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INTEGRATED SOLID STATE SENSORS IN ENGINEERS EDUCATION – EXPERIENCES AND PLANS FOR FUTURE

The measurements of non-electric quantities with electric methods have a long-standing tradition at the Silesian University of Technology. In this paper we would like to present the main idea and topics of the lectures and briefly describe the laboratory exercises. We also discuss the plans for the future.

Key words: *teaching, education, sensors, calibration, measurement systems.*

1. INTRODUCTION

The Faculty of Automatic Control, Electronics and Computer Science offers studies in Automatic Control and Robotics with various specializations. One of them is the speciality *Measurement Systems* maintained by Measurement System Group of the Institute of Automatic Control. A course on *Integrated Solid State Sensors* consists of a lecture on 7th semester and laboratory classes on 8th semester. The course is based on expertise from earlier courses such as *Principles of Measurements* and *Principles of Electronics*.

In the XXI century, when the integrated sensors become irreplaceable not only in industry but also in home appliance and motorization, such a course is very important and desired. Although we run into the integrated, smart sensors at every step, the course is given only for speciality *Measurement Systems*.

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Historically has been established in 1994 and only four laboratory exercises have illustrated the lecture, due to hardware problems. Then it was hanged up for two years and again has started again in 1997 with nine laboratory exercises. The course and the printed series of course [1, 2], in Polish and English version, are the result of three-year TEMPUS project on *Education in Technology and Application of Advanced Se nsors*.

2. LECTURES

It is natural that the students on speciality *Measurement Systems* should have a broad knowledge on the modern sensors, their properties and the range of application. Therefore the object of the lecture is to show the theory of operation, the construction, the technology and the fields of application of modern integrated solid–state sensors. Because of the topic is too broad, to present it during the short course, we have chosen only the widely used types of sensors. There are also presented the new trends in sensor technology and the integration into the network-enabled smart transducers.

The important source of information, besides the books [3, 4] and papers in printed versions, is the Internet. There are many WWW services, which give access to the sensors datasheets, the publication databases as well as the Internet magazines on sensors.

We start the lectures from a presentation, with slides , the examples of different integrated sensors. We show that the semiconductor technology is not only for the integrated circuits, but also for the micromechanical systems manufacturing. We describe briefly the integrated sensors technology, then we move on to a particular sensors presentation.

The sensors are described in terms of the measured quantity. For each we present a few constructions of the sensors. The lectures are taken in a conventional form. The more complicated pictures, diagrams and circuits are given in the printed form. There are also presented the catalogues as well as the sensors in the different stages of manufacturing. The contents of the lectures can be collected into the following time-table.

Introduction: scope of lectures, literature, examples of integrated sensors, microelectromechanical systems (MEMS), integrated sensors technology, applications, markets.

Integrated sensor electronics and signal processing: degree of integration with sensor, sigma delta converters, communication standards, examples of sensors with integrated electronics. Interface of the network–capable transducers according to IEEE–1451.

Temperature sensors: thick and thin film technology, fibre–optic and semiconductor sensors, integration with electronics. Thermal radiation sensors based on thermopiles and bolometers.

Flow sensors: micro–flow sensors based on different measuring methods.

Chemical sensors: general principles of operation, acoustic wave transducers as chemical sensors, fibre–optic chemical sensors, ISFETs. The examples of gas and liquid composition sensors.

Pressure sensors: basic definitions, units of pressure and conversion, sensing elements – diaphragms, bellows, tubes, detection methods – capacitive, piezoresistive, resonant, piezoelectric.

Acceleration sensors: dynamic model of accelerometer, damping and frequency response, cross-axis sensitivity, self testing, force feedback, multiaxial accelerometers, automotive sensors, principles of operation – piezoelectric, piezoresistive and capacitive.

Force sensors: basic types of sensors – piezoresistive, capacitive, resonant, piezoelectric, tactile sensors – force sensitive resistors, piezoelectric tactile sensors.

Humidity sensors: impedance sensors (resistive and capacitive), chilled mirror sensors – methods of condensation detection.

Fibre optics sensors: multimodal fibres, sensors with internal and external amplitude modulation, luminescent sensors, singlemodal fibres, interferometers and their fibre optics realisation, polarometric sensors.

3. LABORATORY CLASSES

1.1. AIM AND STRUCTURE

The aim of the laboratory classes is to present the applications of integrated sensors, the methods of calibration and some sensor development and investigation. It illustrates the lecture and extends it of some non-integrated but important sensors, not presented in the other courses. The laboratory classes consist of nine, 3 hours long exercises:

1. Temperature sensors,
2. Profibus DP,
3. Pressure sensors,
4. Acceleration sensors,
5. Humidity sensors,
6. Ultrasonic sensors and measurements,
7. Fibre optic and optoelectronic temperature sensors,
8. Fibre optic displacement sensors,
9. Surface acoustic wave (SAW) gas sensors.

The last three exercises (7, 8 and 9) are performed in cooperation wit The Institute of Physics, where such sensors are developed and investigated. Some of the exercises are designed to illustrate applications of integrated sensors and investigations of their metrological characteristics.

Temperature sensors. In the exercise the applications of the sensors are presented. The two types of silicon temperature sensor are used. The first one has a current output proportional to the absolute temperature and it is used in a thermocouple cold junction compensation circuit. Students analyse the circuit and then adjust it for a particular thermocouple. Then the efficiency of the compensation for a varying cold junction temperature is investigated.

The second sensor is a resistance dependent thermometer based on a spread resistance effect. Based on this sensor, and a 555 type oscillator, students build a thermometer with a frequency output, check its characteristics and determine the nonlinearity error.

Profibus DP. This exercise is designed as an extinction of the lecture classes. An example of a industrial bus is presented, which enables the connection of different types of transducers, including based on the integrated sensors. The task is to communicate with the sensors connected to the bus using LabVIEW – the graphical programming environment.

Pressure sensors. In the exercise the properties of the piezoresistve pressure sensors as well as the methodology of testing their metrological properties are shown. Presented methodology is commonly implemented in the sensor production and the in–field applications.

The sensors under test are placed in an environmental chamber. The intrinsic and temperature errors are investigated using a computerized control and data acquisition system [1, 5]. The students perform the wide range of tests, which consist of the measurements of metrological characteristic of the sensors and the temperature errors compensation.

Acceleration sensors. During the exercise students are meet with the accelerometers of different types and with the methods of determining their characteristics and parameters. There are shown the two most popular sensors: a charge output piezoelectric accelerometer and a fully integrated single chip capacitive accelerometer. Firstly the calibration with use of the secondary calibration method (back-to-back comparison) according to [6] is performed. The laboratory stand is equipped with a vibration exciter, a power amplifier and a sine wave generator. The reference sensor is the piezoelectric accelerometer coupled with a measuring amplifier. The sensor under test is the capacitive sensor. The output voltage is measured using a digital voltmeter. The following characteristics and parameters are determined: the nominal sensitivity, the sensitivity characteristic, the frequency response and the cross-axis sensitivity.

Next the vibration monitoring of the machinery is performed. A membrane pump consisting of an electric motor is diagnosed. The sensor used to measure the vibrations is a triaxial piezoelectric accelerometer with a voltage output. The data acquisition and processing is handled by a PC data acquisition board and a dedicated software.

Humidity sensors. In the exercise humidity calibration procedures and equipment are presented. There are discussed the principles of generation of a humid air and a humidity calibrators design. The standards used to test the humidity sensors are the salt solutions - the so-called fixed points and a divided flow humidity generator. A frequency output transducer based on a linear capacitive sensor and the 555 type oscillator is tested. There are investigated a linearity and a histeresis of the sensor. The psychrometric measurement of a relative humidity is also performed. The results are compared with read from a digital thermohygrometer. The dynamic characteristics of the sensors are measured with use of the salt solutions standards and the two fully integrated single chip sensors. There are compared the properties of the protected by a filter layer and the unprotected sensors.

Ultrasonic sensors. This exercise is designed as an extinction of the lecture. The purpose is to familiarise the students with the ultrasonic sensors, their properties and applications. The methods of ultrasonic measurements were not discussed in details during the lecture and therefore students have to prepare themselves for the classes unaided. They are given the detailed manuals and the supplementary publications in which the basics of the ultrasonic methods are described.

The laboratory stand is equipped with an ultrasonic defect analyser manufactured as an expansion board for a PC. There are also the ultrasonic heads of different types, a reference reflector and the test objects. The students determine the most important parameters of the heads and the ultrasonic waves propagating in a medium. The measurements of the small and large defects in the steel blocks are also performed.

Fibre optic and optoelectronic temperature sensors. Two types of the fibre optic and optoelectronic temperature sensors are examined: a bend sensor and a luminescent sensor. The test of the bend fibre optic temperature sensor with a reference channel is performed in a temperature measurement system UPT. The system provides the sensor excitation by means of a BSP23 light emitting diode, the signal detection, the amplification and its transmission to the computer. The luminescent sensor is also tested in the UPT system. The receiving/transmitting unit generates a short light pulse from a xenon lamp (from a lower visible range and the UV range) and then detects and amplifies the photoluminescence signal, dependent on the sensor temperature. The luminescence signal, corresponding to the measured temperature is transmitted to the PC computer where the signal is processed.

Fibre optic displacement sensors. This exercise is designed to show the investigation on the modern fibre optic sensors. A multimodal fibre optic sensor with an external reflective amplitude modulation is shown during the exercise. First a calibration of the sensor is performed. The sensitivity characteristic is determined and an optimal sensitivity and a working range are chosen. Next the amplitude measurement of an acoustic speaker membrane is executed.

Surface acoustic wave gas sensors. During this exercise the application of a SAW sensor in the gas concentration measurements is presented. The sensitivity characteristic of the sensor is determined.

4. SUMMARY

The integrated solid state sensors technology is one of the fastest developed trade. Thus the programme of the lectures is frequently updated. Every year the laboratory exercises are reviewed and update of the new sensors or equipment is considered. Although an introducing of the new exercises is recommended, a budget and time restrictions make it unfeasible. The course on *Integrated Solid State Sensors* presents the new solutions in sensor technology and development perspectives. It shows not only state-of-the-art on the modern sensors but also the future trends.

The new edition of printed series of the course lecture, which will also include the laboratory classes, is planned to publish in the near future.

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