdex

Gumstix Overo Earth

Overo model series is the successor of Verdex series. It is smaller in size, has a powerful processor, but unfortunately there isn't a sufficiently large range of expansion modules. At the beginning of the project, this model seemed very prospective, development of additional modules, however, did not continue according to our expectations. Technical parameters of this model are summarized in Table 6.7 and the module is in the Figure 6.17.

Table 6.7: Gumstix Overo Earth Computer Specifications

Processor	OMAP 3503 with ARM Cortex-A8 CPU 600MHz
Memory RAM	256MB
Memory FLASH	256MB
Interfaces	70-pin AVX 5602 series, 27-pin flex ribbon
Size	58mm x 17mm x 4,2mm
Price	149.00 USD

Figure 6.17: Computer Gumstix Overo Earth.

Calao Systems USB-A9G20-C01

This model is probably most closely resembles to our original idea at size and shape. The single board computer integrates, Ethernet interface and power from the USB port, which was necessary to develop for computer Verdex. The main disadvantage of this computer is a relatively high weight (30g), which is concentrated in the opposite side of the board than the USB connector, which this computer connects to the host PC. This causes considerable mechanical stress, and breaking. Technical parameters of this model are summarized in the Table 6.8 and the module is in the Figure 6.18.

Table 6.8: Calao Systems USB-A9G20-C01 computer specification

Processor	ATMEL AT91SAM9G20 400MHz
Memory RAM	64MB
Memory FLASH	256MB

Interfaces	50-pin
Size	85mm x 36mm
Price	149.00 EUR

Figure 6.18: One-board computer CALAO USB-A9G20-C01.

DIL/NetPC DNP/9200

The computer is primarily intended for development and laboratory environments. Its great advantage is pulling all the external interface onto socket DIL-64. This greatly facilitates the development of prototypes of other devices, because it is possible to use the Universal PCB. In the course of development, we can easily change the connection without requiring any need to develop a new PCB. This model provides all the basic types of interface and is very suitable for sensor management. Technical parameters are given in Table 6.9 and the computer is in the Figure 6.19.

Figure 6.19: Computer DNP/9200

Table 6.9: DNP/9200 computer specification

Processor	Atmel AT91RM9200 32-bit ARM9 180 MHz
Memory RAM	32MB
Memory FLASH	16MB
Interfaces	DIL-64
Size	82mm x 28mm
Price	169.00 EUR

6.11 Other Modules

Unlike all of the previously described WSN nodes, there also exists in the market the possibility to add 802.15.4 wireless connectivity to a previous design that the user had designed already.

This means that these are modules that, on their own, are not capable of anything unless there exists another MCU controlling that module.

These modules are not analyzed in detail in this document, but a brief list of the most popular ones follows.

6.11.1 Digi Xbee and Xbee Pro

Offer modules at different frequency bands (868/915MHz, 2.4GHz) and different power amplifier options (0dBm, 20dBm).

Figure 6.12: ZBee

6.11.2 RadioCrafts

Offered modules cover the 433 — 915 MHz ISM bands.

Figure 6.13: RadioCraft

6.11.3 Meshnetics

This modules are offered as 868/915 MHz and 2.4GHz RF bands modules.

Figure 6.14: Meshnetics

6.11.4 Jennic

This modules are offered as 2.4GHz RF bands modules.

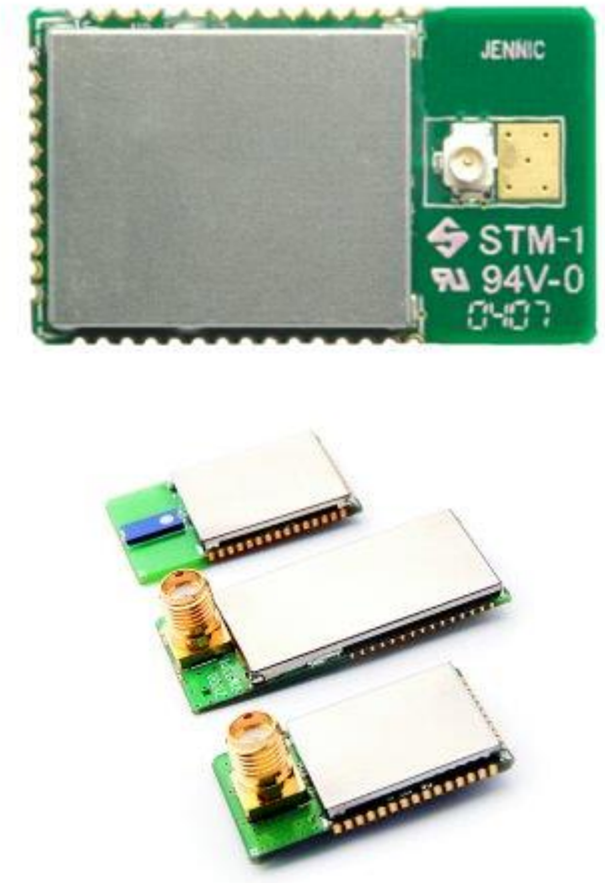

Figure 6.15: Jennic

6.11.5 Microchip

This 2.4GHz is an FCC-certified module by Microchip.

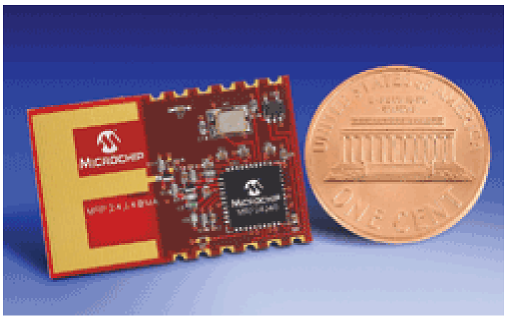

Figure 6.16 Microchip

7 CONCLUSIONS

In this document we have analyzed and summarized the different uses cases described in the story board document. The three final profiles have distinct requirements, especially regarding the communication necessities.

We have also provided the state of the art of the different parts relevant for our work on the project: smart textiles and protective equipment, communication protocols, sensors, hardware platforms.

The key final prototype of our work will implement a t-shirt for emergency units that typically operate under extremely harsh conditions. Firefighter, rescuers and, in general, emergency units, can benefit from new technologies to improve their performance and security conditions when working exposed to risk situations and provide and ideal test case to push wearable computing to its limits.

The main danger originated by working exposed to severe hot conditions is called thermal stress and can be defined as the heat load received, resulting from the interaction between environmental conditions of the workplace, the physical activity and the clothes that workers wear. Under thermal stress, the body is altered and the person suffers physiological overload.

Certain physiological mechanisms (such as sweating and peripheral vasodilatation) make the body leave the heat excess and if even thought, the body temperature exceeds 38 º C, serious health problems and even death may occur. This phenomenon is a major cause of death among firefighters and it can also happen to professionals working with high heat sources such as foundries and metal or glass industry.

The objective of the project is to create a smart t-shirt capable of measuring the rate and thermal stress state which the user is subject to. For that, several sensors will monitor different parameters and send (wireless) the information to a unique central system (a wrist-watch or mobile phone), that will process the information and informs the user about his state and warns him in case of danger.

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