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Measurement and sensor technologies trends, development dynamics and application scope

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THESIS ABSTRACT

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The thesis is an exploratory study. Its aim was to have an overall view of the measurement and sensor technologies trends, development dynamics and application scope primarily in Europe and North America. Additionally, its objectives were to present the most influential and promising measurement trends of the nearest future; to review technology trends that impact the development of single sensors and sensor systems; and to present their application scopes such as medicine, traffic and logistics industries. Similarly, the thesis focused at the European sensor industry progress, which includes geographical mapping of market players, distribution of sensor types and their expected impact.

As an exploratory study, previous studies and literature on the measurement technologies and trends were reviewed in an attempt to explain variety of trends and role of industries and different countries in their development. Moreover, a desk research was conducted whereby a list of 51 European sensor developer companies was gathered. Information was also collected on the geographical areas and respectively to the industry application segments.

The main findings were that physical and mechanical sensors represent the majority of sensor market in Europe, and the key sensors are multiple sensors, smart and interconnected sensors with energy autonomy. The study also revealed that market opportunities rely on new technologies and developments in base materials, converters and electronic processing. Furthermore, it was noted that the new markets and market niches regularly emerge (for example, medical and consumer) because they rely on new sensor features, business models and deployment concepts such as smart systems, sensor networks and autonomous sensors. In addition, the study showed that regulation and standardization are significant issues, which increase market development and help establishing cooperation between manufacturers and technology integrators.

The study was concluded by presenting a recent research, made from application perspective, which includes 3D imaging and distance sensor and sensor networks implementation in logistics industry.

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CONTENTS

1 INTRODUCTION

Measurement technology is an important tool in innovation, research and development processes. It plays a significant role in the modern world. Measurement technology can help people to predict many facts in their life and make their being in society more productive and effective. At the same time, being up to date and using the newest possible technologies are essential factors, which significantly increase organization competitiveness. What are the trends of measuring systems in the modern world? This is one of the key questions, which the author is going to answer in this work.

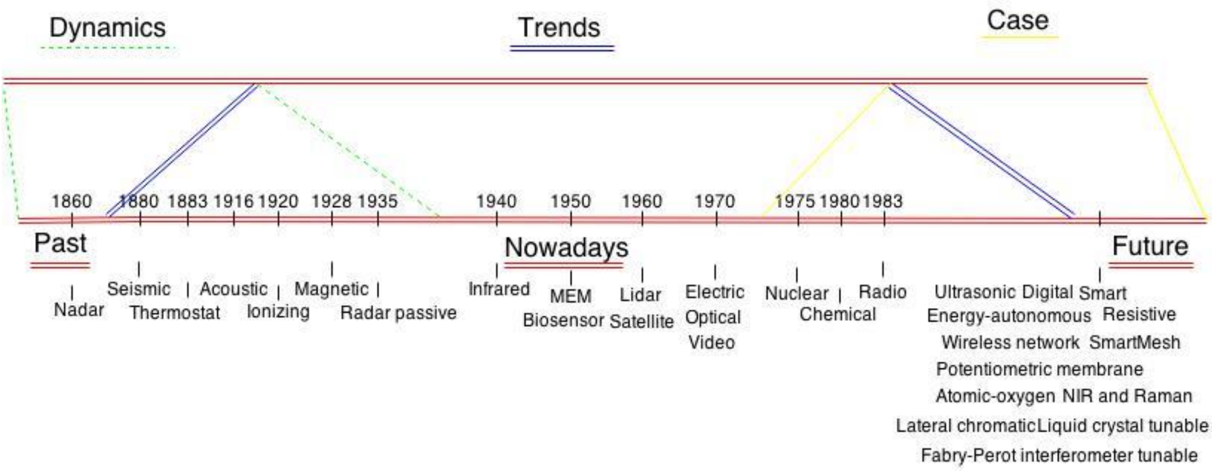
The thesis work includes background information about metrology and metrics, future trends in measurement technologies in general and detailed analyses of some specific types and technologies in metrology. There is also a practical part which includes forecasts of potential inventions and prototypes, and opinion reviews of experts and professionals from the industry.

Measurement technology fundamentals are tightly interrelated with telecommunication technologies, which provide approaches to measurement and the interpretation of results of specific methodologies and measurement tools (devices and control devices). Hence several sections of this work explore the stages of information revolution, which has specific origin of modern scientific and technological progress. It shows that the concept of technology goes to the forefront and requires a new approach to the analysis and description of phenomena, associated with the development of modern paths of communication. This thesis also introduces concepts for description and classification of modern methods of performance measurement in communication networks.

The thesis identifies an extremely high speed of technological changes and a lag, which is manifested in the lack of training and reference materials, a small number of professionals in the technology and low level of articles in the scientific press. This gap is not merely a characteristic of a particular country; it was observed that it is everywhere, even in the most developed countries. In addition to the lag issue, there was identified a time factor, which results in fellowship of the dynamics of technology development in the market, not just observation of major trends. The author investigates modern development of measurement technology from the perspective of its high specialization. The development of modern measuring equipment for telecommunications market has led to the emergence of specialized equipment, intended for operation and maintenance of communication systems. As a result of changing technology, market of special measuring technology always changes rapidly; there is a problem of classification, which needs to be solved. The thesis also underlines one of the most significant factors which affect the R&D activities in the measurement industry and which increases workability of modern equipment. In the case study section, there is an example, which shows a large shift to the usage of complex solutions, which, at their turn, require implementation of sophisticated and complex measurement technology systems.

The technological approach of measurement performance in communication networks is one of the main parts of this work. In addition, several parts of the work are devoted to the description of processes, taking place in the industry of modern measurement technologies. The author explores measurement technologies dynamics, finding solutions for the following questions (Picture 1).

- How and why do technologies replace each other?
- How do technologies expand on the market?
- What are the future influencing measurement technologies?



Picture 1. Timeline of sensor dynamics, trends and case example (Drawn by the author)

Below the author investigates the above-mentioned issues and provides possible conclusions regarding the current situation of measurement technology area and its future prospects.

There is a need to mention that proposed material is a result of author's conclusions that can be challenged.

2 EVOLUTION OF MEASUREMENT TECHNOLOGIES

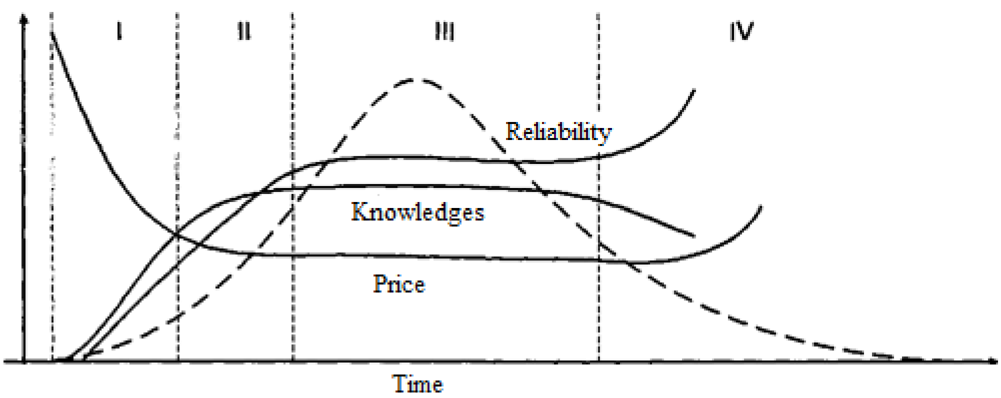
This chapter consists of three parts. They represent practical and application aspects of the trend dynamics of measurement technologies.

- Stages of technological development
- Dynamics of measurement technologies development
- Time lag and methodology problems and firm's sensor development timeline

There is a traditional comparison of technology development as "wave" conducting process. However, the consideration of the processes of technology development in the form of "waves" may be too simplistic. To be fully aware of the idea, that goes with a new technology, and to have comprehensive analysis of its development, we must also consider the social and economic processes that accompany the passage of the "wave" (Vigleb 1989).

2.1 Stages of technological development

The illustration (Picture 2) shows a timing dynamics of technology evolution on the market and the corresponding behavior of a number of important parameters, which usually accompany this process. Particular parameters define the use of technology in telecommunication. It includes setting the value of technical solutions, the average level of knowledge of a connected technology communities and reliability of technical solutions (Maslov 2009).



Picture 2. Dynamics of technology development on the market (Maslov 2009)

Picture 2 shows that costs of technical solutions are extremely high at the early stage of technology development. It involves not only the cost of new high-tech equipment and costs, required to carry out the necessary modifications (according to Murphy's rule, device may not work immediately), but also operational testing of new technical solutions, additional modifications of devices for interfacing with the existing network. Then, during experience growth and technological implementation of internal and external integration of devices, the cost begins to fall and reaches an optimal and stabilized level. Once the technology becomes obsolete and begins slow decrease on the market, the cost of technical solutions increases. The cost of supporting equipment increases rapidly. Spare parts and components of devices disappear from the market, which significantly increases the operating costs of technology (Kotik 2008).

New technology is the amount of new knowledge that should be interpreted and implemented by networked community, experts, operators, suppliers and customers. We may divide the technology development process into four lifecycle periods, which allow us consideration of technological and social shifts, which are unique for every period (Kotik 2008).

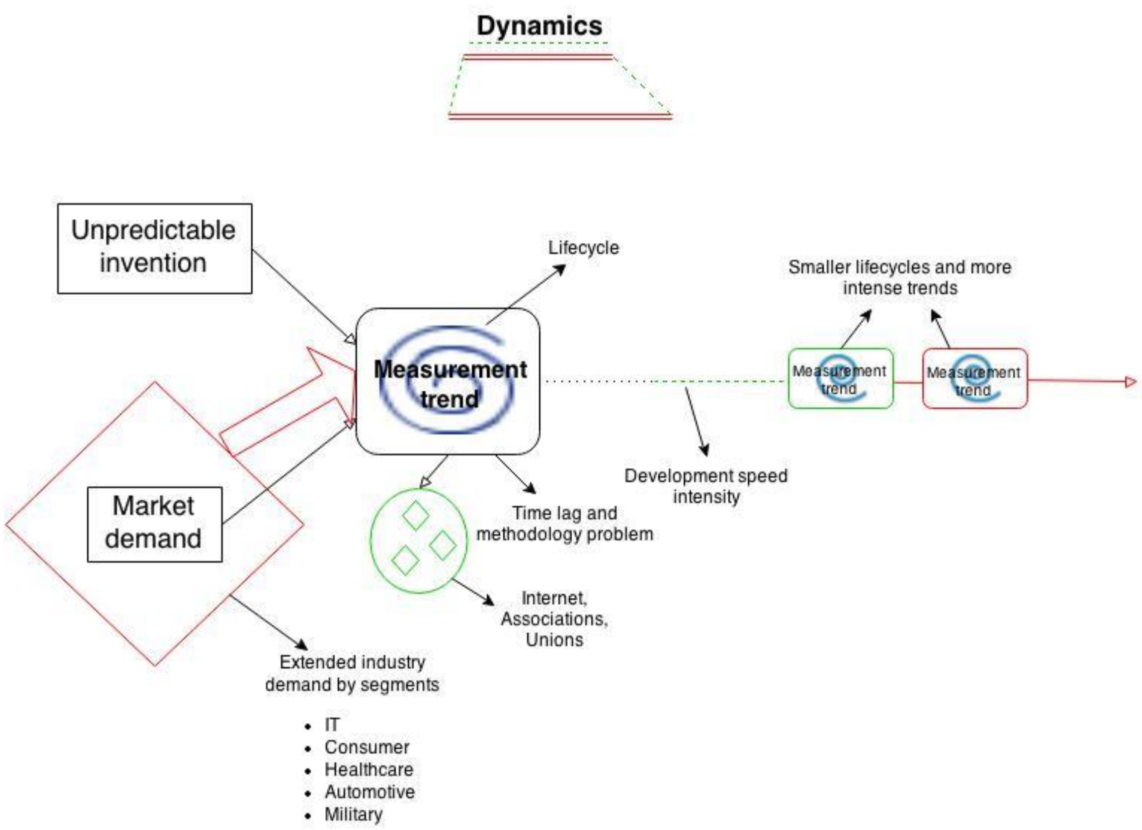
Step 1 is the process of formation technology on the market. New technical solutions have just appeared on the market. They are very expensive. No potential customers or suppliers are fully representing nuances and knowledge of job. The first solutions become unstable and require further development in field experiments. The only plus is that they promise significant benefits in the future. Only large operators in the experimental areas of implementation could allow themselves testing of non-competitive, expensive, unreliable and incomprehensible products. Smaller operators are always at risk of bankruptcy. The implementation of technology at this stage of development is a charitable contribution for the future of communications technology. An example is the ATM technology development, which has been widely promoted and quoted at the beginning of its market share growth. Additionally, there is a substantial risk that the purchased equipment, being new and experienced, will not give the possibility in the future to use benefits of new technology (Zenov 2011, 67).

Step 2 is stabilizing position of technology on the market. At the beginning of this stage there is "misguided epiphany", characterized by controversy in the technical press, stating new technology as an effective, and defining whether it is needed in the market (Zenov 2011). These questions belong to a natural process of transition from primary euphoria to a constructive discussion on the basis of the first experiment. At this stage it is recommended to use technology by most of operators. As a result, new technology becomes fashionable in the best sense of word, and it becomes a paradigm, used by the most operators. The end of this period is characterized by the ratio of healthy enthusiasm for the introduction of a new familiar technology. Decisions, which become reliable knowledge of the technology, are gradually filled into tutorials and become classics. When discussions in the press fall silent, it means that technology has taken its rightful place. Suitable examples from European market may be ISDN (Integrated Services for Digital Network) and SDH (Synchronous Digital Hierarchy) technologies, which have already passed the stage of the debate about their necessity, but have not yet reached a stage of healthy enthusiasm (Beroulle 2001).

Steps 3 and 4 are the maturity and oldness of technology. Generally both stages are characterized by complete silence about technologies' technical issues. It is not necessary since technology is already well known; it entered to the textbooks and manuals. There are good instructions, a broad professional staff with extensive experience in maintenance facilities, based on this technology. Technical solutions are included in educational programs of universities. Examples of technologies at steps 3 and 4 are modem data transfer, PDH and quasi-PBX.

2.2 Dynamics of measurement technologies development

Global technological progress includes many industries such as information technologies, automotive, space, healthcare and military sectors (Picture 3). On their turn, they accelerate development speed and intensity of measurement technologies, which are involved in almost every modern technological development. Therefore, traditional S-shaped figure of technology lifecycle may be utilized, when considering development of measurement technologies. History of technical progress shows that sometimes particular industries have bigger research intensity. Why does it happen? There are two main reasons for that: unpredicted technological inventions and market demand. Unpredictable technological invention opens up further intense industry development. For example, it happened with infrared sensors. Sometimes product or service demand stimulates technological research, which leads to its (demand) satisfaction. For instance, it happened with digital and smart sensor areas, when leading high-tech companies started to use them in production of "touch screen" smartphones. The first reason is almost impossible to predict but the second one may be analyzed and narrowed by industry segments. According to the analyses, conducted in the following chapters of this work, industries include healthcare, automotive, information technology, military, space, consumer electronics, scientific research, energy and manufacturing sectors. Second reason follows traditional direct dependency rule. Applying to our case, it says that the bigger product and service demand appear at particular industry, more intensive research and invention process occur at that sector (Zenov 2011).



Picture 3. Dynamics outline (Drawn by the author)

Generally trends of measurement dynamics follow development dynamics of technological progress among ages. Technological and measurement technologies progresses were both slowed by many reasons at their basic stages. However, the more tools become available and the more inventions have been made, the faster the speed of technological evolution gets. For example, there is a Moore law in the information technologies industry. It states that “the number of transistors in a dense integrated circuit doubles approximately every two years”. In addition to its “own” evolution, there is a constant stimulation to measurement technologies development by various industries. Therefore in the future, the speed and productivity of developments of measurement trends will increase. At the same time, it is hard to predict measurement trends lifecycle changes, since they are dependent on technological and industrial usage. Since measurement trend growth is tightly connected to product and technological progress, it is possible to assume that measurements' lifecycle generally will be reduced. Technology circulation increases its speeds and therefore newer inventions quickly replace older ones. They include miniaturization, efficiency and, consequently, complication in measurement technological area. Concluding, the process of improving measurement technology is closely linked to general trend of high-tech sophistication in their development process in the second half of XX century (Maslov 2009, 49).

2.3 Time lag, methodology problems and firm's sensor development timeline

Nowadays the role of measuring technologies changes the operational practice of most modern companies. Until now measurements were used to monitor network performance and compliance of system elements to domestic standards. There were clear guidelines on measurement methodologies for production and information system, such as tools manuals, measurement technique appliances and measurement parameters. Current situation of technology standardization shows that this process lags behind development of technology itself. There is no clear operational methodology and wide practitioners' support on the usage of newest measuring equipment and they are not foreseen in the near future. This is a very typical and old technological dilemma but significance of measuring tools at some vitally important systems obliges reducing time lags between technology invention, its usage and methodology development. Professional unions, internet communities and industry associations may accelerate solution development of this problem. Open and free accessible tools and libraries may encourage practitioners to share their experiences. The above-mentioned speed lag may bring additional challenges from national and international authorities, which are able to slow down measuring technology developing process and significantly reduce or stop its market penetration motion. As can be seen from the S-shaped figure of technology lifecycle on Picture 2, innovations and trends are especially weak at the beginning stage. One of the history longest sensor development timelines belongs to Texas Instruments Inc. Analyzing timeline it is easy to discover huge influence of industrial, military and consumer industries to directions of sensors evolution (Picture 4).

Sensors & Controls

1930
- 1930
  - First high-temperature thermostat metals introduced
- 1933
  - First room thermostat introduced
- 1938
  - First one-inch motor protector introduced
- 1939
  - Three-quarter-inch motor protector introduced

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1940
- 1940
  - Motor protection devices under the KLIXON® trademark added
- 1941
  - Production of circuit breakers for military vehicles and aircraft begins
- 1945
  - Receives Army-Navy "E" award for contributions to war effort
- 1949
  - 4370 appliance thermostat debuts; first major product for commercial use

Back to top

1950
- 1950
  - Manufacturing begins in Mexico
  - First hermetically sealed thermostat introduced
- 1952
  - S&C becomes the world's major source of aircraft circuit breakers
- 1953
  - Ships first fuel elements for Sea Wolf Nuclear Submarine
- 1954
  - First hermetic motor protector introduced
  - Sine switch launched, entry to precision position switches for military
  - First patents issued for pressure temperature bonding process
- 1955
  - Motor protector assembly begins at plant in Holland
- 1956
  - 3 Phase bimetal breaker introduced
  - Receives license to fabricate reactor core modules
  - Removable fry pan probe introduced
- 1959
  - Merger with Texas Instruments Incorporated

1960
- 1960
  - Tubular Protector for fluorescent light ballasts developed
- 1962
  - Hermetically sealed tubular protectors introduced
- 1963
  - First pressure switch using a snap-action sensor disc introduced
  - Copper-clad aluminum wire bonding process developed
- 1964
  - Electronic clothes dryer control introduced
  - High-volume contract awarded to supply connectors to IBM
- 1965
  - First miniature aircraft breakers introduced
  - Contracted to create switches for the Apollo Command Module, Lunar Rover
  - Positive Temperature Coefficient (PTC) technology introduced
  - $30 million contract awarded by U.S. Mint for clad coinage
- 1966
  - First electronic connector business secured
  - First PTC heaters introduced
- 1969
  - Stainless clad aluminum disclosure filed

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1970
- 1970
  - Stainless-steel aluminum shipped for first volume automotive application
- 1971
  - Calculator keyboard using discs introduced
- 1972
  - Military connector product line launched
  - First PTC electric choke introduced
- 1974
  - 5TI programmable controller introduced
  - Manufacturing in Kuala Lumpur, Malaysia, commences
- 1975
  - 8AM PTC Motor-starting device introduced
  - Crimp-sealed appliance protector introduced
- 1976
  - Electronic controls for microwave oven introduced
- 1979
  - PTC early evaporation device for 1980 Chevette produced

1980
- 1980
  - S&C's Appliance Electronics unit ships first electronic wall thermostat
- 1981
  - First free-disc pressure switch introduced
  - Work begins on Statue of Liberty restoration project
- 1983
  - First 8EA PTC starter produced
  - Aguascalientes, Mexico, selected as site for expansion
- 1985
  - 4TM motor protector introduced
- 1988
  - Automotive Pressure Transducer (APT) production launches for GM
  - Automotive Pressure Transducer produced for Nissan air conditioners
  - TI-RFID introduced for Automatic Rapid Frequency Identification
- 1989
  - Implantable TIRIS™ transporter introduced

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1990
- 1990
  - First battery protector introduced
  - First family of SP Combination Start and Protect Devices introduced
- 1992
  - Low-g accelerometer introduced
  - TIRIS read/write transponder debuts
- 1994
  - Transmission Range Sensor production launches for Ford
  - TI-RFID vehicle immobilizer developed
- 1996
  - Plant opens in Baoying, China
  - Construction begins on new facility in Aguascalientes, Mexico
- 1997
  - Mobil Oil selects TIRIS for use in Speed Pass pay-at-pump transactions
  - Industry's first c24x low-cost motor controller introduced
  - Land Grid Array (LGA) burn-in sockets selected by Intel for Pentium II
  - High-Volume Manufacturing of 0.5mm pitch Chip Scale Package (CSP) begins
- 1998
  - Wholly-owned China manufacturing operation opens in Baoying
  - TIRIS announces Tag-It™ SMART label technology
- 1999
  - Production of DuraFoil™ material begins
  - Subcontracting agreement signed with Videoton in Hungary
  - Tag-It™ SMART label low-cost RFID Transponder introduced
  - Micro-Silicon Strain Gauge sensor introduced

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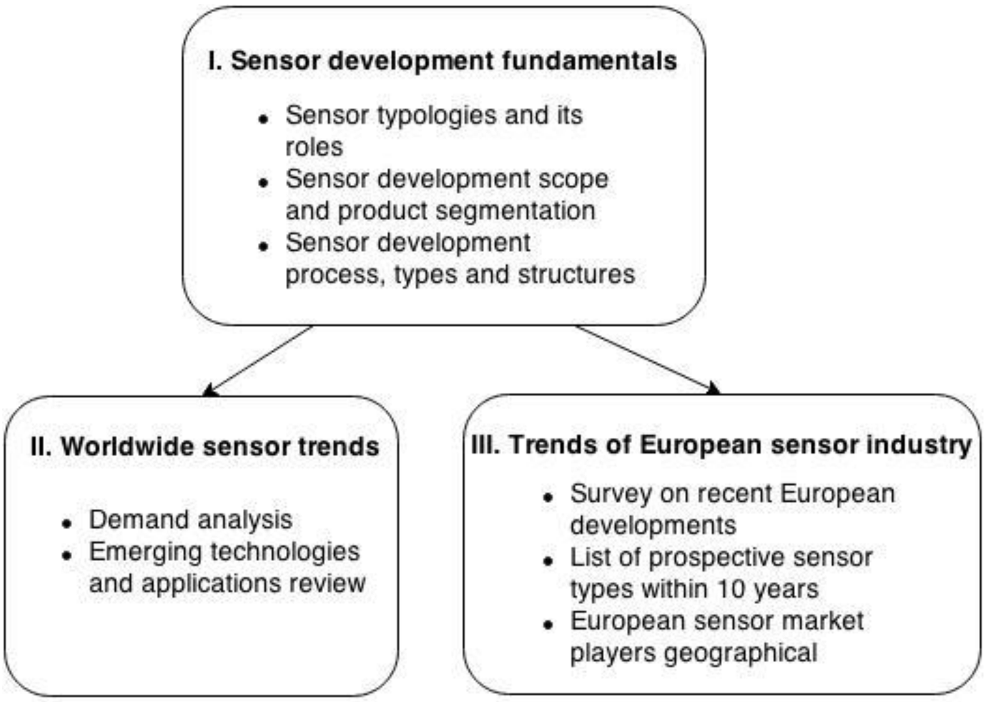
2000
- 2003
  - Automotive passive entry system using an RFID-enabled key created
- 2004
  - ARC Shield™ introduced (fault circuit Interrupter)
  - Second plant in China opens in Changzhou Province after acquisition of the mc tor protector business of Chengheng Company.

Picture 4. Texas Instruments Inc. Sensor development timeline (retrieved from company's website)

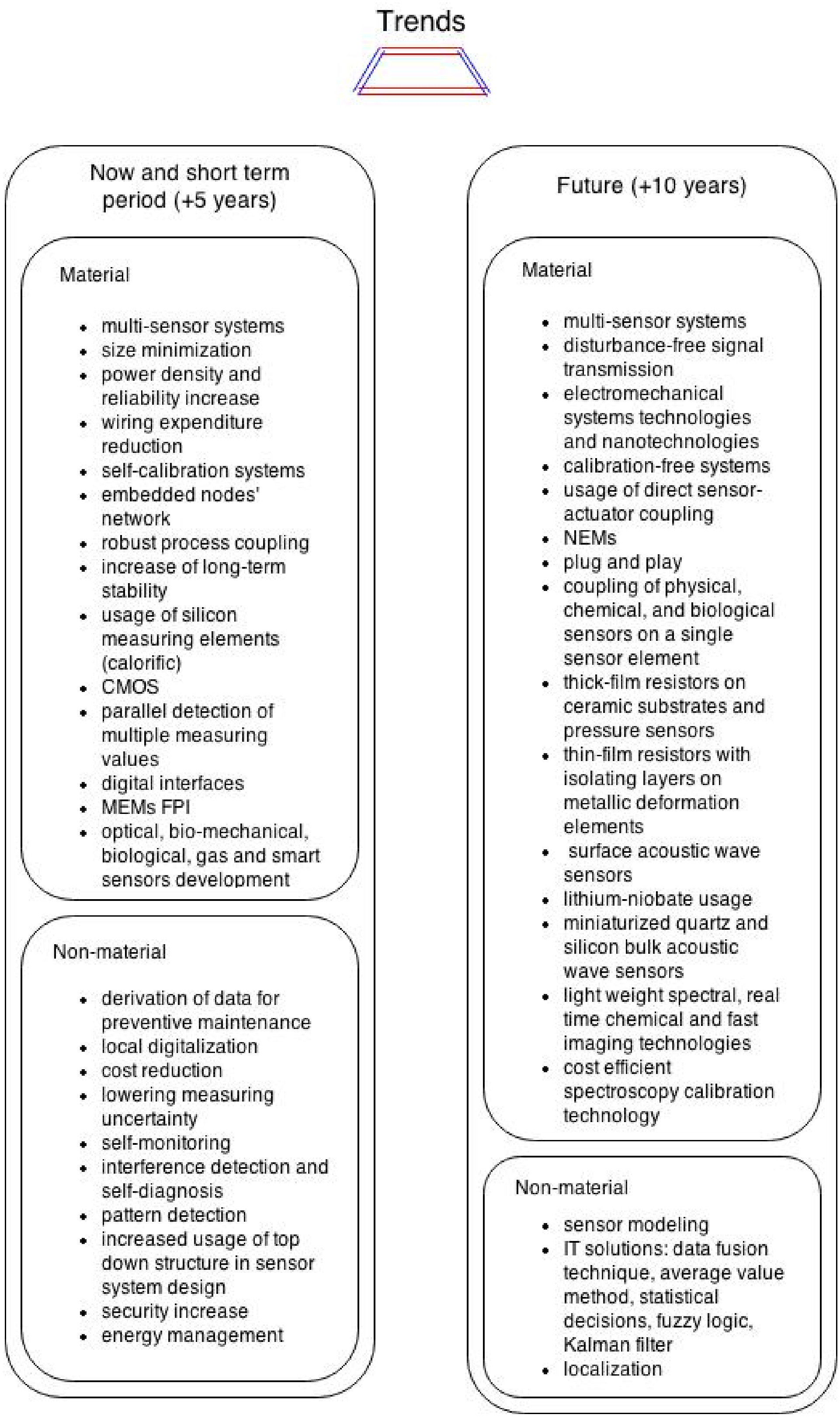
One of the biggest achievements of modern measuring technologies is their ability not only gather data, but collect information, conduct simplified analysis and influence decision or operation processes.

3 TRENDS IN MEASUREMENT TECHNOLOGIES

This chapter is divided into three logical parts. The first one is sensor development fundamentals. At this part we observe essential elements of sensor development, which include sensor topologies and their roles, its development process, sensor product segmentation and development application scope, sensor types and structures and perspectives of information technologies in sensor systems development. The second part is dedicated to analysing worldwide sensor trends, and provides demand analysis and emerging technologies and applications review from the international perspective. The third part observes the European sensor industry. We analyse a recent survey on sensor developments in Europe, propose a list of the most influential sensor types within 10 years perspective and conduct geographical mapping of European sensor market players. The summary of the chapter is presented in the following pictures (Picture 5 and 6).



Picture 5. Chapter outline (Drawn by the author)

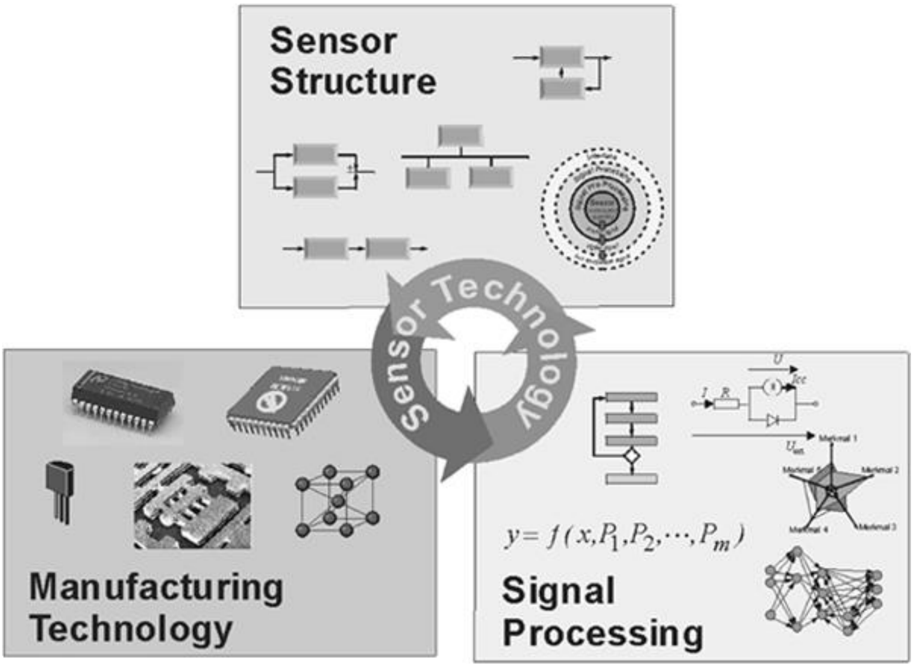


Picture 6. Trends outline (Drawn by the author)

3.1 Sensor technology development

A competition in the markets requires a permanent increase of quality and reliability of products. A rising demand for automation, security, and comfort leads to absolutely new applications for sensor systems. The amount of sensor systems and the diversity in most of applications are permanently increasing. To keep up with the new requirements, the design of sensor systems is required to provide innovative approaches and solutions, profiting from recent developments in science and technology. Sensors technologies and sensor systems achieve their functionality through interlocked interaction of the sensor structure, a manufacturing technology and the signal processing algorithms (Tränkler 2003).

The developments in sensor technology are consequently based on the permanent technical progress at these fields (Picture 7). New emerging technological revolution involves a great potential for completely novel approaches of sensors and sensor systems. A use of new technologies and signal processing methods may lead to considerably improved sensor features.

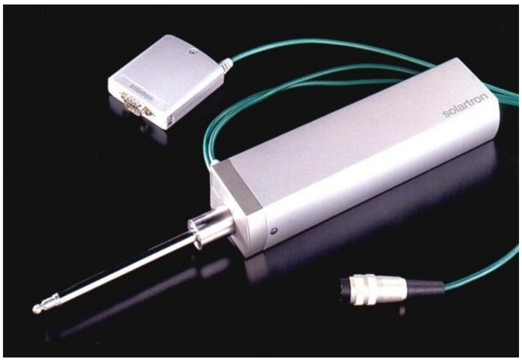


Picture 7. Potential fields for the development of sensor technology (Tränkler 2003)

3.1.1 Sensor typologies and their role in the system

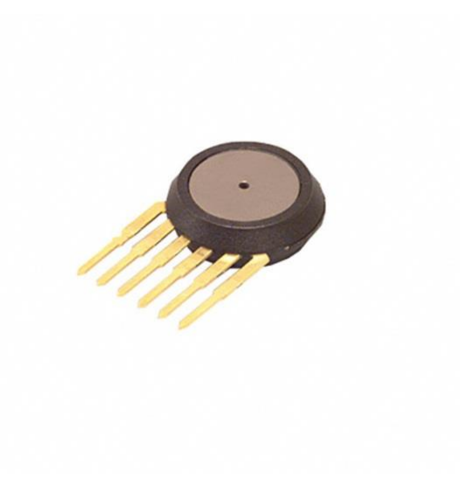
This section explores essentials, hierarchy and role of sensors in different industries. A sensor (also called a detector) is a converter that measures a physical quantity and converts it into a signal, which can be read by an observer or by an instrument (today mostly electronic) (Bulst 2001).

A detector is a discrete element of reduced size, connected to an electronic system and able to measure physical, chemical, electrical parameters. Its sensitive element represents a significant share of the added value (Picture 8).

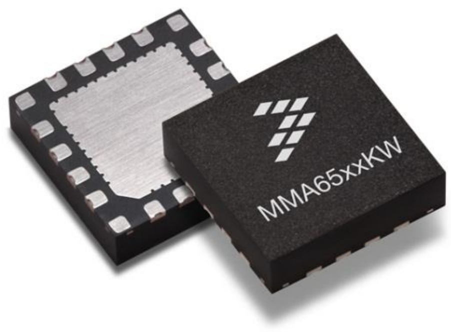


EPCOS sensor

VDO Siemens sensor



Freescale sensor



Android tablet sensor

Picture 8. Examples of sensors (retrieved from maxembedded.com)

Nowadays there are 4 most used types of sensors: transducer, functional sensor, digital sensor and smart sensor. For example, a transducer has a parameter to measure, a sensitive element and the system elements. Functional sensor: parameter to measure, sensitive element, conditioning, and the system. Digital sensor: parameter to measure, sensitive element, conditioning, digital interface and the system. Smart sensor: parameter to measure, sensitive element, conditioning - control/process, digital interface and the system. The most modern of them is a smart sensor. The unique feature of it is possibility of phase 3 and phase 4 to replace each other at any time. It gives engineers ability to control a working process and, consequently, predict and manage results of it. There are many tasks, which sensors conduct during their work; however it is possible to create 4 general categories of sensor role in the system. Sensors are used to satisfy 4 main functions within a system (Radioelectronics essentials 2009).

- Monitoring and control in order to increase the performances and regulate the system

- Security and warning in order to increase the safety of the system and anticipate default

- Diagnosis and analysis in order to understand the system and improve

- Interface and navigation in order to operate the system and increase functionalities.

Today sensors become core elements in the systems, bringing either the new functionalities or reducing total costs of ownerships. Some years ago they have been usually used to cure, but nowadays they are starting to be used to prevent critical situations. There is a strong trend in development of sensors and sensor systems usage, which underlines future significance of the early warning systems and the smart maintenance schemes.

3.1.2 Sensor development process

According to Frost & Sullivan (2006) sensors food chain consists of 4 stages:

1. Component manufacturers: there is a focus on the basis of the converter part

2. Sensors integrators: they take care of electronics, interfaces and packaging
3. System integrators and OEMs: now there is a strong demand of complete and adopted solutions
4. Sensors distributors: they connect manufacturers and system integrators/OEMs

The integration technologies are rapidly developing; however measurement rules and principles are stable. This fact has influence on the industrial sector. A decomposition of sensor' added value is different in accordance to the application segment. For example, 25% of full sensor value is hold by converters; and another 75% take other elements such as an interface, packaging, conditioning, testing and analyzing (Frost & Sullivan 2006).

The consolidation of sensor manufacturers, distributors and system integrators is one of the most important issues, which could make sensor technologies more popular in the each industry area. The sensor market had a huge growth over the last decade. A significant consolidation process helped to create a large industrial conglomerates and holdings through acquisitions. These conglomerates have both huge product and market coverage. The strongest are Baumer, Emerson Process, GE Sensing, Industrial Scientific Corporation, Measurement Specialties, Meggitt and Schneider. There is a strategy to reach critical mass and develop technical and marketing synergies within different business modes. It helps to increase market coverage. By all means, this process will be going in line with an OEM demand, which is usually looking for the working measurement and system solutions (Frost & Sullivan 2006).

3.1.3 Sensor product segmentation and application scope

Sensors are also used in the stand-alone configurations. However the vast majority of sensor industry is represented by detectors. They market share is at least 65 to 75%. Most of them provide Boolean information: YES/NO, 1/0, ON/OFF.

The sensor systems are used in every market segment, from the industrial process regulation to the military remote controls. They are especially needed in the following areas: automotive, building and infrastructure, consumer, energy and networks, environment, industrial process and manufacturing, IT infrastructure, aerospace & defense, medical healthcare, security and transportation.

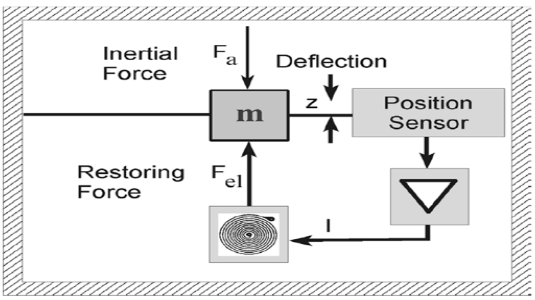
Sensors are used to conduct measures and analyze 4 main categories of parameters: mechanical, physical, chemical and electromagnetic. The mechanical parameters are level, position/displacement, proximity/distance, absolute position and force/deformation. The physical parameters are acoustic, flow, humidity, pressure and temperature. The chemical parameters are solid, liquid and gas conditions. The electromagnetic parameters are voltage, magnetic field and currency (Kotik 2008).

3.1.4 Sensor types and structures

The core of a sensor system is a sensor element, which changes its output depending on the measured quantity. At the preprocessing unit, sensor signal is transformed into an adequate amplified signal using analog signal processing techniques. Using digital signal processing, the measured quantity can be calculated under consideration of the manufacturing variance, influence factors and aging processes (Kotik 2008).

The structure of sensor with self-monitoring functionality differs from the standard structure. It requires a supplementary knowledge of the actual measurement information. The specific relationships are required to identify sensor behavior and expected confidence limits of the sensor properties (Tränkler and Kanoun 2003).

The condition of sensor system can be inspected by a comparison of the real output to the expected value due to the previously known relationships. For instance, the acceleration sensors with a closed-loop structure compensate inertial force by acting on the mass through the electrically generated restoring force (Picture 9). Self-tests can be carried out through the usage of restoration forces with the well-known values.



Picture 9. Example of an acceleration sensor with a closed structure (Tränkler and Kanoun 2003)

A silicon micromachining is one of the most significant micro technologies for the sensor systems. The main properties of the silicon material, such as the freedom of hysteresis errors, and the early advances in the field of microelectronics stimulated this important technical evolution.

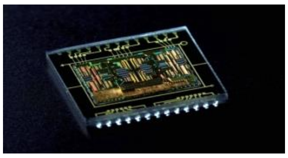
3.1.5 Perspectives of information technologies as a key factor in the sensor systems

It is a fact that sensor technology developments rely on the constant technical progress in the manufacturing and informational technologies areas. The choice of target sensor technology is not always associated with the improved sensor features. Combining solutions from different fields enables the synergetic rules, which results to outstanding solutions. Therefore the most significant engineering developments belong to more than one scientific field. The cost of the optimal performance ratio is a main factor, influenced by choice of the target technology and combination of manufacturing technology and signal processing (Blinov 2009).

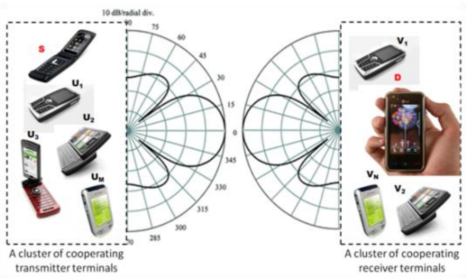
The developments in sensor technologies are usually driven by the technical progress in different fields such as a sensor manufacturing technology and information technology. They have the very close relations and usually depend on one another. Therefore, an increase of speed of developments of one of them, eventually lead to the new invention in another (Taylor et al. 2008).

For example, the microsystem technologies integrate the sensors mechanical structures and multifunctional materials for the signal processing on the same substrate. The use of these systems gives numerous advantages with the regards to the application scope such as the low-cost solutions, minimizing size, power density and reliability increase (Technol. Rev. 2003).

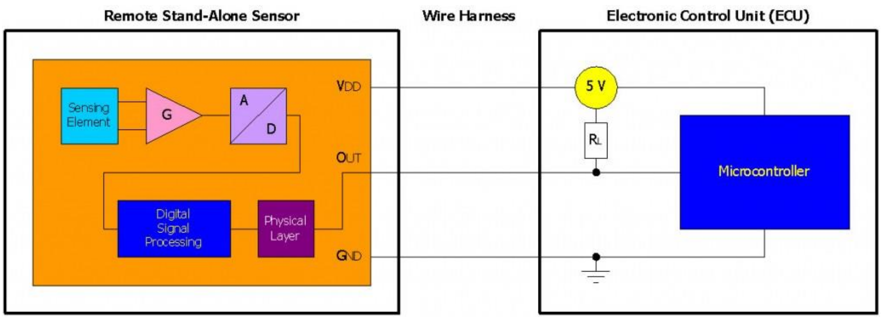
The information technology increases its role in the field of sensor technology. A large upturn takes place in the last 2 years. It contains of the all parts of the sensor structure such as the modeling, simulation and testing in sensor design; the modeling and developing sensor parameters, compensation of negative effects in signal processing; and the wireless technologies, networks and error correction in the sensor communication areas (Pictures 10, 11, 12).



Picture 10. Changes in the core sensor structure: design (retrieved from stackexchange.com)



Picture 11. Changes in the core sensor structure: signal processing (retrieved from stackexchange.com)



Picture 12. Changes in the core sensor structure: sensor communications (retrieved from intechopen.com)

The main result of the sensor design modeling and simulation is reduction of a cost of the manufacturing processes. It is also important to shorter a production time of sensors so they are delivered to the market earlier. In the signal processing, an information technologies are used to eliminate negative effects of the sensor signals and to make controlling more efficient (Schröder 1999).

The communication gateways are also very important factors, especially, for the final consumers. They provide ability to apply sensor signals to the high-level systems and integrate them in the wide range of applications. For example, the security and safety areas, smart systems and industrial monitoring (Tränkler and Kanoun 2003).

A design of the intellectual sensors has a significant role. The use of information technologies can significantly contribute to improve the efficiency of design, optimization and testing process of sensors. The development of a sensor part or element according to the particular sensor principle is a long process with much iteration. Therefore many trials are conducted, in order to choose the proper materials, components and dimensions. The computer simulation and modeling can help during the all stages of the design development step. The goal of this process is to shorter a sensor time-to-market value; hence, a successful system design becomes applicable from the first fabrication attempt. The possible results of simulation and modeling processes can be collected in one database. Using special measurement tools and statistical analysis help to find the best solutions in many cases. Statistical parameters, which describe behavior of particular parts of the sensors, can be easily calculated. The simulation strategies are also used to adapt signal processing and design of the sensor systems. In some specific fields, simulations help to reduce expenditure of the investigation sensors such as fire detection and disaster recognition devices. A process of sensor modeling provides results during the experiment along with the useful simulation environment (Zenov 2011).

There are many information technology methods, which play key role in the process of signal processing. The typical techniques are following (Looney et al. 2000).

- Data fusion technique, average value method and statistical decisions
- Fuzzy logic and neural networks for qualitative formulated problems
- Kalman filter for fusion of sensor rough data

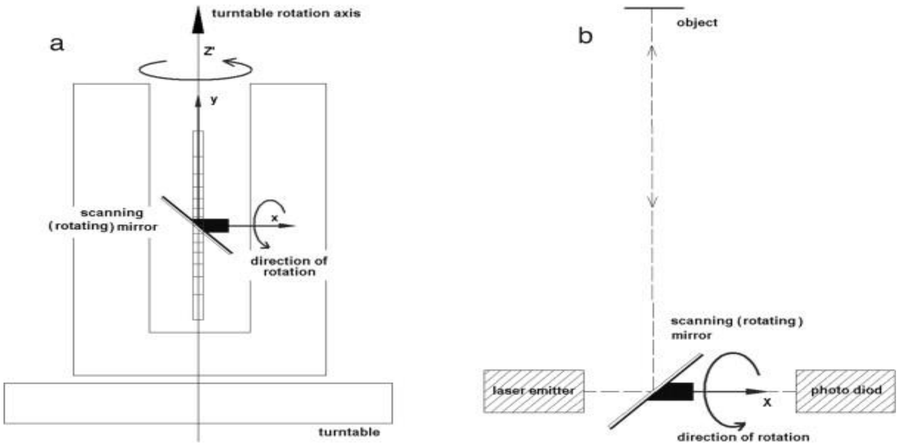
A significance of wireless communication is rapidly gaining importance. For instance, an infrared communication can be used for a high transmission rate so the problem with distances will not appear immediately. A constant LOS (Line-of-sight) between the basis stations is required. This is a reason of high popularity of the radio frequency communication in many applications. All of these techniques become more reliable and cheap, especially in comparison with the traditional methods, such as a cable connection. They involve many advantages for the applications in different industry areas. For example, at the applications, where long distances are to be bridged, or a large number of distributed components is required (Sysoeva 2008).

The results of improvements in the measurement technologies are improvements in accuracy, decrease in costs, reliability, speed of work and wide range of different applications. The essential parameters for the smart development trends in sensor technologies are economic aspects, market situation, customer requests and requirements for an implementation in the target applications (Isermann et al. 2006).

In the modern world, an information technology is a main development and analysis tool for the single sensors and sensor systems, which support deeper cooperation and integration in high level systems. Sensors enter large consumer sector and their application fields become wider. Hard conditions and environments are often unavailable for the traditional engineering applications. The process simulation, modeling and other information technology tools are able to help sensors to work better in these fields. For example, a high-temperature condition, corrosion, toxicity, electromagnetic interference and radiation. The packaging concepts for the harsh environments should have reliable and high level thermal management and reasonable costs.

The miniaturization, micro electromechanical systems technologies and nanotechnologies are keys for improving reliability, reducing power consumption and minimizing costs of the sensors and sensor systems. Silicon material will play more active role in the structure design of future sensors because of its freedom of hysteresis errors. The simulation methods and modeling are going to play important role in the process of improvement of the sensor design. A combination of the simulation methods and experimental tests will shorter development time so released technologies and products will get to the market faster (Egorov et al. 2009).

The requirements for sensors become more complicated, so materials, combining more than two functional and protection layers and several positive effects, will be in the focus of modern developers. For instance, the nanostructured multifunctional layers and nano-crystal layers are of a big importance. The use of different structures and properties of customized nano-crystals will help developers to reach necessary requirements. The innovations in signal processing will also increase many sensor parameters. The more accurate mathematical and logical models will be developed for the sensor systems. Traditional difficulties of analog devices with digital conversions are no more relevant. An online self-calibration of multi-sensor systems becomes one of the most significant trends in the nearest future (Picture 13) (Zenov 2011).



Picture 13. Example of sensor self-calibration process (retrieved from midetechnologies.com)

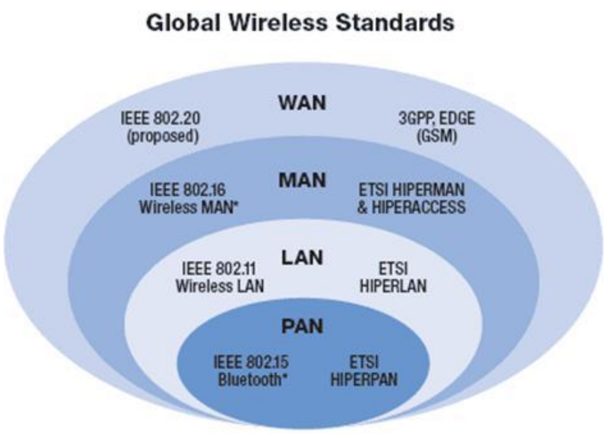
Future sensors will be developed on the slight border between technological innovations, manufacturing design and structure and modern processing methods. Development and researches of the single sensors and sensor networks require studies in three different areas: passive and active sensing; hardware, software and algorithms computing; interface data transfer and analysis communications (Picture 14) (Looney et al. 2000).

Sensors	*Size*: small (e.g., micro-electro mechanical systems (MEMS)), large (e.g., radars, satellites) *Number*: small, large *Type*: passive (e.g., acoustic, seismic, video, IR, magnetic), active (e.g., radar, ladar) *Composition or mix*: homogeneous (same types of sensors), heterogeneous (different types of sensors) *Spatial coverage*: dense, sparse *Deployment*: fixed and planned (e.g., factory networks), ad hoc (e.g., air-dropped) *Dynamics*: stationary (e.g., seismic sensors), mobile (e.g., on robot vehicles)
Sensing entities of interest	*Extent*: distributed (e.g., environmental monitoring), localized (e.g., target tracking) *Mobility*: static, dynamic *Nature*: cooperative (e.g., air traffic control), non-cooperative (e.g., military targets)
Operating environment	Benign (factory floor), adverse (battlefield)
Communication	*Networking*: wired, wireless *Bandwidth*: high, low
Processing architecture	Centralized (all data sent to central site), distributed (located at sensor or other sites), hybrid
Energy availability	Constrained (e.g., in small sensors), unconstrained (e.g., in large sensors)

Picture 14. Parameters of sensor systems (Gardner et al. 2001)

Nowadays, it is time of the wireless and ad-hoc networks expansion for various industry areas and application. It may occur due to the significant improvements in sensors' characteristics, decreasing its physical size and lowing price. The most popular type of sensor technology is MEMEs process (microelectromechanical system), that makes possible to work through wireless networking and use inexpensive low-power processors (Gardner et al. 2001).

In the same time, current sensor techniques can use technologies which have not been available 30 years ago. They conduct actions, which have not been possible in the past. However, problem of prevalence and demand of high level sensors is still exists. Some of private companies are doing commercials and providing vision of how people's daily lives can be enhanced through a network of embedded sensor nodes. The use of different home devices, gadgets and tablet PCs help people to understand an importance of sensors in their life. For instance, there is a special technology, which allows owners of smartphone to create a personal area network (PAN) to share private information, using Wi-Fi technology and IEEE standard (Picture 15). Personal networks defined to have a radius of 5 to 10 meters. Many standardization committees and scientific laboratories encourage development of technologies for these short range systems. This fact stimulates development of low-cost sensor nets and nodes. Network of short-range sensors is an ideal technology to be employed in PANs (Egorov et al. 2009).



Picture 15. Global wireless standards (retrieved from rfidc.com)

Improvements in chip capacity, processor speed and power capabilities reduced energy requirements for computing and communication parts. Nowadays it is possible to perform all three parts in the one chip and reduce its costs in several times (Egorov et al. 2009).

The advances of MEMs technology encourage sensors' production, which is a more capable, versatile and low-cost procedure. Wireless networks and sensor systems of disposable micro sensors provide high quality sensing capabilities in many unexplored applications (Distributed sensor networks 1986).

The reason of the fast growth of sensor networks is usually military applications. There are many military sensor networks that use large-scale acoustic systems and small unaccompanied networks for the ground target detection. In the same time, all of the mentioned achievements in the military area created low-cost sensors and communication networks for the consumer market. Commercial industry has been interested in the sensing devices for a long time. Mainly it needs cost reduction, machine and user performance improvements, speed and flexibility. Factories continue to automate production and assembly transporters, using remote sensing nets and nods, and implementing complicated in-line quality control systems, embedded by sensors. The wireless and remote sensor technologies can also be enabled to the plants as special instruments after a process of their testing and maintaining compliance with the appropriate services (Gardner et al. 2001).

Spectral and optical sensing is facilitated by miniaturization. The size of elements becomes smaller and the quality better. The final aim of industrial sensing is to enable matrix sensing. It means that inputs from thousands and hundreds micro sensors, collected into database that can be queried in any number of ways to get possibility to look at the real time process. Sensors and sensor networks have used for the traffic control for many years. The best of traffic sensing devices have overhead and buried sensors to detect vehicles and control traffic lights and barriers (Karpenko et al. 2006).

3.2 Worldwide sensor trends

This chapter section consists of the industry demand analysis and major development trends of sensors worldwide. Author discusses about the major international sensor application areas, prospective sensing principles, systems designs and features. There are several sensor systems proposals, such as Smart Dust and SmartMesh for construction, transportation and military industries. In addition, author analyzes the emerging technologies, where sensors can be used. For example, a real time chemical imaging, multi-point spectroscopy, fast imaging technologies, light weight spectral imaging, MEMS FPI and cost efficient spectroscopy calibrations. In analysis they connected to industrial overview, prepared by VTT, which enables a strategic view at the sensor development trends.

3.2.1 Industry demand analysis and sensor development trends from international perspective

There are many development trends in the sensor technology. They depend on different aspects, such as a market-economic situation, general consumer trends and the specific requirements of particular applications. However, there are two main development trends in the sensor technology. They are miniaturization and increasing use of the multisensory and wireless systems (Picture 16) (Frost and Sullivan 2006).

Miniaturization is a key strategy of success in the modern technologies. A reduction of characteristic dimensions usually results in the shorter response times so that higher speed is achievable in the signal generating and processing. Miniaturization reduces costs because of higher integration rate, lower power consumption and higher reliability. Miniaturization gains importance at most of major fields of applications, where smaller structures and greater precision become decisive to the market acceptance of the individual products. The development trend to miniaturization goes on within nanotechnologies, which will open up access to even smaller dimensions. For example, at the human body monitoring devices, health care elements can be used so that emergency call is released automatically in the case of unconsciousness of observed person. Usually user does not notice it, and live normally without being obliged to take it off in any situation during the whole time.

Picture 16. Areas of future trends in sensor technology (retrieved from rfwirelesssensors.com)

The use of multisensory systems becomes more important at many application areas. Their use includes the monitoring and automation of manufacturing processes, robotics, smart homes, process control, environmental engineering and biotechnology. The multisensory systems provide an advantage that enables higher precision rates during economical use of sensors. A large amount of available information is managed by using the traditional sophisticated signal processing techniques so that the systems may achieve a better performance. The use of the wireless systems implies good convenience and cost reduction. Wireless sensor systems have an advantage, which allows them to be placed anywhere and record measured quantity closely to its occurrence. Wireless sensors can communicate over ultrasonic or infrared signals. For example, the surface acoustic wave devices can be used for the object identification and measurement of the physical, chemical and different biological quantities. The development trends of multisensory systems lead to creation of the modular systems (Tränkler and Kanoun 2003). They may be easily extended with new elements without disturbance of an already available functionality.

The energy-autonomous sensors will also gain an importance among wireless sensors because wires are no longer necessary, even for the electricity supply chains. They can be used for many applications, where long distances are needed to be bridged. Many resistive and capacitive methods are still prevalent for this area of sensors and sensor systems. A list of major trends is overviewed below (Beroulle et al. 2001).

- Lower measuring uncertainty
- More robust process coupling
- Increased long-term stability and use of direct sensor-actuator coupling
- Increasing use of MEMS and beginning use of NEMS (micro or nano-electromechanical systems)
- Increasing use of silicon measuring elements, including calorific and chemical parameters

Despite of the number of different applications and trends in sensor industry, as well as increasing costs of their parts, there are several major areas that can be discerned (Schröder 1999).

- Introduction of novel measuring processes for the detection of spatially distributed measuring data, such as a tomography for industrial application and spectroscopy

- Increasing application of energy-autonomous sensors and sensors with wireless communication:

    - Activation only on demand

    - A networked miniaturized measuring sites for the collective detection of measuring values

    - Application of various of the micro-generator principles for the autarkic energy generation: thermoelectric, electromagnetic, chemical (fuel cell) and photovoltaic (solar cell)

- Increasing holistic sensor design such as an utilization of the novel 3D design tools, FEM (finite elements method) computation, Matlab and use of exact material data

- Increasing functional integration, based on the integrated components in the sensor electronics and safeguarding of the additional functionality. (Egorov 2007)

    - Self-monitoring, and interference detection and diagnosis

    - Derivation of data for preventive maintenance and plug&play method

    - Localization (positioning) and pattern detection

- Coupling of physical, chemical, and biological sensors on a single sensor element

- Utilization of highly integrated components for the real-time signal conditioning and processing, such as programmable logic devices, semiconductor memories, coupling modules for the electrical interfaces (wired, wireless), high resolution and fast A/D conversion

According to the main researches in this area, following is the list of the measuring principles, which can be industry dominating in the nearest future (Frost and Sullivan 2006).

- Resistive and piezoresistive. For example, the film, thick-film, thin-film strain gauges and crystalline effects in silicon
- Capacitive, such as ceramic or silicon sensors with thin-film electrodes
- Magnetic, such as hall and magneto-resistive elements (AMR, GMR) on semiconductor basis
- Ultrasound and microwave sensors, such as runtime and Doppler measuring processes
- Optic, including reflection processes, interferometers, semiconductor and solid-state lasers, and photodiode cells

Pressure-sensors include stain gauges, thick-film and thin-film sensors on metallic deformation elements or ceramics (Beroulle 2001).

- Strain gauges and pressure sensors
    - Miniaturized foil gauges < 2 x 2 mm²
    - Continued development of the deformation elements and novel materials
    - Integration into machine components and textiles, e.g. into the carbon fibers
    - Conductor materials
- Thick-film resistors on ceramic substrates and pressure sensors with reformation elements and LTTC ceramics (so-called flexible forming)
- Thin-film resistors with isolated layers on the metallic deformation elements, including optimization of substrates and layers passivation

Capacitive silicon sensors include:

- Integration into the sensor systems with low energy consumption
- Direct allocation of the primary electronics as a two-chip solution

- Continued miniaturization, e.g. pressure sensor elements with a surface area < 0.5 x0.5 mm^2

Microwave sensors could be used in:

- Tomography with ultrasound and microwave methods
- Configuration into an ultrasound sensor array with directional radio effect
- Continued miniaturization

Recent inventions will allow resonance following sensors and trends:

- Surface acoustic wave sensors
- Use of new materials, such as lithium-niobate
- Miniaturized quartz or silicon bulk acoustic wave sensors.

Optical sensors will be:

- Miniaturized spectrometers and adjustable semiconductor lasers
- Miniaturized optical solid-state resonators on semiconductor basis
- Bragg fiber grating arrays for temperature measurement.

Gas sensors will also be demanded. There are many development criteria for the gas sensors. There is no single technological approach for this development, such as silicon micromechanics for physical sensors. At the most of cases, involved technology is adapted to the specific application and available technology for the sensor suppliers (Schröder 1999).

However there are some technological trends, which can be discerned. The electrochemical trends extend following ones:

- For selective gas detection, a potential measurements hold sway in case of cost-critical applications

- An increased use of silicon MEMs (hot plates) and integration of multiple sensors on a single hot plate (sensor arrays); it is also used for the pattern detection

- An increased miniaturization and integration.

There are two general development trends in sensor elements for the chemical industry. The first one is new measuring tasks and requirements, which solutions are conducted by contending principles. The second one is chemical parameters analysis of the gas and liquid concentrations that can be measured by means of physical methods. The reason for this is an improved reproducibility and long-term stability of currently available sensors (Blinov 2010).

The transition to silicon micromechanics is not only due to the availability of inexpensive mass production, but also due to the inherent advantages offered by silicon micromechanics. For instance, reduced energy consumption enables battery powered operation. This allows increases in the selectivity. Based on the same principle, the thermal conductivity sensors can be made for H2 detection (Decision Etudes Conseil 2008).

The trend is towards the integration of multiple sensors on a single hotplate (sensor arrays). New applications can be opened in many different areas because of the pattern recognition. There are three different tendencies that are going to emerge in the nearest future. All of them are able to replace the present sensor principles.

1. Potential measurements instead of resistive ones. Development of the direct and indirect thermoelectric gas sensors for detection of VOCs (volatile organic compounds).

2. Methods for selectivity increase. Currently there are researches, carrying on applying of the catalytic and absorption filters; as well as studies on micro-gas chromatographs.

3. Optical methods. Attempts to apply optical principles for selective sensors also look promising. Examples are NH3 or O2 detection, backed by laser diodes.

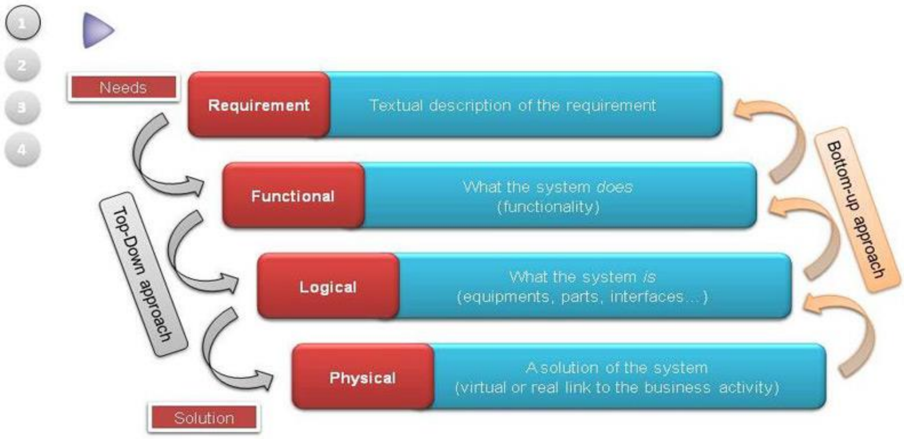
At the electronics and semiconductor technologies new trends may be noticed. Relatively simple sensors of the past are changing into integrated and intelligent sensor systems, boasting hardware with increasing capabilities. Mixed signal becomes the most spread type of data processing. At the same time, digital and analogue types still remain the most popular ones. There is a tendency for the early digitization and digital signal processing. The functionality of sensors increases. Nowadays, they are already able to perform correction calculations, compensate cross-sensitivity and provide application-specific algorithms. Improvements and innovations in sensors are being attained by the parallel development of primary electronics and sensor-specific signal processing. An optimization of primary sensor, signal conditioning and processing provide greater efficiency for the sensor systems than would be possible by optimizing the measuring element itself. Following is a list of the other potential features of sensors (Dumas et al. 2006).

- The lower energy consumption and higher maximum ambient temperatures
- Faster signal processing with a lower noise level and higher resolution
- Increase of the error reports on challenging states or threshold values instead of mere value transmission.

The following trends may be noticed in regard to the design of sensor electronics and systems (Decision Etudes Conseil 2008).

- System design and architectural design become more complex (higher resolution, increasing complexity, greater sophistication of compensation and linearization)
- Sensor-system design has top down structure (specifications and verification as early as possible and step-by-step system simulation) (Picture 17)

Many industries, such as automotive engineering and automation technology, use sensor electronics, which implement not only the task of signal conditioning, but also evaluate a measured value, self-monitoring and communication results. The connection and communication of control levels make changes not in the values but rather at theirs thresholds or interference values. Intelligent sensors send report when a critical set temperature exceeds, but they do not transmit current temperature values permanently. This feature reduces bandwidth for sensors' networks. Along with the further development of simple sensors into highly integrated sensor networks, the following trends can be noticed in the implementation of sensor-signal processing: reduced analogue signal conditioning and increased digital processing.



Picture 17. Common industrial design methodology for sensor systems (retrieved from scielo.br)

Digital signal processing has many advantages in comparison with classic analogue signal conditioning. For example, they are greater stability, reliability, and reproducibility; greater flexibility, easier implementation of variants and modifications; better cost digression.

The big part of digital and mixed-signal ICs (integrated circuits) is produced by using CMOS (Complementary Metal–Oxide–Semiconductor) techniques. In accordance to these predictions, predominance of CMOS technology will continue growing for the next ten years. The roadmap for CMOS technology reflects the Moore's law for over then 40 years. Structure size in CMOS technologies is reduced every three years by a factor of ½. Current development of the high-volume standard products is also being carried out with 65-nm technology. The technological foundation for mixed-signal ICs with a significant analogue portion has followed this technological trend in the past (Gardner 2001).

In the meantime, a trend can be made out in the certain technology that has a longer service life for new designs and also for a production. There is a list of reasons for that (Beroulle 2001).

- The maximum permissible supply voltage is reduced, based on scaling rules.

- Parameter fluctuations are significantly increased for the adjacent components, due to small structural sizes. In addition, leakage currents are increased exponentially, because of structure dimensions decreases.

- The size of components (transistors, resistors) is not automatically scaled with the minimal structure dimension. It is determined by required circuit parameters (such as noise and amplification).

This development is apparent at the mixed-signal area of European ASIC (an application-specific integrated circuit) suppliers: 350 nm or 180 nm technologies provide a good compromise in regard to the performance and costs. A major objective of the R&D activities is exploration of the existing digital semiconductor technologies towards platforms to develop hybrid systems (Estrin 1999).

There are some industrial areas, where requirements for reliability of sensors and silicon-based sensor signal conditioning are increasing (such as an automotive and auto electronics). Less than ten years ago sensors and control devices in vehicles worked in separate ways. For example, maximum a sufficient temperature in engine for signal conditioning was about 150 °C. Nowadays, by industry progress, this temperature is more than 175 °C. All trends of sensors and system integration of electronics lead to further increases of maximum temperature. At the same time, semiconductor industry stimulates this perspective trend (Gardner 2001).

More manufacturing companies develop their silicon processes in accordance to the automotive limits. Usually there are observed two main reactions of self-monitoring sensors: disturbance and noise diagnostics. These types of support of monitoring processes increase sensor reliability. At the same time, some of additional processes reduce overall reliability of autonomous sensors. Thus the future trends lead to recoup these disadvantages by creating the special balanced tools. The parameters, affecting self-monitoring sensor reliability improvements, have increased availability, quality monitoring, security, serviceability, and dependability, and decreased interface sensitivity.

The sensor used to be an autonomous system. The reason of that fact is that the self-monitoring and sensor configuration is based on the information, coming from sensor. This approach is necessary for the adaptation to sensor manufacturers in order to make as application-neutral sensor as possible. At the same time, sensors suppliers want to provide autonomous devices that can be used in a broad range of applications. Following is a list of five self-monitoring processes for autonomous sensors (Estrin 2010).

- Analysis of the measuring signal and impact of a fault variable

- Analysis of supplementary signals in the measuring chain
- Generation of a reference value
- Application of redundancy.

Many sensor suppliers move their value development activities into the signal processing, energy management, miniaturization and self-monitoring sectors. Hence the cost of ownership is diminishing. The potential trends in this area are following (Schröder 1999).

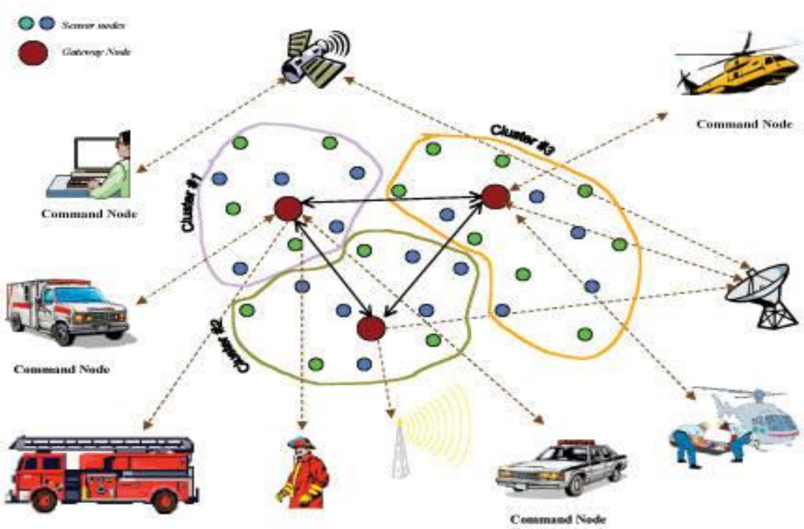
- Expanding of wireless sensor technology and digital interfaces
- Processing of measurement values
- Parallel detection of multiple measuring values
- Autonomous and miniaturized sensor systems and networks
- Self-diagnosis and auto-calibration.

The main challenge for sensor technology is reduction of the constructive efforts, required from the application. According to standardization rules, this leads to increasingly miniaturized designs, decentralized signal processing and asynchronous disturbance values. Energy management and self-monitoring become more complicated (Kotik 2008).

Digital interfaces begin to prevail. At the same time, the application-specific interfaces continue to have their place. For that moment, widely used interfaces are: CAN automotive, EIB/LON, field bus, Profibus, Ethernet, AS interface; two-wire and 4-20 mA.

The wireless sensing is a new and very potential area in the sensor technology. Significant number of participants and applications fragment industry, commerce and end-user sectors with wireless sensors. Wireless data transmission, which needs to be measured, is not a novelty. Nevertheless, its potential recently became apparent for the industry and end-users sectors. Many market participants divide these sectors by different applications' usage. The beneficial advantages however bring many challenges; therefore its implementation has a very slow progress.

There are many limitations that have been posed by the new technologies. One of the most serious problems was lack of reliability. It is expected that the end users will start using wireless sensing at the nearest future. During this way it would be possible to find new routes into the similar sectors, and also abilities to solve real application problems, which cannot be solved or solved with the great difficulty. Some of the developing sensor companies already started their shift into the new direction; therefore wireless sensor technologies soon will open new opportunities (Picture 18) (Beroulle 2001).



Picture 18. Example of wireless sensor network (retrieved from intechopen.com)

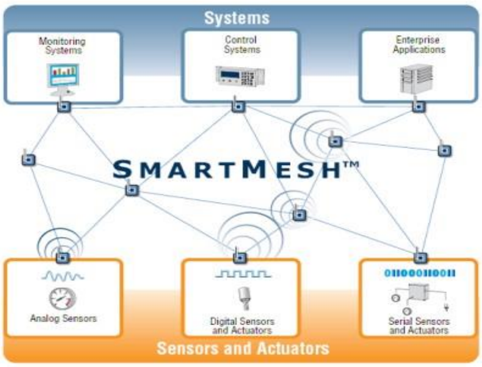
ISM (industrial, scientific and medical) bands are usually used for the wireless sensor networks. Their frequency ranges are 433 MHz (radio thermometers, remote controls and meter readers), 868 MHz (alarm systems and remote controls), 2.4 GHz (WLAN, Bluetooth, ZigBee, video transmission and microwaves). Although the standard products for Bluetooth, WLAN and ZigBee are available at the low cost levels, they have following disadvantages in their capabilities: high real-time capability, quality of service, expense of high dissipation loss and complexity (a guaranteed delay) (Dumas 2006).

One of the most reliable proprietary formats is ZigBee. Usual battery life of the device, equipped ZigBee sensor, in tens time more than Wi-Fi and Bluetooth analogs. However, a data rate has a low level: ZigBee: 10…115 kbps, while Bluetooth: 721 kbps and Wi-Fi: 11…54 Mbps.

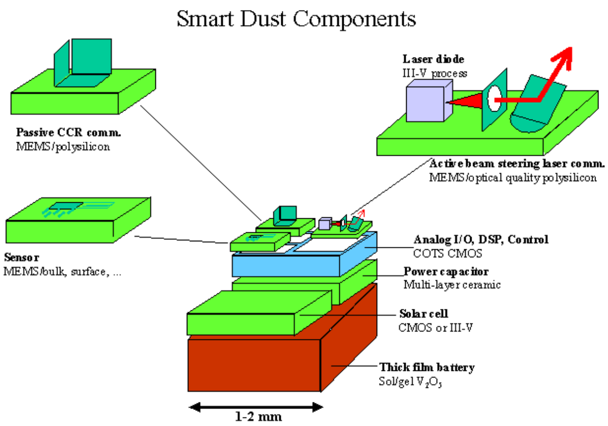
ZigBee is mostly used for the industrial controls, sensor applications and wireless switches in standard applications. Further technological improvements and standardization will support following different types of wireless networking: wireless USB, wireless Industrial Network Alliance, near-field communication (NFC) and ultra-wide-band systems (UWB) (Mekid 2007).

Usually it is off the interest where and when physical event has taken place. Through the process of embedding sensors into the existing communication networks, we can understand and use categories of space and time. Suitable mechanisms for localizing and synchronizing sensor networks become necessary. The Internet and global integration of the sensor networks and nodes into the global connected network provides many significant tools for services and resources. IPv6 over low power wireless personal area networks and IEEE 802.15.4 can be used as bridges to reduce cost links to the Internet (Dumas 2006).

These devices are applied to multi sensors with the wireless connection model that detect and transmit measuring values in arrays of hundreds of nodes. They are also known as a "smart dust" (Pictures 19, 20). Motes widely used in military applications, they are also useful for the climate control in buildings, medical applications, traffic management systems and monitoring in dangerous environments. Among their functionality advantages are energy management, communications, self-monitoring and system interface management. These systems have functionality of a smart dust, but they have larger sizes and designed like heterogeneous microsystems. Therefore smart dust becomes an actual trend towards autonomous microsystems (Gardner et al. 2001).

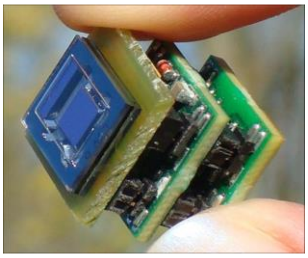


Picture 19. SmartMesh system (retrieved from radio-weblogs.com)



Picture 20. Smart Dust system components (retrieved from robotics.eecs.berkeley.edu)

Autonomous sensor systems are characterized by the independent energy supplies and wireless communications. They use power supply and data communication, provided by conventional two-wire principles. The main group components of autonomous microsystems are sensor elements, signal amplifiers or transducers, microcontrollers, data memories, RF transceivers, antennas, energy supplies and application-specific multifunctional housings (Picture 21) (Gardner, Varadan, and Awadelkarim 2001).



Picture 21. A miniaturized example of autonomous sensor systems (retrieved from memsjournal.com)

The lowest energy consumption is a crucial criteria in the process of selecting components for the autonomous sensor systems. An energy saving starts with choosing of the measurement or sensor principle, and continues with selection of microcontroller through wireless communication that has also been chosen. The micro batteries and rechargeable batteries are used for energy store. There are many other kinds of information storages, such as capacitor storage. All of the parts of functionality, operation and control of autonomous sensor systems are accomplished by the special platforms. The most important part of these platforms is a sleep function for individual components, such as microcontrollers and transceivers (Isermann 2006).

The usual mechanical, chemical and thermal functions are assumed by the multifunctional housing of an autonomous sensor system. They are usually equipped with a visual function display and interfaces to reset and program new functions. Some of them are also equipped with software that enables autonomous sensor network generation. The market leaders in automation technology offer the receiving devices with which sensor data from autonomous sensors can be read in the conventional communication structures. There are many different features of sensor systems (Schröder 1999).

- In logistics industry special tags are used for including sensor functions, such as temperature, acceleration, GPS. These types of sensor systems are often referred to active transponders.

- In the food and retailing industries, tracking and documentation systems are usually developed using autonomous sensor systems, such as electronic labeling with sensor functions.

- There are many discussions about implementation of the autonomous sensor systems for the condition monitoring in the goods industry.

- The industry of consumer goods has been also involved in the process of using these systems.

- The energy, nuclear and power industries also implement first steps in the application development and autonomous sensor systems use.

3.2.2 Emerging technologies and applications

According to the research and data analysis, provided by technological team of VTT Technical research center of Finland, there are seven main interest areas in the measurement technologies at the nearest future. It is difficult to predict or even make a forecast about "technological future". However, at the moment there are many ongoing researches. Also there is particular demand from industries for a physical realization of technologies and devices, which will be able to reduce costs, improve quality and speed of their systems and mechanisms. This include following areas:

1. Real time chemical, light weight spectral and fast imaging technologies
2. Multi-point spectroscopy
3. Hand-held and portable devices
4. MEMS FPI – high volume applications
5. Cost efficient spectroscopy calibrations.

Device prices of the selected categories vary from 100 euros to 150 000 euros for single sensor. The development and implementation of system complexity goes from the most difficult to the least. MEMs and FPI are the cheapest and easiest elements for sensor development. At the same time, they have disadvantages, which fast imaging technologies or light weight spectral imaging typically avoid.

VTT experts discuss about photonic devices, which are able to provide higher levels of accuracy then best sensors types from the list above. However, there is a need in sophisticated researches and tests, which usually take large amount of time. Hence, following types of the measurement technologies should have long-term investments and expectations periods. This factor mainly reduces interest to them from middle size investors and investing funds, which affects a speed of development for the whole industry. Therefore it becomes "trouble area" for governments, which should take additional expenses from governmental funds to keep competitiveness level of the state at particular research industries on a stable level. There is so-called "chain reaction", when the most developed organizations and states start to spend more money for the long-term scientific projects, which will provide them, in its turn, large advantages in the far future.

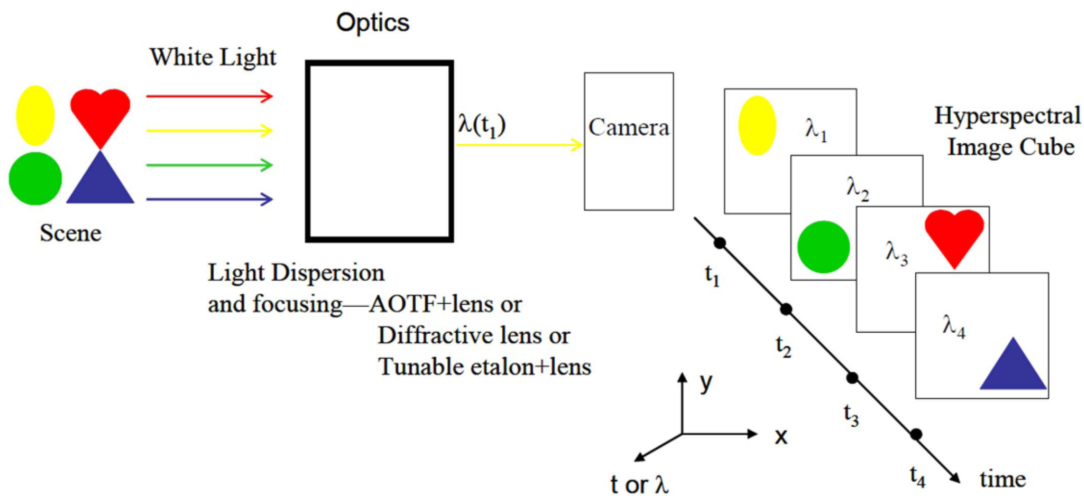
3.2.3 Real-time chemical imaging

At all of the stages of the measurement technologies development, an imaging technology was one of the essential tools to implement measurements in the technological, biological and pharmaceutical areas, where there is always a temporary need in high resolution and quality of data outcome. The reason for this lies in fundamental nature of each of these areas. Technological mechanisms and devices tend to become smaller. Hence, there is a need in improved tools to conduct measurements. For instance, VTT specialists developed new technologies for use in different application areas (Malinen 2011).

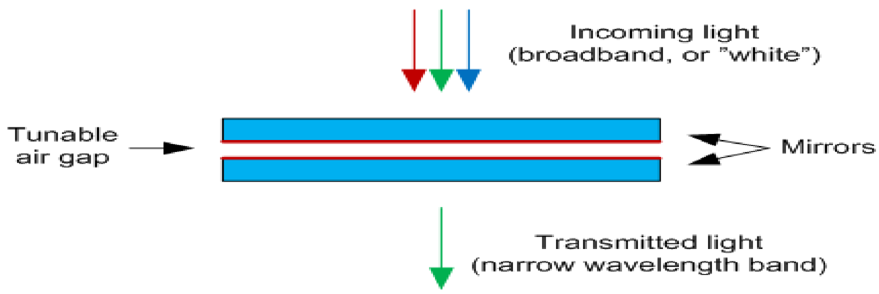
- Malvern, Liquid crystal tunable filter (LCTF)
- Specim, SisuCHEMA, Prism-Grating-Prism
- Innopharma Labs, EyeMap,Tunable FPI.

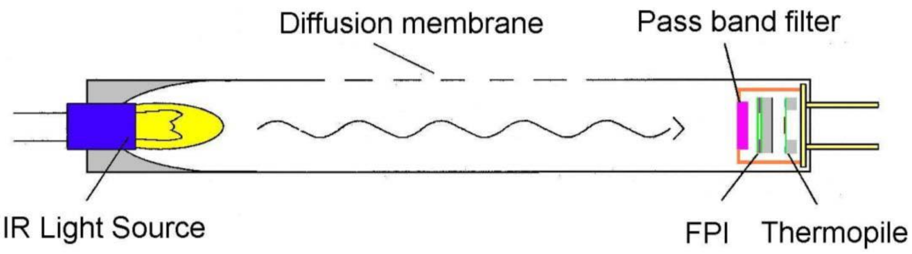
The first example is Liquid crystal tunable filter (LCTF). These are optical filters that use electronically controlled liquid crystal (LC) elements to transmit a selectable wavelength of light and exclude others. LCTFs are known for their high image quality and relatively easy integration with regard to the optical system design and software control but relatively low peak transmission values due to use of multiple polarizing elements. Main difference with original Lyot filter is that the fixed wave plates are replaced by switchable liquid crystal wave plates (Beeckman et al. 2011).

Fabry-Perot Interferometer tunable (Tunable FPI) filter spectral imager offers the fast way to acquire target images at multiple spectral bands, adapted to the application. It is compatible with light-weight UAV. At the same time, size, power consumption and mass of spectral imager are low (Picture 22, 23). It is used for the medical imaging, forest inventory with UAV, environmental monitoring and remote sensing of atmosphere (Saari 2012).



Picture 22. Tunable filter spectral imaging concept (Gupta et al. 2008)





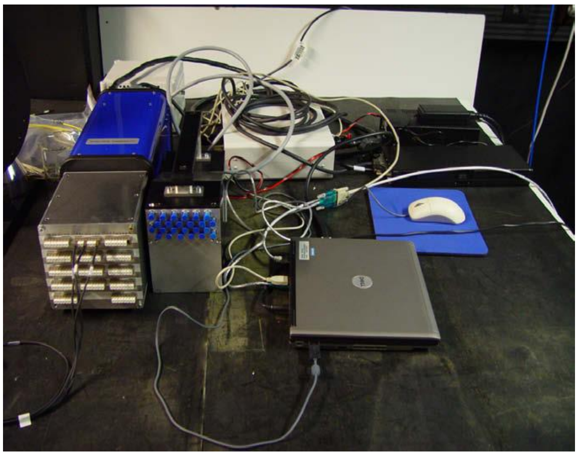
Picture 23. FPI and Spectroscopy model (Saari 2012)

Another technology is Prism-Grating-Prism (PGP). It uses a new type of direct vision dispersing component, invented by Finnish researcher Mauri Aikio. PGP provides small and low-cost hyperspectral imaging to spectrographs, limited by transmission of the grating material. Research applications in these cases lay in wavelength range from 320 nm to 2700 nm (Aikio 2013).

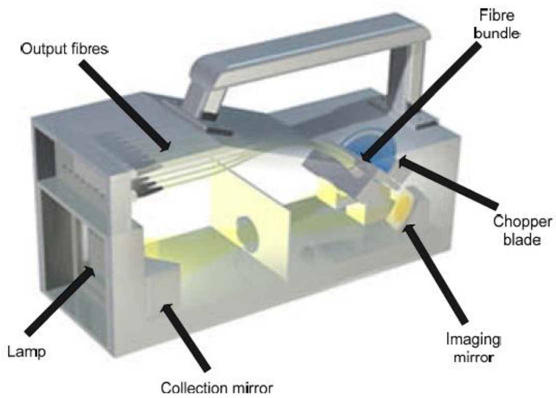
3.3.4 Multi-point NIR and Raman spectroscopy

Near-infrared (NIR) spectroscopy is a spectroscopic method that uses near-infrared region of electromagnetic spectrum (from about 800 nm to 2500 nm). Typical applications include the pharmaceutical and medical diagnostics (including blood sugar and pulse oximetry), food and agrochemical quality control. They also include research in functional neuroimaging, sports medicine & science, brain computer interface and neurology (for example, neurovascular coupling). When measuring process is going on, amount of data, collected by using multi-point system, is bigger than using single-sensor tools. At the same time, amount of the collected information makes challenges with its collecting and analysis, especially if analysis is produced in the same time with data generation. The main advantages of this measurement method are lower cost /measurement point, high speed and calibration transfer.

On the picture below there are multi-point NIR measurement system and fiber-optic light source, which is conducting sensing and producing data for the future analysis (Picture 24, 25).

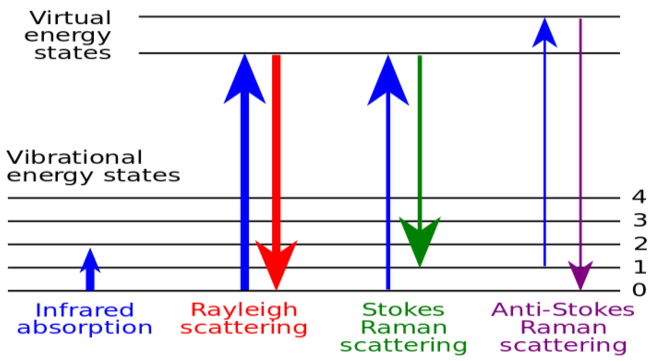


Picture 24. Multi-point NIR measurement system (Heikkilä 2009)



Picture 25. The fiber-optic light source (Heikkilä 2009)

Raman spectroscopy is a spectroscopic technique, used to observe vibrational, rotational, and other low-frequency modes in a system. For example, the sample element is illuminated with laser beam. Light from the illuminated spot is collected by lens and sent through a monochromator. An energy level diagram shows states, involved in Raman signal. The line thickness is roughly proportional to the signal strength from different transitions (Picture 26) (Gardiner 1989).



Picture 26. Raman energy level diagram (retrieved from vhosts.science.nus.edu.sg)

3.2.5 Process technologies fast imaging

The Lateral chromatic imaging (LCI) method uses special optical phenomenon, called Lateral chromatic aberration. It is phenomenon, where image aberrations both in size and color, appear towards image periphery and progressively worsen with increasing distance from the image center. This gives high resolution information of the surface topography and the internal structure of transparent materials. Advantages of this method are simultaneous images (2D, 3D and depth image), high dynamic range and depth of focus for images, instant topography of a line of 1000 points and applicability for most of the surface types (transparent, diffuse and glossy) (Focalspec 2009).

3D-process measurements use different methods for conducting data in accordance to chosen measurement tools. There are structural light, photometric stereo, 3D optical point cloud sensing and many others. Most of them provide better quality control, especially during on-line measuring processes. They usually used in road and infrastructure measurements and in-process and quality control in metal industry (Malinen 2011).

At the moment there are many ongoing researches on these technologies. Many scientists try to connect current consumer technologies with recent inventions in optical imaging fields, which allow producing better quality and higher consumption rates for devices that use various measurement methods. For instance, group of researches in Canada developed a framework, which combines classical 3D optical metrology, advanced by possibilities of the cloud systems (Mony 2011).

3.2.6 Light weight spectral imaging

A hyperspectral imager is a spectrometer, which uses each pixel in the image for obtaining a spectral data. The hyperspectral imager concept utilizes multiple transmission orders of a Fabry-Perot interferometer with different spectral sensitivities of RGB-image sensor pixels. With built-in hyperspectral imager, it is possible to acquire 2D spatial images at one, two or three selected wavelength bands simultaneously (Mäkynen 2009).

Usually technology is used for identifying and analyzing hyper or multispectral data at 10nm resolution at video speed. It means a high quality of outcomes. At the same time, the weight of original power source is approximately 400 grams, which makes it very useful in using at transportable devices and machines, such as aircrafts and space shuttles. Mentioned devices are widely used in medical and pharmaceutical industry. Many scientific centers and universities develop researches, which require usage of equipment and devices of highest quality. They allow researchers to reach a proper quality of their studies and get better results. Forest industry is also one of the biggest users of these sensors. Different forest inventory, equipped with UAVs and sensor systems, is able to produce better quality and large amount of work.

3.2.7 Mobile and hand-held applications

Due to technological progress, the sizes of measurement and sensing devices and mechanisms are decreasing. This fact allows their usage in very small and portable devices, which opens new application fields. It enables following new technologies and opens opportunities for making revolution within this field (Mäkynen 2009).

- MEMS, LED technology and imager technology
- Design integration: electronics, mechanics and optics
- Embedded data processing.

3.3 European sensor industry trend overview

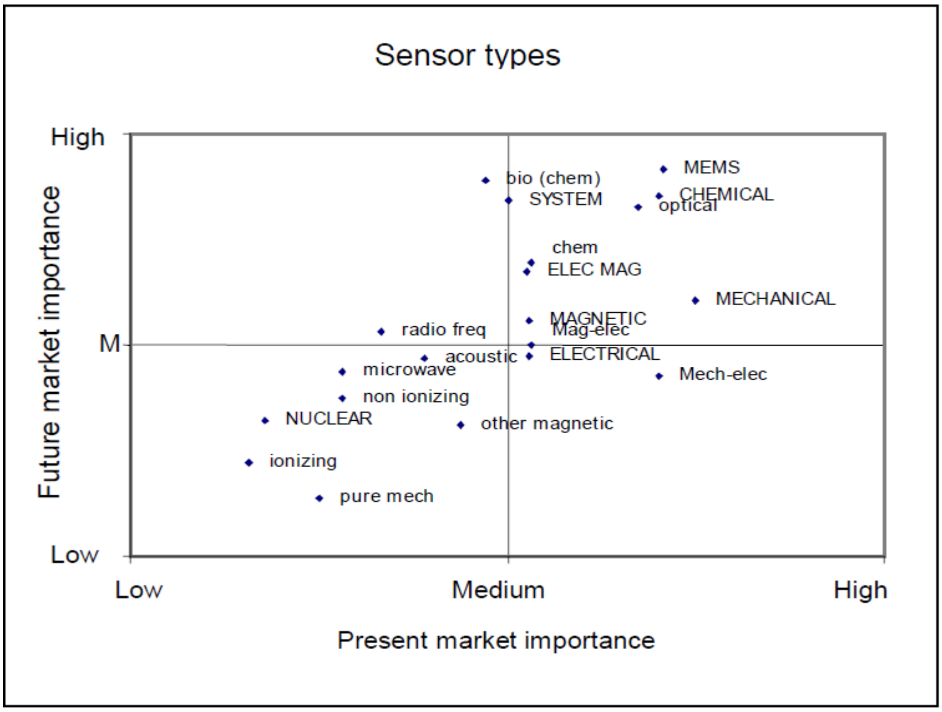
This part of work analyses European sensor industry, its market and trends. Three sections consist of it. The first part is detailed analysis of sensor industry in Europe in general and several European countries in particular. The diagrams and chats are also provided; they show sensor industry per product segment (temperature, pressure, etc.) and application sector (automotive, industrial, etc.). In addition, there are consumption estimates in million euros per product segment and application sector and forecasts in value terms from 2010 to 2015. The second part is analysis of sensor manufacturers and integrators, localized in Belgium, France and Netherlands. Analysis is conducted per activity type in these countries, and mapped per product segments and application sectors. The third part consists of summarizing points.

3.3.1 European sensor industry

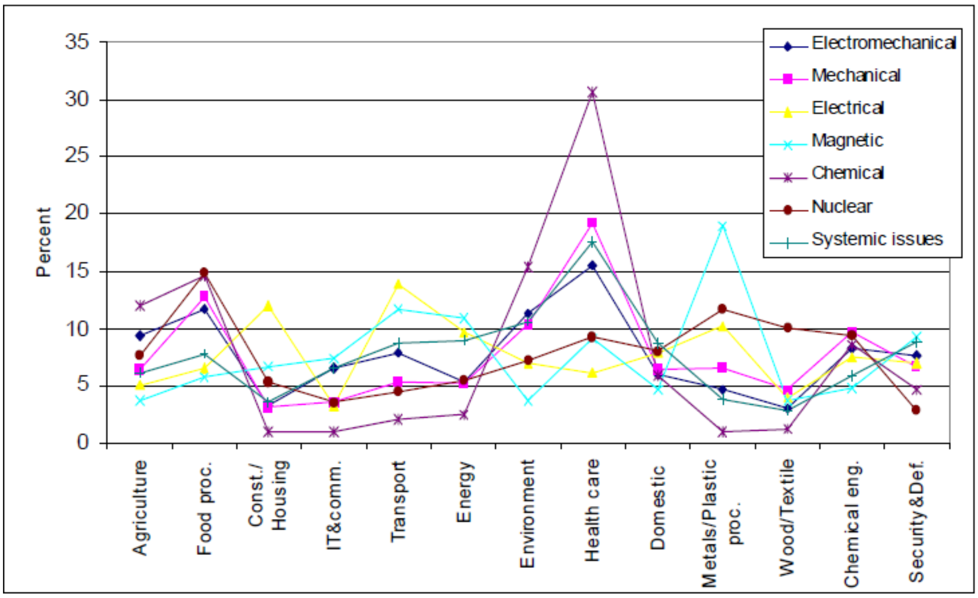
The resulting data for this part of work is collected from the survey, made by The European Foresight Monitoring Network. Author observes ideas and significant results and quotations from the survey.

According to this project, six categories of sensors have been analyzed: chemical, electromagnetic, nuclear, electrical, mechanical and magnetic. Experts have been asked for additional opinions and information referred to the following elements: sensor type, basic technology, area of application and development stage.

This survey asked experts to respond to each statement, such as time horizon or barriers for realization and potential market volume. Approximately 130 statements were formulated on basis of the 217 topics, arising from data collection process; they were narrowed down to a final 50, used as the basis for the questionnaire. The following diagrams summarize the results of this survey in terms of future and present market potential of various sensor types. The following charts show results of the survey in terms of expected impact of different sensor technologies on markets; results are also linked to the specific application domains (Picture 27, 28) (Andersen et al. 2004).



Picture 27. Diagram of results a survey on sensors about present market importance (Andersen et al. 2004)

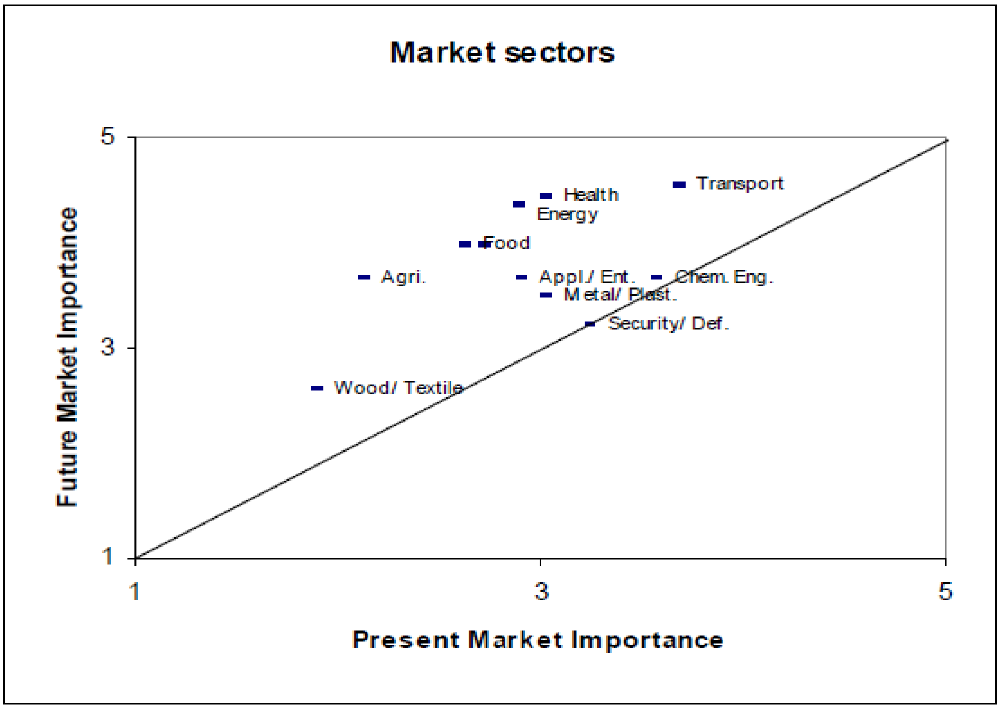


Picture 28. Chat of results of survey on sensors about expected impact (Andersen 2004)

In accordance to the final conclusion of this survey, the most impacted market by sensor technologies is a healthcare one. The following is a list of prospective types of sensors and sensor systems over the next 10 years in terms of market volume (Sensor technology foresight 2012).

- MEMs (Micro-Electro-Mechanical Systems)
- Optical sensors
- Biomechanical sensors
- Biological sensors
- Sensor systems of mixed type for complex usage.

A conflict of assessment has been noticed for the future of biosensors. On the one hand, there is a wide use of biosensors. On the other hand, the use of implanted biosensors and human-like sensors is unlikely to be considered. It is ranked at the bottom of a technological feasibility list. However, increasing usage of sensors is predicted for almost every market area (Picture 29). Micro-Electro-Mechanical Systems usually stand out together with sensors that are small, low cost and flexible devices. They refer to physical sensing devices that have a small size and are usually integrated into the signal processing technologies, using special fabrication techniques. It is also expected that sensors will be developed as integrated sensor systems, which can be used for multiple applications and different purposes (Andersen et al. 2004).



Picture 29. Present market importance of sensors (Sensor technology foresight 2012)

The results of survey showed that there is a lack of cross-market, cross-disciplinary and cross-sector collaboration and partnership. Well educated human resources will also be needed during growth of the sensor industry.

3.3.2 Geographical mapping of sensors manufacturers

Over 1000 companies work in sensor industry in Europe. Most of them are small and niche players. Many EU states suffer from a deficit of sensors developers and manufacturers with respect to the end demand of OEMs (see full list of them at the Appendix chapter) (Mekid 2007).

The European sensor market is estimated at 20 billion euros in 2013-2015. In comparison, the world sensor market is 60 billion euros. Therefore European segment is only 30% of global market. An average sensor market growth is estimated at 8% in time terms between 2011 and 2015 years (Table 1). In the same time, Europe represents 20% of the world electronic equipment production; its share of the sensor market is significantly larger (30%) (Frost & Sullivan 2006).

	Europe			
Sensor Type	**Number**	**Million euros**	**Market share**	**Forecast 2011-15**
Industrial	1	2 643	26%	8%
Automotive	2	2 304	23%	2%
Aerospace/Defense	3	1 684	17%	10%
Consumer	4	724	15%	1%
Medical	5	534	6%	15%
Security	6	250	2%	5%
Transport	7	226	2%	4%

Building	8	204	2%	4%
Energy	9	199	2%	4%
Home Appliances	10	183	2%	1%
Environment	11	160	2%	14%
IT infrastructure	12	138	1%	5%
TOTAL		9 249	100%	

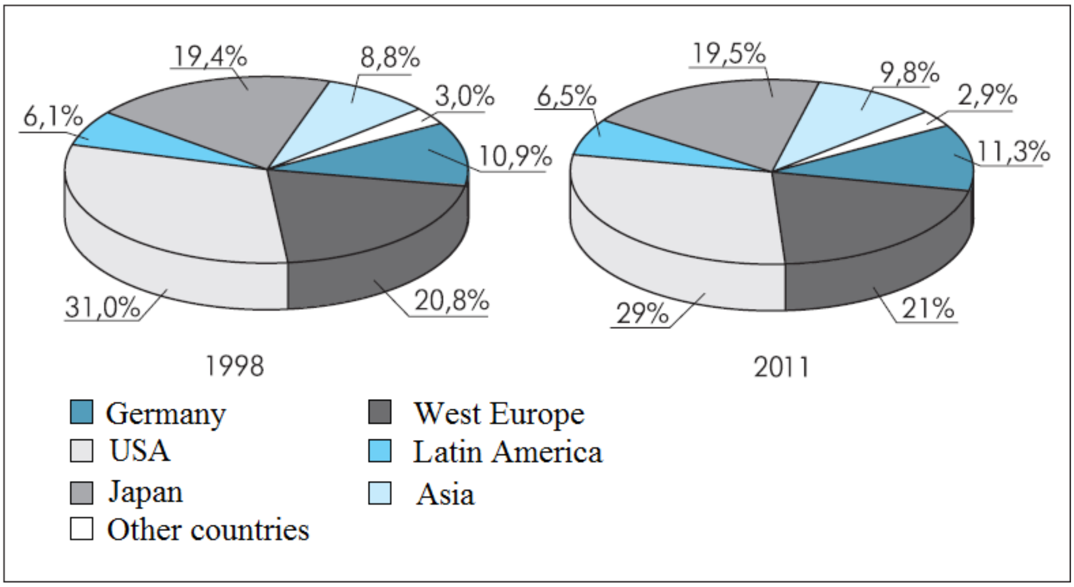
Table 1. European consumption. Source: Russtat

The reason of this fact is leadership position of European business in application sectors such as industrial, automotive and aerospace & defense segments. The average growth trends are similar to world electronic equipment markets growth during the same period of time (Blinov 2009).

- Growth rate of the electronic component market in Europe is doubled.
- Sensors tend to get new functionalities along with market developments at electronic and industrial sectors.

Developed countries give the highest priority to problems and prospects of control and measurement techniques development (Picture 30). For example, the Ministry of Research and Technology of France prepares a program of long-term prospects' studies for control and measurement equipment during 2060-2100 years. Plans of the Ministry should give a frame of possibilities of modern measurement techniques and identify objects and methods of measurements in the future. It is expected to conduct research on more than 20 different areas, covering a wide range of issues, from the functional analysis of foundations of metrology measurements to the economy impact assessments (Corella 2003).

Development a system of sensors for the different types of equipment, especially weapon and military segments that meet modern requirements, must be based on the following critical technologies and components: artificial intelligence and virtual reality systems; mathematical modeling systems; microsystem technologies; laser technologies; materials with special parameters; precision technologies; ionic and plasma technologies.



Picture 30. Structure of the worldwide sensor market (Blinov et al. 2010)

The following are summarizing points from the European sensor trend analysis.

- New applications of the inertial sensors and gas sensors are incentives for both product segments
- The structure of the sensor consumption per product segment is more fragmented than per application sector (the reason is a large scope of parameters for measurements in industrial, aero and auto segments)
- More mature sensor products like temperature, position, flow, force and electromagnetic are still growing (Frost & Sullivan 2006)
- Physical and mechanical sensors represent the vast majority of sensor market in Europe (it is 75% of the global market)
- The industry has very heterogeneous nature in terms of added value from actors and especially in terms of end application markets
- Several high potential markets have long industrial cycles, such as aerospace, defense and infrastructure
- At the same time, new markets and market niches regularly emerge (for example, medical and consumer), relying on new sensor deployment concepts, features and

business models (smart systems, sensor networks and autonomous sensors) (Taylor et al. 2008)

- The introduction of new product segments (bio-sensors and spectrometers)
- Invention of many different features, which can trigger development of new applications in medical, environment and security segments
- Market opportunities rely on new technologies and developments in base materials, converters and electronic processing (Taylor et al. 2008)
- The key research fields are multiple sensors, smart and interconnected sensors (such as sensor networks and self-diagnostic capabilities), and energy autonomy (energy harvesting methods)
- Regulation and standardization are significant issues, which increase market development and help to reach acceptable costs (Gardner et al. 2001)
- Collaborations between manufacturers and system integrators throughout food chain can also help in developing efficient solutions, based on available technologies.

4 A CASE

It is difficult to consider many measurement industry trends mostly appear at scientific conferences and researches. Only some of them mature to the stage of practical implementation. Sometimes this happens because of the time lag phenomena, mentioned at the first chapter; at some cases, technological progress moves so fast, that recently "new" technologies become "old" ones just a little time after. There are also measurement technologies, which have long and constantly updated lifecycle due to their basic origin (for example, radio and optical sensing). For us, one of the most interesting measuring technologies could be technologies, which are trendy now or going to be trendy in the nearest future. At the same time, their application and usage stage have already started. An example of this measurement trending technology can be the 3D sensor.

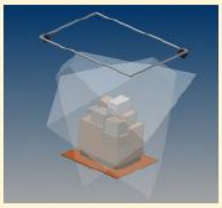
4.1 3D sensor for commercial usage

Nowadays there are many devices, which are able to conduct 3D image sensing. They include smartphones, tables, and separate toolkits such as MS Kinect or Nintendo Wii. Most of them operate at the mass customer market. At this case DHL's company shows, how 3D sensor may be implemented to commercial usage.

Shipping and logistic industry companies are dependent on two key parameters: freight flow and related information flows. They continuously research and apply new systems, which provide them better performance for both parameters. However, at most of cases, such systems require long application and in-house designing time frame, significant investments and flexibility of the customer companies. For example, traditional systems, used at shipping processes, are proven to be bottleneck due to their construction origin. They have long processing time period, in addition to the extra work, required to identify scanned pallets images. Hence, shipping companies start to study new trends and available systems, which suit they constantly growing needs. Small and unexpansive 3D scanners with sensing elements may be able to provide required time and productivity performance. As DHL specialists say "*By acquiring an object's surface contours with a total of 640 x 480 range values per scan and at up to 30 scans per second, 3D models of scanned objects can be generated, even when objects are moving relative to the* *scanner".* A sensing element generates matrix-like pattern of the light points, which is (pattern) altered by surface structures of the object. The original and altered image patterns are compared, which makes device to recognize depth values between them. A depth matrix is used to conduct volumes of particular objects, and an additional 2D camera is able to make objects pictures to notify about possible risks. Many shipping and logistics companies try to develop and implement such system design, which combine volume-weight-picture mobile scaling systems with small capital investments and fast process integration.

4.2 Findings

A DHL prototype sensor system has two sensors on a gate structure. This helped engineers of the company to implement low-cost 3D sensor, employed to scan volume, which is able to scan pallets in pre-defined reading range. According to DHL and Fraunhofer IFF experts' evaluation, it helped to cut measuring duration at 50%. Engineers of company developed such concept, which allows conducting several actions at the same moment of time. Actions include units weighting on forklifts, color image picturing from additional 2D camera, installed at the sensing device, barcode scanning from items labels and a following information transfer to higher-level information systems and databases. In addition, engineers applied dynamic measuring principle, which made it possible to set up measuring system at forklift. This achievement removed a large time waste, when all necessary pallets have to be moved at static place for the barcode scanning. It also gave more flexibility to most of inline storage systems, increasing amount of free space at warehouse and partly their workload. At the following table, developed by Fraunhofer IFF, we can see comparison point of both gate and mobile in-storage logistics systems, equipped with 3D measuring systems (Picture 31). DHL highly valuated results of the experiments. It states that system significantly increased whole systems performance, reduced process times, and relatively lowered capital outlay (approximately five times faster than current solutions of the company).

	Arrangement		Results	Use Cases
Gate System		▪ Two depth-imaging sensors in inclined arrangement ▪ 3D measurement of a defined area ▪ Installation above scales ▪ Stationary solution	▪ Measurement and photo documentation of all visible sides of an object ▪ Low shading effects even with complex structures ▪ Complex system calibration	▪ Optimized packing sequence ▪ Status documentation ▪ Contour check prior to loading ▪ Volume-based pricing
Mobile System		▪ Two depth-imaging sensors on forklift mast ▪ 3D measurement of the area on forks ▪ Integrated fork scales ▪ Wireless data transmission to database	▪ In-process measurement for short process times ▪ Classification of pallets and height measurement ▪ Complex system integration	▪ Volume-based sorting ▪ Optimized packing sequence ▪ Status documentation ▪ Contour check prior to loading

Picture 31. 3D sensing systems solution (source: Fraunhofer IFF)

4.3 Proposals and challenges

There is set of suggestions, made by practitioners of logistics industry. Most of them are able to implement, while using 3D sensing systems. For example, it is possible to create 3D images, use color labeling and object contours recognitions options. Placed ahead of sorting line, a sensing system may significantly increase work flow at the warehouse. Additionally to the stable solution, sensing systems, placed at pre-defined places in storage rooms, are able to monitor and signal about free space availability of the whole warehouse. They utilize so-called "dynamic items flow". DHL experts broaden implication area by adding mobile logistics assets. They suggest installing volume scan-modules into trucks' cargo areas so sensing systems are able to dynamically measure trucks capacity and coordinate fleet actions.

However there are negative and challenging points at the 3D sensing systems practical implementation process; for example, uniqueness of each sensing system. Every warehouse has its own location, design and transportation supply, which make designing and implementation of successfully working and reliably system a very sophisticated and experience demanding procedure. In addition to actual system implementation, the industrial and logistical enterprises ask question about sensors quality. Since these systems are objects to very small investments, it is not possible to expect the same workload and quality parameters as professional and "expensive" vendors add into their products. Moreover new "cheap" systems should have decent resistance characteristics in order to function properly at the complex industrial environments. The last but not least point is an official certification and standardization by appropriate organizations. Nowadays it is almost impossible to install any sophisticated system into the factory without approval from official bodies.

Finally, the 3D sensing systems tests discover high potential of low-cost 3D sensors at logistics and manufacturing industries. The tests underline a new trend of transferring- and non-sensing consumer electronics technologies at the areas of industrial application.

5 CONCLUSION

Measurement technologies, especially sensors and sensing systems, are going to play more significant role in the human's life. In 21^{st} century, where information became one of the most needed resources, ways of conducting data and analyzing results become vital. Starting from technological revolution in 20^{th} century, where sensors have been mechanically constructed and focused at little amount of users, modern sensors are wide spread, intellectual and mostly hidden tools, which have many additional, non-native parameters, such as self-calibration, processing, analyzing and data collection.

Main driving forces of current market production and consumption are high-tech innovations and technologically sophisticated products. Actual research showed that worldwide consumer goods, pharmaceutical and transportation industries continue to be the most sensor demanding market segments. European and North American markets expect to represent the largest market shares for MEMs, proximity and approach sensor types. Demand to physical and nano sensors continues its stable growth. Major research and development hubs are located in European and North American regions while developing countries play role of manufacturing centers. Measurement technologies dynamics research shows that constantly increasing dependence of sensor innovations to information technologies will shift measurements' research and development hubs from traditional sites closer to centers of IT evolution.

Finally, commercial sector continues to implement the newest measurement technology innovations. Industrial segmentation is very wide, and it starts from manufacturing and logistics industries, which are already flexible enough to implement consumer market sensing solution in order to reduce prices, increase operational processes speed and business efficiency. Industrial segmentation continues with heavy machinery and aerospace industries, which are traditionally depended on high quality measurement solutions. This will create a new boost of activities and investments into the sensor research organization and will bring new technologies, increasing the progress speed at the same time.

SOURCES

1. Maslov V.P. Information system and technologies. Lvov, 2009. P. 20-21
2. Karpenko S.G., Popov V.V. Information system and networks. Kyiv, 2006. P. 45
3. Radioelectronics essentials. Workbook. Kharkov, 2009.
4. Zenov N.V., Karpov V.G. Theory of electricity chains // Energy. Kyiv, 2011
5. H.-R. Tränkler and O. Kanoun, "Symbiosis of information and sensor technologies," in Proc. Sensors, Nürnberg, Germany, 2003.
6. W.-E. Bulst, G. Fischerauer, and L. Reindl, "State of the art in wireless sensing with surface acoustic waves," IEEE Trans. Ind. Electron., 2001.
7. Beroulle, V., Bertrand, Y., Latorre, N., Nouet, P.: Test and testability of a monolithic MEMS for magnetic field sensing, Journal of electronic testing 17, 2001.
8. Schröder, N.: Sensor Markets 2008, Intechno Consulting, Basel 1999.
9. Decision Etudes Conseil: European Sensor Industry: Technology, Market and Trends 2007-2011. Paris, 2008.
10. Dumas, N., Azais, F., Latorre, N., Nouet, P.: Electro-thermal stimuli for MEMS testing in FSBM technology, Journal of electronic testing 22, 2006.
11. Isermann, R: Fault-Diagnoses Systems, Springer Verlag, Heidelberg 2006.
12. J.W. Gardner, V. K Varadan, and O. O. Awadelkarim, Microsensors, MEMS and Smart Devices. New York: Wiley, 2001.
13. Dannemand Andersen, P.; Jørgensen, B.H.; Rasmussen, B. (2001). Sensor Technology Foresight, Risø-R.
14. Sensor technology foresight, http://www.risoe.dk/rispubl/SYS/ris-r-1292.htm (Read 20.02.2012)
15. Dannemand Andersen, P.; Jørgensen, B.H.; Lading, L., Rasmussen, B. (2004). "Sensor Foresight – Technology and Market", TECHNOVATION.
16. Market Prospects for Position Sensors. Taylor J. Venture Development Corp. Sensors, Feb 1, 2008.
17. "10 emerging technologies that will change the world," Technol. Rev., Feb. 2003.
18. Decision Etudes Conseil: European Sensor Industry: Technology, Market and Trends 2007-2011. Paris, 2008.
19. Frost & Sullivan: World Wireless Sensor and Transmitter Markets, 2006.

20. Egorov A.A., Egorov M.A., Chekhlova T.K., Timakin A.G. Research of a computer-controlled integrated-optical sensor of concentration of gaseous substances // Quantum Electronics. 2008.

21. Egorov A.A., Egorov M.A., Tsareva Yu.I., Chekhlova T.K. Study of the integrated-optical concentration sensor for gaseous substances // Las. Phys. 2007.

22. Looney, B.B; Falta, R.W., (Eds.) Vadose zone Science and Technology Solutions. Battelle Press, Columbus, OH, 2000.

23. "Distributed sensor networks," MIT Lincoln Laboratory, Lexington, MA,1986.

24. J.W. Gardner, V. K Varadan, and O. O. Awadelkarim, Microsensors, MEMS and Smart Devices. New York: Wiley, 2001.

25. D. Estrin, R. Govindan, J. Heidemann, and S. Kumar, "Next century challenges: Scalable coordination in sensor networks", 1999.

26. Blinov A., Kritenko M., Lebedev D. Sensor of new generation. Moscow, 2010.

27. Sysoeva S. New concepts of speed and position sensors // Components and technology, 2008.

28. Sysoeva S. Automotive speed sensors. Structure analysis and development prospects // Components and technology, 2004.

29. Sysoeva S. Intellectual automotive position sensors. Modern technologies and new prospects. Part 14. Final analysis. Editions and conclusions // Components and technology, 2006.

30. Dumas, N., Azais, F., Latorre, N., Nouet, P.: Electro-thermal stimuli for MEMS testing in FSBM technology, Journal of electronic testing, 2006.

31. ZMD: Mehrkanal-Sensorinterface-IC, 2008.

32. NAMUR and VDI/VDE-GMA: Technologie-Roadmap: process-sensors 2005-2015, Düsseldorf 2005.

33. F. Zhao, J. Shin, and J. Reich, "Information-driven dynamic sensor collaboration for tracking applications," IEEE Signal Processing Mag., 2002.

34. S. Mekid Intelligence improvement in sensor clusters in manufacturing process // Sensors and systems, 2007.

35. Matalucci, R.V.; Esparza-Baca, C.; Jimenez, R.D. Characterization, monitoring, and sensor technology catalogue. SAND95–3062, Sandia National Laboratories, Albuquerque, NM, 1995.

36. Lui, T.; Sullivan, J.P. Pressure and Temperature Sensitive Paints; Springer-Verlag: Berlin, Germany, 2005.

37. Vigleb G. Sensors. Development and practical use. Moscow, 1989.

38. Kotik A.F. Sensors development in modern metrology. Moscow, 2008.

39. Telco Sensors, http://www.telcosensors.com/solutions/industries/paper_and_pulp (read 15.02.2013)

40. Potentiometric Membrane Sensor as a Probe for Determination of Some Pharmaceutics, http://onlinelibrary.wiley.com/doi/10.1002/elan.200804374/pdf (read 18.02.2013)

41. Turck Industrial Automation, http://www.askturck.com/docs/TURCK-Factor1-White-Paper.pdf (read 18.02.2013)

42. Altech Corp. “Inductive Proximity Sensors”, http://www.altechcorp.com/HTML/Sensors_Standard-A.html (read 18.02.2013)

43. International union of pure and applied chemistry “Chemical sensors definitions and classification”, http://www.iupac.org/publications/pac/1991/pdf/6309x1247.pdf (read 18.02.2013)

44. News medical “Biosensors - What are Biosensors?”, http://www.news-medical.net/health/Biosensors-What-are-Biosensors.aspx (read 19.02.2013)

45. Malinen J., Emerging sensing technologies and applications, VTT. Finland, 2011.

46. Liquid-crystal photonic applications, http://opticalengineering.spiedigitallibrary.org/article.aspx?articleid=1158267 (read on 21.02.2013)

47. Liquid crystal tunable filter, http://en.wikipedia.org/wiki/Liquid_crystal_tunable_filter (read 21.02.2013)

48. Prism-Grated-Prism technology, http://www.vtt.fi/inf/pdf/publications/2001/P435.pdf (read on 21.02.2013)

49. Miniaturized spectral imager for UAV remote sensing, food quality and medical applications, http://www.fotonica-evenement.nl/assets/Fotonica-2012/Presentaties-27-maart/VTT-Technical-Research-Centre-of-Finland-Heikki-Saari-PDF-AKKOORD.pdf (read on 22.02.2013)

50. Hyperspectral imager development at Army Research Laboratory, Gupta et.al. Proc. of SPIE Vol. 6940 69401P-3, 2008. http://lib.semi.ac.cn:8080/tsh/dzzy/wsqk/SPIE/vol6940/69401P.pdf (read 22.02.2013)

51. Multipoint-NIR-measurements in pharmaceutical powder applications, VTT, http://www.vtt.fi/inf/pdf/publications/2009/P704.pdf (read 23.02.2013)

52. Gardiner, D.J. (1989). Practical Raman spectroscopy. Springer-Verlag.

53. Low-cost sensor technologies, DHL, Fraunhofer IFF, http://www.iff.fraunhofer.de/de/presse/presseinformation/2012/ehrung-magdeburger-forscher-erhaelt-dhl-innovation-award-2012.html (read 29.09.2014)

54. 3D Imaging Sensors and Systems for Online Surface and Layer Quality Control, VTT, http://www.vtt.fi/files/sites/eemeli8/10_Focalspec_0111006.pdf (read 23.02.2013)

55. Intelligent Measurement Processes in 3D Optical Metrology: Producing More Accurate Point Cloud, Creaform Inc., http://www.vds.ch/cms3/images/CMS3/Produkte/Broschueren/Creaform/Funktionsweise.pdf (read 23.02.2013)

56. A Lightweight Hyperspectral Imager, Jussi Mäkynen, http://lib.tkk.fi/Dipl/2009/urn100105.pdf (read on 26.02.2013)

SENSORS APPLICATION SECTORS DEFINITION

Application sector	**Definition**
Aerospace and Defense	Embedded sensors in aerospace and military platforms (civil and military aircraft)
Automotive	Embedded sensors in passenger cars (engine, body)
Building	Embedded sensors in home, office and public buildings (civil engineering)
Consumer	Embedded sensors in mass market products (mobile phones, TVs, media players, computers)
Energy	Sensors used in power plants as well as energy transportation networks
Environment	Sensors used to monitor environmental parameters (meteorological sensors, air and water monitoring)
Industrial	Sensors used in industrial process and manufacturing including petrochemical industries, equipment manufacturing and assembly plant, food industry
Medical	Embedded sensors in medical equipment including medical imagery, drug delivery, homecare devices
Transport	Sensors used in railway and marine transportation equipment and networks
Security	Sensors used for personal, goods, site and homeland security
IT infrastructure	Embedded sensors in computer and telecom networks and infrastructure

Source: Russtat

LIST OF EUROPEAN SENSOR MANUFACTURERS

- ADT
- AIRINDEX
- AKOTRONIC
- ALLEGRO
- ASC Instrument
- ASCO INSTRUMENTS
- ASHCROFT Instruments
- BALLUFF
- BERTHOLD
- CMR
- CORREGE
- DOERLER
- EFE
- ELECTRICFIL
- EMERSON
- EPCOS
- FLINTEC
- FUJI Electric

- GAROS
- GEORGIN
- HEITO
- IFM Electronic
- IJINUS
- INDUSTECHNIC
- ITECA SOCADEI
- IXSEA
- KISTLER
- KROHNE
- LESCATE
- LOREME
- LITTOCLIME
- MEGATRON
- METRAVIB
- MICREL
- NIVUS
- OMRON
- PARATRONIC
- PROSENSOR

- SCHLUMBERGER
- SCHNEIDER ELECTRIC
- SENSEOR
- SENTRONIC
- SETNAG
- SIEMENS BUILDING TECHNOLOGIES
- SOFRASER
- STEDAM
- TRONICS
- TURCK BANNER
- VAISALA
- VISHAY
- WENGLOR SENSORIC