Recent Advances in Sensor Technology

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Abstract- **The recent advances of sensor technologies have been powered by high-speed and low-cost electronic circuits, novel signal processing methods and innovative advances in manufacturing technologies. The synergetic interaction of new developments in these fields allow completely novel approaches increasing the performance of technical products. Innovative sensor structures have been designed permitting self-monitoring or self-calibration. The rapid progress of sensor manufacturing technologies allows the production of systems and components with a low cost-to-performance ratio. Among microsystem manufacturing technologies, surface and bulk micromachining are increasingly winning recognition. The potential in the field of digital signal processing involves new approaches for the improvement of sensor properties. Multi-sensor systems can significantly contribute to the enhancement of the quality and availability of information. For this purpose, sophisticated signal processing methods based on data fusion techniques are more effective for an accurate computation of measurement values or a decision than usually used threshold-based algorithms. In this state-of-the-art lecture we will give an overview of the recent advances and future development trends in the field of sensor technology. We will focus on novel sensor structures, manufacturing technologies and signal processing methods in individual and multi-sensor systems. The predominantly observed future development trends are: The miniaturization of sensors and components, the widespread use of multi-sensor systems and the increasing relevance of radio wireless and autonomous sensors.**

Keywords **– Sensors, Sensor Systems, Technology, Signal Processing, Future Trends.**

INTRODUCTION

The competition in markets requires the permanent enhancement of quality and reliability of products. The rising demand for automation, security and comfort leads to completely new sensor applications. The number of sensor systems required and the diversity of their application is permanently increasing. Nowadays, sensor technology intrudes in new application fields and mass markets like automobiles [1] or smart homes [2]. To keep up with the requirements in these application fields and with additional rapid developments in science and technology, the sensor design is required to provide novel approaches and solutions. An exhaustive consideration of the newest developments in the wide spectrum of sensor technology is very important to promote synergy effects in this field. For new applications, even well-known solutions should be in general adapted to specific requirements.

DEVELOPMENTS OF SENSOR TECHNOLOGY

Sensors and sensor systems achieve their function through an interlocked interaction of sensor structure, manufacturing technology and signal processing algorithms. The developments in sensor technology are consequently based on the permanent technical progress in these fields (fig. 1). Particularly, in the last years a significant upturn is observed in this fields involving a great potential for completely novel approaches of sensors and sensor systems. Using new technologies and signal processing methods, even wellknown measurement principles could be used leading to considerably improved sensor features. With selected examples, we will give in this state-of-the-art paper an overview about the significant developments of methods, structures, manufacturing technologies and signal processing characterizing today's sensors and sensor systems.

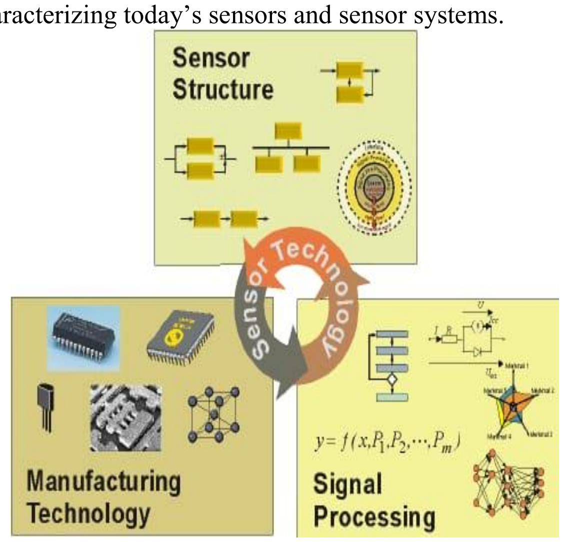

Fig-1 Decisive fields for the development of sensor technology

SENSOR DESIGN

In the design process the technical and economical consideration of the target application are generally necessary. The specific requirements and boundary conditions are useful for the concrete specification of the sensor system on which the design of the sensor system bases. At beginning, several libraries of well-known system structures, sensor elements, simulation models and signal processing methods are available. These generally result from earlier approaches and solutions. In a pre-design step, rough structures of the sensor system are specified and evaluated. As a result we obtain the sensor concept, which is gradually refined. The final component are generally obtained after an experimental examinations within the total system.

Simulation techniques are usually used in order to considerably shorten the sensor time-to-market and to improve the sensor properties during the design process. The realized efficiency of the design cycle thereby can lead to a successful system design on the first fabrication attempt, so that the total resulting costs are significantly reduced. Some cases of operation, which occur accidentally or are only realizable with difficulties, can be precisely investigated. Making use of simulation techniques, statistical characteristics describing the behavior of the sensor system can be easily calculated.

SENSOR STRUCTURE

In the kernel of a sensor system is the sensor element, which changes its output depending on the measured quantity (fig. 3). In a pre-processing unit, the sensor signal is transformed in an adequate signal using analog signal processing techniques. By means of low-cost analog-digital converters, signal processing is increasingly shifted from the higher system level in the sensor level. The diverse facilities in the field of digital signal processing involve new approaches for the improvement of sensor properties.

For instance, the consideration of manufacturing variance caused by fluctuations during the technological production process becomes a simple task, which can be carried out during the system configuration. In order to be integrable in higher-level systems, an adequate interface, such as a bus interface is generally conceived as an essential component of the sensor system itself.

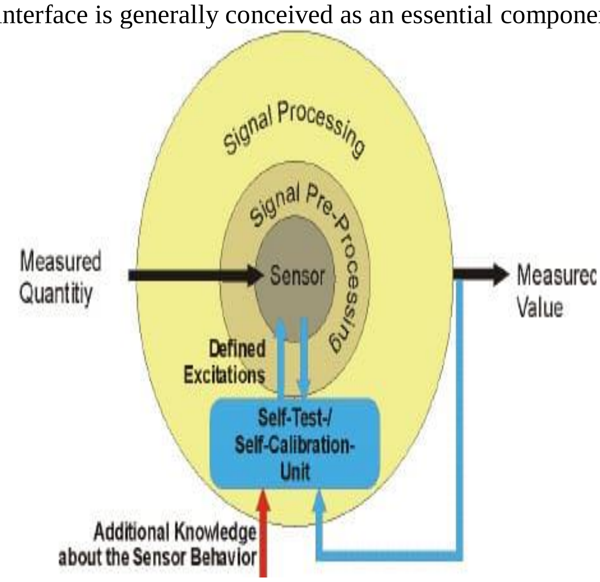

Fig-2 Sensor structure with self-test or self-calibration

In recent research, other functions, such as online self-test or self-calibration, are being embedded in the sensor structure during the design process. That way designed sensor systems have many advantages especially considering the system reliability and the cost reduction of installation and maintenance.

The structure of a sensor with self-monitoring differs from the standard structure in particular through the consideration of supplementary knowledge to the actual measurement information. Generally, specific relationships are required about the sensor behavior and the expected confidence limits of sensor properties . The state of the sensor system can be inspected by a comparison of the real output to the expected value due to the previously known relationships. For instance, by acceleration sensors with a closed-loop structure, the inertial force acting on the mass is compensated through an electrically generated restoring force. Through the application of restoring forces with well-known values, self-tests can be carried out .

A further potential of built-in self-tests is possible in multisensor systems, making use of more information provided by the individual sensors. For instance, through a comparison of the outputs redundantly available sensors, strongly deviating sensors can be detected and eliminated from the following signal processing. For a self-calibration process, the real sensor outputs by fixed well-known inputs are moreover used in order to calculate sensor parameters. Through self-calibration, sensor aging effects can be considered, so that defined measurement accuracy limits could be guaranteed during the operating time. The trend towards built-in self-test or self-calibration function leads up to the design of totally calibration-free sensor systems.

SENSOR TECHNOLOGY

Many recent advances in the sensor technology become mainly possible by means of micro technologies. These new technologies offer low-cost systems with smaller size, lower power consumption and higher reliability. Among micro technologies, silicon micromachining is one of the most significant micro technologies . The eminent properties of the silicon material, such as the freedom of hysteresis errors and many advances in the field of micro electronics have permitted this important technical evolution.

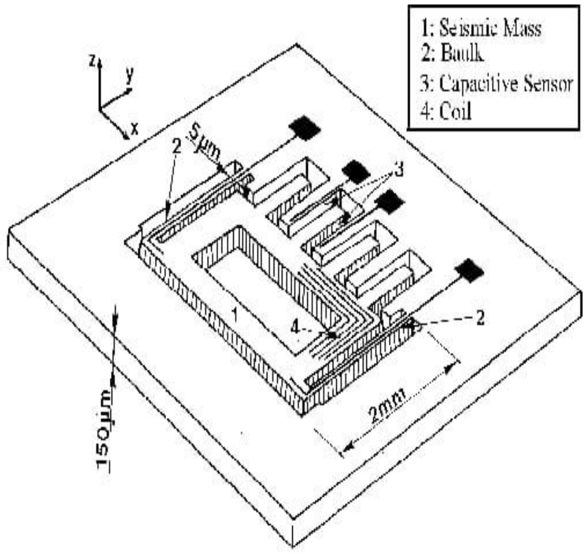

Fig-3 Accelerometer in a closed-loop structure

In case of bulk micromachining the substrate is structured by means of wet and dry etching processes. In an isotropic process, the etching speed is independent from the direction in the substrate . On the contrary, in an anisotropic process the etching speed is direction dependent. The manufactured devices in this technology have a high aspect ratio. This means, that the structure height is high relative to the minimal lateral dimension of the whole structure. Therefore, for some applications, bulk micromachining is more suitable than surface micromachining.

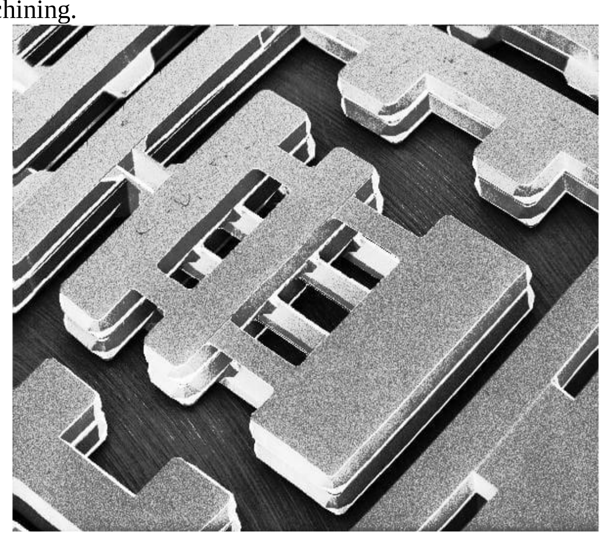

Fig-4 Rotary rate sensor in bulk micromachining

In case of surface micromachining, three-dimensional mechanical and mechanical structures are developed through successive separation and structuring of sacrifice layers, which is mainly a SiO_2-layer (fig. 8). The individual layers are separated with sacrifice layers which generally get structured before the next layer is separated. For instance, figure 7 shows the individual steps for the manufacturing of a detached poly silicon micro bridge in surface micromachining. Examples for successfully developed micro machined sensors are pressure, rotary rate , and acceleration sensors.

Because of the fluctuation of several factors during the production process, sensor devices show generally a certain manufacturing variance. Influence factors, such as temperature, pressure and humidity can have an effect on the sensor behavior. Aging processes are in some cases considerable and affect sensor properties, such as the sensitivity or the zero point.

The signal processing has the task to determine the measured quantity from the measured data in spite of all these effects, which are in some cases unavoidable and represent a systematical source of measurements errors. Making use of appropriate signal processing techniques, the properties of the sensor systems and especially the precision of measurement can be significantly improved.

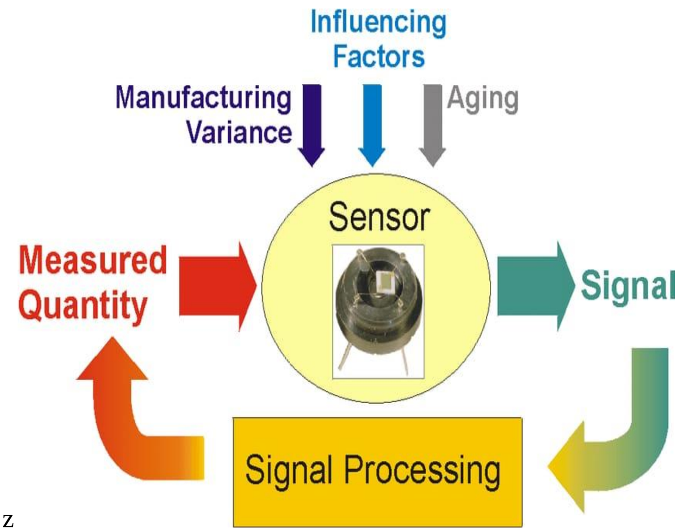

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Fig-5 Signal processing for sensors

Signal Processing for individual sensors

Whereas the sensor element can deliver a weak signal, the transmitted signal should generally have a high signal level and perhaps a suitable values, in order to reach superior units undisturbed and to simplify the calculation of the measurement value. Therefore the sensor signal should be generally pre-processed. Thereby many important tasks could be realized , such as:

• Special measures for the secure operation
• Conjunctions with other components in a chain, parallel or closed-loop structure
• Signal amplification
• Scaling
• Linearization
• Signal conversion

Nowadays, a current practice is the local digitalization of the sensor signal. Through the increasing use of distributed systems with bus based networking, the signal digitalization is becoming more and more necessary. In addition to the disburden of the total system, the local signal digitalization have the advantage, that the measurement data could be transmitted without precision loss independently of the distance between the sensor and the higher processing unit.

For instance, giant magneto resistance (GMR) elements are able to measure an angle with a high resolution. A particular property of these elements, is e. g. that they can measure the direction of a magnetic field independently of its amplitude. In this case, the sensor signal must be generally amplified and the temperature influence compensated. The actual calculation of the angle is carried out by an analog signal processing in a half or a full bridge circuit with GMRelements with different preference magnetization .

Signal Processing for Multi-Sensor Systems

In general, single sensor systems can only provide partial information on the state of the environment while multisensor systems combine related data from multiple similar and/or different sensors. The goal by using multi-sensor systems is to provide synergetic effects that enhances the quality and availability of information about the state of the measurement environment. The aim of the signal processing by multi-sensor systems is to acquire a determined information using the necessary set of measured data. Generally a certain level of e. g. precision or reliability is required, that only one sensor could not achieve.

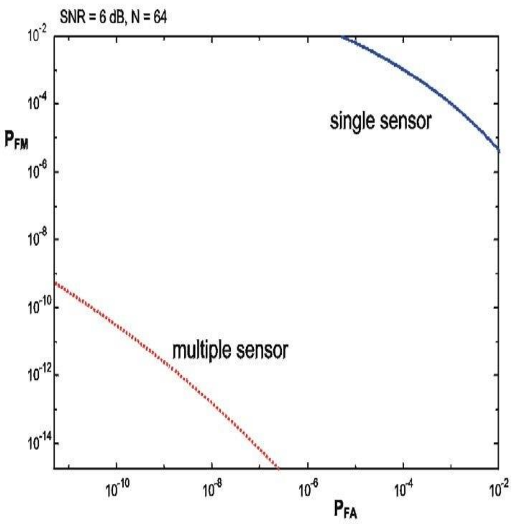

Fig-6 Receiver Operating Curves of : PFA-probability of false alarm, PFM – probability of false dismissal.

A sophisticated signal processing based on data fusion techniques can generally improve the measurement accuracy more than usually used simple threshold based algorithm. The process of multi-sensor data fusion should be specially designed in each case under consideration of the special circumstances in the target application, in order to ensure the right calculation of the required measurement values or decisions.

For instance, in gas measurements, while individual sensors are generally not accurate enough for a precision measurement, the use of high quality analyzing devices is expensive and therefore not acceptable for many applications. The use of several low cost sensors in a multi-sensor system can reach a significant improvement of reliability and precision in the gas concentration measurement . Important circumstances for the data fusion are in this case the cross sensitivity of the sensors and effects of influence factors such as temperature, humidity or pressure. The relevant influence factors should be generally measured by separate sensors. Through calibration processes, the reaction of the multisensor system on different lead gases is tested. Depending on the sensor reaction, the combination of the sensors for the data fusion is determined by the sensor management module, so that an accurate concentration measurement can be carried out in spite of the deficiency of the individual sensors.

Multi-sensor systems are nowadays indispensable in hazard warning applications such as free range protection by video signal evaluation, detection of lying persons or in the fire early detection, because of the required high level of reliability. For instance, in the early fire detection, sensor arrays including optical scattered light detectors and gas sensors have been proposed . In this case the signal processing should be able to discriminate between fire, not-fire and disturbing event situations by identifying fire signatures from measured sensor responses.

A feature extraction unit is required in order to reduce the dimensionality of the measurement space and to extract suitable information characterizing fire situations. The extracted features are than classified by means of neural network, in order to estimate the class to which the measured data belong and to know if an alarm should be sent to the fire brigade.

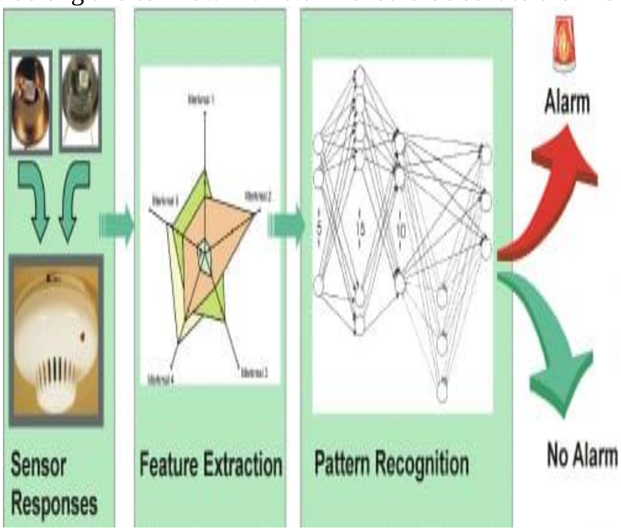

Fig-7 Structure of a sophisticated fire detection algorithm

FUTURE TRENDS IN SENSOR TECHNOLOGY

The development trends in sensor technology result from market-economical aspects, general customer requests and the requirements for an implementation in the target applications. Costs reductions, improvements of accuracy, reliability and speed are reached using measurement methods with a higher performance, new manufacturing technologies and sophisticated signal processing methods.

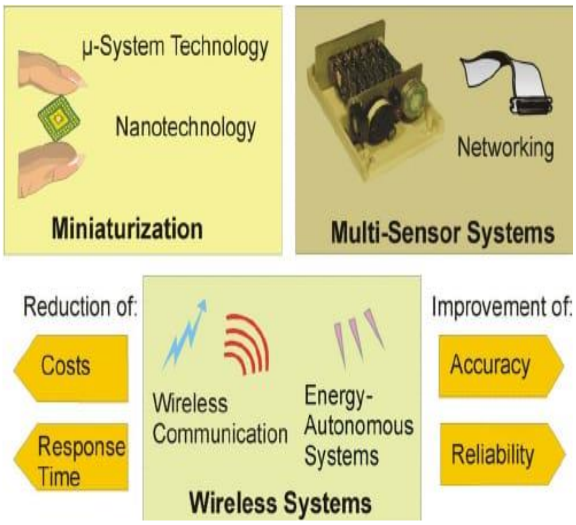

Fig-7 Future trends in sensor technology

Trend to Miniaturization: Micro system Technology

Miniaturization is an outstanding strategy of success in modern technologies. A reduction of characteristic dimensions usually results in shorter response times and higher resonance frequencies so that a correspondingly higher speed is achievable in signal generation and processing. It reduces production costs and increases performance by integration of micro components.

Miniaturization is gaining importance in all fields of application where smaller structures and greater precision are becoming decisive to the market acceptance of individual products. Even whole sensor systems are concerned by this trend, particularly in application fields where the acceptable volume or weight is limited. The development trend to miniaturization go on within the Nanotechnologies.

For instance, for the monitoring of vital parameters of human beings, health care devices can be used, so that an emergency call could be released automatically in case of unconsciousness of the observed person. For acceptance by users, the device should be light and provide a unhindered mobility. The user should be able to ignore it and to live normally without being obliged to take it down in any situation during the whole day.

The concept of the MIT-ring , as a highly miniaturized solution, that can fulfill the requirements for this special application. A light-emitting diode in the ring continuously emits light into the finger of the observed person. By an evaluation of the reflected light, the ring can measure the pulse rate, the potential cardiac condition and may be the blood pressure. By means of an embedded antenna signals can be transmitted to a signal receiver in the surroundings.

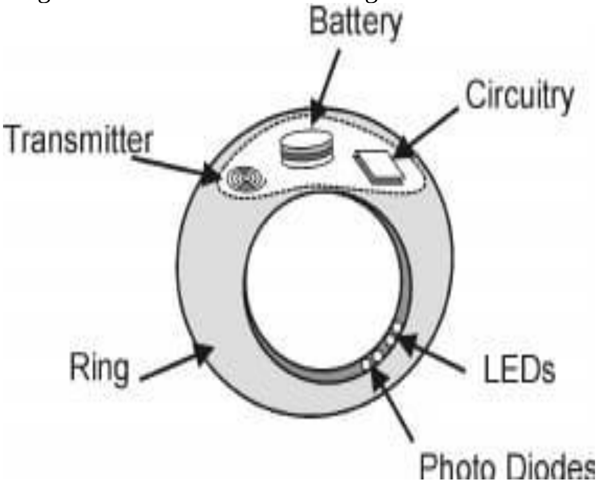

Fig-8 MIT-Ring for healthcare

Trend to the Use of Multi-Sensors

The use of multi-sensor systems is becoming more important in widespread application fields . Their applications reach from the monitoring and automation of manufacturing processes to robotics, automotive applications, smart home, process control, environmental engineering, biotechnology and life sciences.

Multi-sensor systems provide the advantage, that economical sensors can be used even for the achievement of a high level of precision and reliability. Thereby a big set of available information is managed using sophisticated signal processing techniques, so that the system can achieve a better performance.

Multi-sensor data fusion is in effect intrinsically performed by animals and human beings to achieve a more accurate assessment of the surrounding environment, thereby improving their chances of survival.

Trend to Wireless Systems

Trend of wireless system With the big amount of components, which are indispensable for the achievement of the required functionality, the electric wiring of spatially distributed systems becomes complex and causes difficulties in the system's handling. The use of wireless systems implies a better convenience and lead to a considerable costs reduction. Wireless sensor systems have the advantage, that they can be un restricted placed, and can therefore record the measured quantity closely to its occurrence independent of potential harsh circumstances.

For instance, surface acoustic wave devices (SAW) are novel sensor elements (transponders) for object identification and for the measurement of physical, chemical, and biological quantities such as temperature, pressure, torque, acceleration or humidity.

A radio frequency burst impulse transmitted by a local transceiver is received by the antenna of a passive SAW device and re-transmitted to the receiver part of the local transceiver. Amplitude, frequency, phase and time of arrival of this RF response signal carry information about the SAW reflection and propagation mechanisms which can be directly attributed to the measured effect.

OUTLOOK

The sensor technology profits from synergetic concurrence of both of manufacturing technologies and signal processing methods. New sensors provide promising technical solutions which can significantly contribute to an improvement of quality, reliability and economic efficiency of technical products.

For the development of new sensors, an interdisciplinary work of key competence from university and industry is indispensable. In the future sensor systems would be designed in an integrated design processes including not only the technological aspects, but also the design of the specific manufacturing steps.

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