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SENSORS – WHAT AND HOW SHOULD WE TEACH?

Abstract: There is no question 'if' or 'why' we should teach sensors. The contemporary world cannot operate without them. A basic understanding, principles of choice and principles of application of sensors in instrumentation systems are of fundamental importance in all disciplines of engineering. Fascinated by information processing people often forget that the function and also properties of every instrumentation system are defined by both the sensor and the software support provided. This paper presents some basic information on sensors and sensing, and the main problems faced when teaching them. It is intended to be a platform for discussion.

Key words: sensor, smart sensor, sensing system, education

1. INTRODUCTION

Man communicates with the external world using his five natural senses: eyesight, hearing, touch, smell and taste (at present psychologists distinguish also the sense of balance and the sense of feeling, e.g. of temperature) and uses his intellect in cognition of this world. He gains information from receptors connected with his brain via the body's neural system. An extension of human perception and intellect are instruments (measuring devices) enabling objective observation and measurement of physical phenomena. In the instruments functions of the receptors are performed by sensors. Sensors are physical devices that deliver information (usually in a form of electrical signals) about the state of various objects, natural and man-made, about the state of the environment surrounding them and the physical and chemical processes occurring in them. Receivers of this information are all measurement and control systems – from the simples ones, like an iron with a bimetallic temperature controller to the most complicated, for example the automatic take-off and landing system for air-planes. Sensors are the

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first, nearest to the object of measurement, elements of every measurement system (fig. 1). In objective cognition of the world they do not only substitute for the natural human senses but often can offer considerable improvement to human sensing. Thanks to sensors we get information with much higher sensitivity and much faster than available from natural senses and can get quantitative information on physical quantities often beyond the range of his senses (e.g. magnetic field, ultrasound, etc.).

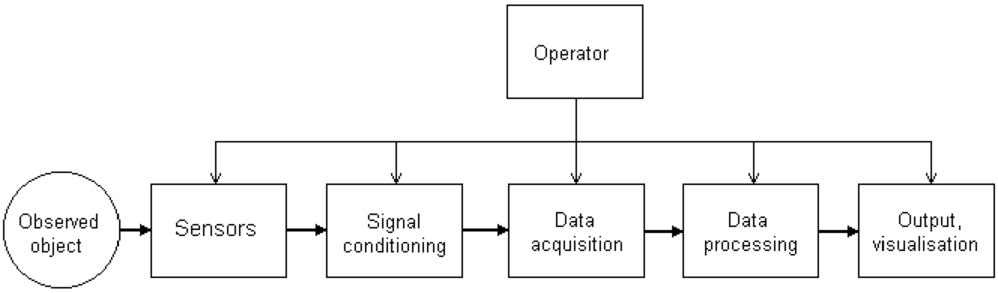

Fig. 1. Measurement system

There is no question ‘if’ or ‘why’ we should teach sensors. The contemporary world cannot operate without them [14]. In all disciplines of engineering a basic knowledge about sensors is of fundamental importance [7]. The more so as people, fascinated by information processing, often forget that the function and also properties of every instrumentation system are defined by both the sensor and the software applied. The main questions are: ‘what’ and ‘how’ should we teach?

2. SENSORS, THEIR PROPERTIES AND PRINCIPLES OF CHOICE

Sensors are expected to perfectly trace changes of the measured quantity and therefore the following properties are required of them: selectivity, high sensitivity, negligible influence on the object of measurement, adequately fast time response, low noise, resistance for environmental influences and interference, etc. [2,16,20]. In practice it is rather impossible to find sensors having all these virtues by themselves [6]. Usually application of a suitable signal conditioning or/and signal processing is necessary to improve one or more of the sensor's properties.

The choice of sensors appropriate for a particular application requires the engineer to consider: the object of measurement, the type of system and its environment, its price, etc. (a multi-dimensional criterion). Adequate definition of the task is of essential importance. One must answer the questions: "what quantity has to be measured and for what purpose?" and "is just this quantity necessary or another quantity would be more appropriate?" Also span of the range, time response and required accuracy are of crucial importance. Then, simplicity of use, compatibility with other sensors in the system, price, time of delivery, etc., must be considered. Selection of the sensor should be made at early stage in the design of the system.

3. EVOLUTION OF SENSORS, INTELLIGENT SENSORS

Sensors determine cognitive and productive abilities of a man. Then again, the development of sensors follows progress in science and technology. At the stage of advanced extension of applications of electricity, large measurement systems appeared and together with them also measurements of non-electrical quantities using electrical methods. In the beginning, mechanical sensors were equipped with elements converting mechanical quantities to electrical signals, later new types of sensors were elaborated. Incorporation of electronics and improvements in analogue signal conditioning and handling offered a substantial improvement of metrological and usable properties of sensors: widening of measuring span, increased accuracy of conversion, linearization and shaping of characteristics, various static and dynamic corrections and compensations. In this way simple sensors evolved into complex system transmitters equipped with electrical voltage or current outputs.

Development of sensors has been forced by users demanding improvement of the sensors' capabilities and reduction of costs of purchase, installation and exploitation [12, 13]. Then again, it is feasible thanks to advances in the related technologies like computer aided design (CAD), microelectronics, materials engineering and communication technologies. The most significant progress in development of sensors has resulted from the adoption of low power microprocessors and A/C converters, which, in connection with the basic circuitry of sensors, can operate using low power requirements available in transmitters with conventional 4 – 20 mA current output [5]. It has provided many enhancements which include: application of digital methods of signal processing, advanced calculations, uploadable FLASH programming, storage / data logging and telemetry of results (remote digital transmission) [4, 16]. The major advantages have been:

- software realization of the sensing function (sensing function = sensor + software),
- improvement of the sensor's properties using software,
- bi-directional communication using digital transmission,
- compatibility with digital computers.

A sensor having the first two features is called „smart". If the internal microprocessor manages also the digital communication, the sensor is called "intelligent" [5, 16, 3].

Complexity of contemporary systems requires implementing some of the intellectual functions of a man [17,15]. Intelligent systems have to operate unfailingly regardless of circumstance. They must sense and recognize multi-dimensional information and convert it to a suitable form, with simultaneous detection of abnormal conditions or states. Therefore, also the sensors are set new tasks. It is required of them to operate in the system, self-dependently and effectively, often in extreme conditions. A demand for intelligent sensors and intelligent sensing systems produced necessity of structural strengthening the sensors, by using a matrix of the same type sensors or a set of different type sensors, in conjunction with information strengthening – in the aspect of data processing by a computer. Examples of such sensing systems may be the "electronic nose", capable to recognize particular smells and thanks to that test the maturity of cheese [15], or the "electronic tongue" capable of evaluating taste and freshness of milk [21]. Such sensing systems need additional means supporting their artificial intelligence. In the case of quantities that haven't a deterministic behaviour artificial neural network [18] or/and inference according to fuzzy logic theory [19] may be applied. Fuzzy logic may be helpful also in the measurements of well defined quantities, like the distance, but when the sensors operate according to different principles – e.g. optical and acoustic [1]. Then the distance estimation is based on fuzzy data fusion.

Two trends can be observed in the development of intelligent sensor technologies: connection of sensors and micro-controllers in one integrated structure (integrated circuit) or merging computing power of a computer and resulting from it graphic capabilities of high level software with classic sensors (virtual intelligent sensors).

4. WHAT AND HOW TO TEACH?

The scope of problems presented in chapters 2 and 3 contains wide, interdisciplinary knowledge. One of the main tasks of a teacher is adjusting the content (selection of proper material, adequate proportions, etc.) and the form of teaching to rapidly growing requirements of the contemporary world, considering allotted time and attainable technical goals using available financial means. The domain "sensors and sensing" has two components [10]:

- "sensor science" – how to detect or sense (and therefore measure) new things or to sense things better,
- "equipment for measurement" – how to select, properly use, etc., sensors in creation of measurement systems.

The first one belongs to physics (however, physicists often teach the material related to sensors and sensing in a quite different way to the engineering environment). The second component is engineering and it is the design dimension of the field.

An important aspect of teaching measurement and instrumentation, likewise sensors and sensing, is orientation towards design and construction, because:

• teaching by design is the best way of teaching a "systems approach",
• "the number of measurement tasks, and the available methods to meet them, are too numerous and diverse to be treated as a catalogue, even if it is based on systematic methods of description and analysis" [7],
• "a major engineering motivation for study of theory is the enhanced capability to perform design. The design dimension may be used to advantage by measurement science and also 'selling' the discipline to students" [10].

All the main methods of teaching are helpful:
• lecture – presents main ideas, principles and methodology,
• project – contains operations on models (circuit and field models, static and dynamic models), according to a suitable methodology [7, 8, 9],
• experimental work – the most expensive and troublesome but a vital part of engineer's education, enables familiarization with basic physical phenomena, properties of real objects, sensors and methods of measurement, verification of theoretical models.

Two aspects of teaching should be distinguished as essential: a physical approach and computerization [11]. Computerization seems to be something obvious for everybody. However it must be used with great care so as NOT to loose or reduce the vital physical aspects. It is unacceptable to limit teaching to operations of models and computer simulations.

5. TEACHING OF SENSORS IN WROCŁAW UNIVERSITY OF TECHNOLOGY

Sensors and sensing are taught in the Faculty of Electronics of Wrocław University of Technology within the subjects: „Sensors and transducers", „Principles of sensing and converting physical quantities" or "Measurements of non-electrical quantities". Related subjects are: "Computer modelling", "Computer aided engineering", "Measurement system design". All basic forms of teaching are employed: lecturing, laboratory experiments, projects and seminars.

6. SUMMARY

Academic study of "sensors and sensing" are of fundamental importance in the teaching of measurement and instrumentation. In this field we should teach: physical principles, with reference to methods of measurement, mathematical models considering static and dynamic properties of objects and sensors, and principles of application of sensors in measurement systems, i.e. methodology of designing. We should use all available forms of teaching. Physical problem solving in teaching is important – since the graduate engineer should know and feel well physical aspects of measurement.

REFERENCES

[1] BAGLIO S., GRAZIANI S., PITRONE N., *An intelligent sensor for distance estimation based on fuzzy data fusion*, in: Trans. Inst. MC, vol. 18, No 4, 1996, 217-220

[2] BENTLEY J. P., *Principles of Measurement Systems*, Longman Scientific & Technical, 1995

[3] BLOCH G., EUGENE C., ROBERT M., HUMBERT C., *Measurement Evolution: from Sensor to Information Producer*, in: IMEKO TC1 and TC7 Colloquium, London 1993, 335-341

[4] BRYZEK J., *Advanced methods of signal processing in intelligent sensors* (in Polish), in: Elektronizacja, 5/1994, 5-9

[5] COLVILE R.F., *Intelligent instruments for process measurement*, in: Measurement and Control, vol. 17, April 1984, 153-156

[6] DOREY A..P., BRADLEY D.A: *Measurement science and technology - essential fundamentals of mechatronics*, in: Meas. Sci. Technol. **5** (1994), 1415-1428

[7] FINKELSTEIN L., *Design oriented teaching of instrumentation*, in: Sensors and Instrumentation Systems - What should we teach? How should we teach?, IEE C11 Colloquium, London, June 1996

[8] FINKELSTEIN L., *Modeling in Measurement and Instrumentation – A Genral Overview*, in: 1st International Conference-Workshop on Modelling in Measurement Processes, Institute of Electrical Metrology, Wrocław University of Technology, Szklarska Poręba 1993, 2-11

[9] GRATTAN K. T. V., *Modelling in the Measurement of Physical Phenomena, Using Optical Techniques*, in: as above, 20-28

[10] HANCOCK N. H., *Measurement Science – Presentation as an „Advanced" Academic Dyscypline*, in: Proceedings of the IMEKO TC1 and TC7 Colloquium, London 1993, 158-163

[11] HOFFMAN D., *New Strategic Challenges for Education and Training in Measurement and Instrumentation*, in: IMEKO XV World Congress, Osaka, Japan, June 1999

[12] JOHNSON A.K., *When are smart transmitters the smartest choice?*, in: Instr. and Control Systems, March. 1987, 37-39

[13] MABREY T., *Smart sensing solutions*, in: Instr. and Control Systems, Aug. 1987, 25-28

[14] MOROŃ Z., *Contemporary world cannot operate without sensors* (in Polish), in: Elektronizacja 7-8, 1998, 26-29, 34

[15] MOROŃ Z., *Intelligent sensors – what is their intelligence and what purpose does it serve?* (in Polish), in: XXXI Polish Intercollegiate Conference of Metrologists, Reszów 2000

[16] NOLTINGK, B.E., *Instrumentation Reference Book*, Butterworth-Heinemann, 1995

[17] OHBA R., *Intelligent sensor technology*, John Wiley & Sons, 1992

[18] PERSUAD K.C., KHAFFAF S.M, PISANELLI A.M., *Measurement of sensory quality using electronic sensing systems*, in: Meas. and Control, vol. 29, Febr. 1996, 17-20

[19] RUSSO F., RAMPONI F., *Fuzzy methods for multisensor data fusion*, in: IEEE Trans. IM, vol. 41, No2 , April 1994, 288-294

[20] STEIN P. K., *The Unified Approach to the Engineering of Measurement Systems*, Stein Engineering Services, Inc., Phoenix, Arizona, 1992

[21] WINQUIST F., KRANTZ-RUCKLER C., WIDE P., ..., *Monitoring of freshness of milk by an electronic tongue on the basis of voltammetry*, in: Meas. Sci. Technol. **9**, 1998, 1937-1946